that require further investigation include the net effects of external influences on thunderstorm electrification (*14*); the electrically enhanced coalescence of cloud droplets to form raindrops, especially cloudbursts (*15*); and the formation of sulfate aerosol particles by gas-to-particle conversion mechanisms involving ions (*16*). Without a significant increase in research effort, it is likely that ^{85}Kr will accumulate in the atmosphere faster than our knowledge of related phenomena accumulates.

Conclusion

Nonradiobiological phenomena affected by ^{85}Kr include environmental radioactivity, atmospheric electricity, and inadvertent weather modification. If release of ^{85}Kr into the atmosphere continues unabated, global changes in the atmospheric electric circuit will occur within 50 years. Our present understanding of atmospheric processes is insufficient to determine the extent of consequent weather changes and whether they would be beneficial or harmful. Because of the 10-year half-life of ^{85}Kr, global changes may last decades.

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An Expanded Approach to the Problem of Disappearing Species

Species, as part of the common heritage, require common action to protect them.

Norman Myers

The problem of disappearing species has hitherto been tackled mainly from the standpoints of biology and ecology (*1*), with less attention to the economic and institutional factors that bring species under threat. Yet the principal destructive process at work now is modification or loss of species' habitats, which arises for the most part from economic development of natural environments. In this article I examine the problem from the economic and institutional perspectives, in order to identify opportunities for an expanded approach to conservation of species.

Animal species and subspecies at present known to science and recognized as threatened total slightly over 1000, with an extinction rate put at one per year (*2*), compared with a rate of roughly one every 10 years from 1600 to 1950 and a natural rate of perhaps one every 1000 years during the "great dying" of the dinosaurs. In addition, 20,000 flowering plants are thought to be at risk. The world's stock of all species is now estimated at 10 million, of which 8.5 million have still to be identified (*3*). The scale of the potential threat seems clear: if present land-use trends continue, and unless better conservation measures are implemented, society stands to lose a substantial part of its heritage in species and genetic resources within a few decades.

This article is based on the premise that such loss would be detrimental to human welfare. Our investigations of the genetic attributes of species are still in their early stages, but they have already contributed to modern agriculture, medicine and pharmaceuticals, and many industrial processes. Indeed the spectrum of species can be reckoned a repository of some of society's most valuable raw materials. Moreover, loss of species will affect generations into the indefinite future, whose options to utilize species in ways yet undetermined should be kept open. Yet certain sectors of the contemporary community have difficulty keeping themselves, let alone other species, in being, and I wish to emphasize this aspect of the situation. Whose needs are served by conservation of species, and at what cost to others?

Certain other trade-offs should be considered. Many temperate-zone environments have already been fundamentally modified. The disruption of North America's forests led to the extinction of the passenger pigeon, a species that could not adapt when its particular form of forest habitat disappeared, but it also led to the proliferation of the white-tailed deer, a successional species that thrives

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off disturbed vegetation. Which event has had a greater impact on man's well-being? There is benefit in maintaining genetic diversity not only among species but within species. I believe that we should keep as many options open as possible until, through research, we can reduce the areas of uncertainty.

A principal conservation need is to set aside sufficient representative examples of biotic provinces to extend protection to entire communities of species. Such measures have been urged by a number of international bodies. In particular, Unesco's Biosphere Reserves concept envisages a comprehensive network of protected areas and urges that sample biotopes be preserved for the benefit of present society and future generations (*4*). It does not consider socioeconomic factors or ways to motivate nations to implement the proposal.

A restricted approach of that sort may prove inadequate, especially in tropical regions of the developing world, which are thought to contain a large majority of the world's species (*5–7*). In these areas, the upsurge in human numbers and aspirations exerts increasing pressure on wildland habitats. Many nations in question are not in a position to designate extensive tracts of land as off limits to development (their present efforts to safeguard the bulk of the earth's species in effect subsidize the rest of the global community). A strategy to conserve the world's wealth of species must be made economically acceptable and politically practicable if it is to withstand competitive pressures from other forms of land use.

Tropical Rain Forests

Tropical rain forests are considered to contain more species than any other biome (*3, 5, 7*). Present patterns of forest exploitation suggest that few parts of this biome will escape gross disruption by the end of the century (*6–8*). A principal reason for this is the global demand for forest products, to which developing countries respond readily since it assists their trade earnings and immediate economic development. The principal consumers of processed forest products are developed nations, which thereby bear a degree of responsibility for what happens to tropical forests. By the end of the 1970's, shortages of forest products could precipitate a supply crisis to match the present shortages of fuel and food (*9*).

In Southeast Asia, the value of forest exports has now reached $2 billion per year (*10*). Most of the hardwood lumber goes to Japan, although the final product consumers are North American and European countries. To sustain this export trade (as well as some local consumption), 3 million hectares of forest are cleared each year. In West Malaysia, the value of output of veneer and plywood increased between 1960 and 1971 by 783 times (*11*). Within another 10 years, all accessible virgin forests of West Malaysia may have been logged (the same is true for the Philippines) (*11*). In Indonesia, timber exports make up 26 percent of the gross domestic product (*12*). Forest concessions in Indonesia totaling 570,000 km^2 have been assigned to over 500 timber firms, many of them foreign corporations with a total investment in 1973 worth $856 million. The Japanese are predominant, while a good number are American: Weyerhaeuser is among the largest, with an investment of around $35 million.

Of the Amazon Basin's 4 million km^2 of forest, as much as 100,000 km^2 are cleared each year, to open up virgin lands for livestock and crops as well as to exploit timber and other forest products (*13*). Many Amazon exploiters are multinational corporations, mostly American with some Dutch and Norwegian (*14*). Volkswagen do Brasil is about to go into cattle raising in the Amazon, with an investment of nearly $30 million for 10,000 km^2 of artificially created pastures. Japanese corporations are now offering investments for logging opportunities up to $500 million, and are to put $600 million into a pulp project (*14*).

In Central America, the area of planted pasture and number of beef cattle have doubled since 1960, almost entirely at the expense of natural forests, until two-thirds of the forests have now been cleared (*15*). As an instance of foreign-inspired exploitation, several fast-food chains in the United States find it cheaper to obtain hamburger beef from parts of Costa Rica that were recently virgin forests but are now cattle-raising grasslands than to purchase their meat from conventional sources in the United States. During the 1960's, Costa Rica's beef production increased by 92 percent while local consumption declined by 26 percent: almost all the extra output was exported to the United States (*16*).

These instances illustrate how the progressive depletion of tropical forests is not only attributable to unsound forestry policies on the part of developing nations. Developed nations also contribute, both directly and indirectly, to the destructive processes.

A principal way to safeguard species and genetic reservoirs is through parks and reserves. According to a recent review (*13*), however, parks and reserves in Southeast Asia comprise only 1.8 percent of the forest zone, in South America 0.67 percent, and in Africa 2.67 percent. By contrast, preliminary estimates suggest that as much as 20 percent of forests would have to be preserved, in selected localities covering distinct ecosystems, in order to ensure protection for endemic species. Moreover, since many species in this highly differentiated biome are characterized by localized distribution, a few large parks and reserves would not suffice to protect the range of biotic diversity. An extensive and strategically located network would be needed (*17*). Meantime protected areas are often unable to withstand economic pressures to put their lands to more useful-seeming purposes. A good number of parks and reserves have been violated by logging operations, hydroelectric power projects, highways, and settlement schemes. Throughout the rain forest biome, the conflict between conservation and development seems likely to grow critical for protected areas in years ahead, unless conservation policies and practices can better integrate parks with their socioeconomic and institutional environments.

Pragmatic Purposes of Species Conservation

Conservation of threatened species serves pragmatic purposes of immediate value. Genetic reservoirs make a significant contribution to modern agriculture (*18*), to medicine and pharmaceuticals (*19*), and to industrial processes in all parts of the world—especially in the advanced world, with its greater capacity to exploit genetic resources for a wide variety of purposes.

To consider one sector of agriculture, pest control is assisted through certain plants that produce chemicals to repel insects or inhibit their feeding. Pest control can likewise be advanced through selective breeding of adapted species of insects—a method that could prove more effective and economic in the long run, and result in less environmental disruption, than broad-scale application of persistent toxic chemicals. For instance, the little-documented ichneumonid wasps in tropical forests comprise at least one-quarter of a million species, certain of which could be used as predators and parasites of insect pests.

Plant species offer many starting materials for medicines and pharmaceuticals.

One group of significant drugs, alkaloids, are derived from nitrogenous substances found in certain plants (*20*). To date, a mere 2 percent of the planet's estimated 200,000 flowering-plant species have been screened for alkaloids, producing nonetheless about 1,000 different forms. The pyrrolizidine and acronycine alkaloids seem likely to prove active against several forms of tumorous cancer, while other recently discovered alkaloids are used to treat leukemia. The glycoside alkaloids are used for cardiac complaints, while still others show therapeutic promise against hypertension. The most abundant sources of alkaloid-producing plants are found in tropical forests.

Despite limited knowledge about genetic reservoirs, it seems a statistical certainty that tropical forests contain source materials for many pesticides, medicines, contraceptive and abortifacient agents, potential foods, beverages, and industrial products. Of particular value for human purposes are the specialized genetic characteristics of many localized species—yet these attributes are associated in many instances with restricted range, precisely the factor that makes them vulnerable to destruction.

Resource Economics of Threatened Species

Species can be considered an indivisible part of society's heritage now and forever. At least, that is how many people perceive species. The general public, notably in developed regions, expresses interest in the tiger, gorilla, vicuna, and many other species. It believes that the heritage of humanity, as well as that of Mauritius, has been impoverished by the loss of the dodo. Many people sense a degree of responsibility for species in other lands as part of mankind's patrimony.

At the same time, everybody's heritage is treated as nobody's business. However much the community may regard species as its estate, it has no effective way to express this interest through institutional devices such as ownership. An individual can own a cow, which enables and encourages him to take care of it and induces others not to use or misuse it. But species are not subject to readily identifiable property rights, and the same applies, of course, to species' habitats.

For centuries, the marketplace (*21*) and law (*22*) have tended to formulate and consolidate the rights of private property. (There are, of course, numerous exceptions to this sweeping statement, but this article deals primarily with the impact of Western marketplace mechanisms on natural environments of tropical regions, and the broad assertion concerning institutional rights of private property generally holds good for the countries in question.) The needs of common property—including not only species but the atmosphere and large water bodies—have suffered by default. This state of affairs has not mattered much until recently. Now that common-property resources are depleted and endangered through misuse and overuse, institutional mechanisms to safeguard them are in short supply (*23*).

Indeed the nature of species as common-property resources is not always recognized, even though it is central to the problem of conserving them. Two basic aspects of this situation are relevant. First, a species' intrinsic value is indivisible; if the tiger (like the atmosphere and the oceans) brings benefit to one person, it brings benefit to all. Second, since a species has no effective owner, it is subject to "open access" exploitation. Any individual can exploit the tiger for its skin, or the tiger's habitat for a variety of purposes. The consequence of this situation is that exploitation is almost always wasteful, and safeguard measures are almost always lacking (*24*).

So when species are endangered or extirpated, it is not such a clear-cut case of human short-sightedness and prodigality as is sometimes suggested. It is due more to the status of species and their habitats as common property. For example, the golden lion marmoset in southeast Brazil once inhabited 6500 km^2 of forest, but now the last 600 animals are confined to 550 km^2. This forest remnant will not, when exploited to elimination, produce overall economic benefits greater than those which could be generated were the golden lion marmoset found to lend itself, in the manner of the cotton-topped marmoset, to the development of anticancer vaccines (*25*). But forest clearing brings immediate profits to a limited number of individuals, hence the benefits to each are concentrated and appreciable; by contrast, protection for the golden lion marmoset brings benefits which, although they may extend over a far longer time, will be spread among many beneficiaries, hence will be diffused. Given the way society's institutions weight the choice, short-term benefit for private persons wins the day.

The rationale for the marmoset applies, on a larger scale, to the Transamazon Highway. This project may already have caused the extinction of a number of species of insects and plants with highly localized distributions in the rain forest (*26*). The benefits of saving these species would be dispersed and delayed, whereas the benefits of the highway are immediate, apparent, and quantifiable. Moreover, the highway constructors are almost certainly unaware of their impact on a range of species—thus, the irrational destruction of unique resources of potentially universal value.

Many of the factors enumerated above can be perceived at work through a single phenomenon—spillover effects, or effects external to the intended context of action (*27, 28*). Because of their common-property status, species are especially susceptible to the spillover impact of people's actions, which are directed at a hundred and one goals other than the destruction of species. The people who engender most spillover effects are those most engaged in economic activities, not only the exploiters but the consumers. With one-fifth of the world's population, the affluent nations account for four-fifths of raw materials traded through international markets—materials which frequently derive from tropical zones and whose exploitation or extraction causes modification of natural environments. Affluent sectors of the global community are thereby responsible for many spillover effects in other countries, and stimulate disruption of species' habitats in developing regions.

Proposals for Expanded Conservation of Species

A number of institutional initiatives could improve the situation. Three examples follow to indicate the scope for action.

1) Public organizations such as the U.S. Agency for International Development (*29*) and the United Nations agencies could be required to prepare environmental impact statements for their development projects, along the lines of those mandated for public works in the United States (*30*). Insofar as public organizations are not subject to the profit and loss considerations that govern private enterprises, it should be no unacceptable burden for these organizations to consider in more detail the environmental consequences of their activities. For example, the Jonglei Canal project in southern Sudan is designed to channel water away from several thousand square kilometers of Sudd swamp, an exceptionally rich biotic community.

The project could entail considerable—and hitherto largely unconsidered—consequences for species. Principal responsibility for its execution lies with international agencies. Sometimes a unique biotope with its genetic diversity can be protected at little extra project cost, provided the opportunity is identified in time. Sometimes, however, the ecological gain may be reckoned too limited or too diffuse or too long-term to offset an urgent need for, say, greater food output in the area in question (this is a major reason why environmental impact statements have not always been popular with developing countries or with international aid agencies). But at least the participants should be obliged to pay explicit attention to environmental costs.

2) Corporations could be required by law in their home countries to take account of environmental consequences of their activities overseas. They could be obliged to determine which wildlife communities would be affected either marginally or conclusively by their operations, and what reasonable steps they could take to avoid irreparable harm to endemic species. This measure would be in line with recent proposals (*31, 32*) that multinational corporations be obliged to disclose information on many of their activities, as part of an agreement to conform to standardized codes of conduct. Further, conservation measures on the part of multinational corporations could be encouraged through taxation systems in home countries. For example, were a forestry enterprise to leave part of its concession in an undisturbed state, it could be allowed a tax rebate; if it engaged in a form of exploitation that proved unusually damaging, it could be required to accept an extra tax burden. Its after-tax revenues would then reflect not only a corporation's private output but its net social impact (*33*).

3) Spillover effects could be adjusted by compensatory payments from the developed world to the developing world, through an international organization. The payments would be explicitly intended for use by developing countries to offset opportunities forgone to exploit natural environments containing exceptional diversity of species. (To avoid extortionist threats to exploit, compensation should perhaps be made available only to countries that put up significant funds of their own for the purpose.) The assistance should not be supplied as another form of foreign aid, but should reflect a recognition of joint responsibility for a deteriorating asset of the common heritage. This compensation idea accords with the "additionality principle" adumbrated at the Stockholm Conference on the Human Environment (*34*), a principle that proposes that payments be made by the community at large to developing nations in order to offset adverse repercussions on their emergent economies from measures for environmental conservation (*35*).

This last proposal, like the idea of tax rebates for commercial enterprises that adopt conservationist practices, amounts to a mechanism to persuade communities whose land-use practices are destructive of species to desist through compensatory measures. "Bribes" of this sort are an accepted method of regulating sectoral economic activities in order to safeguard community interests (*21, 28, 32, 33, 36*). In the present case, they would have to be on a scale large enough to offset the economic activities that undermine species' survival. Sufficient funds could be raised only through some form of tax on the sectors of society that are affluent enough not only to pay but to register an interest in conservation of species and that bear some responsibility for the decline of species in developing regions.

Were this compensation proposal to be implemented, it would be subject to periodic appraisal. If the public in donor countries began to object to the financial strain, the scheme would have to be ended. Citizens of donor countries would thereby act with more explicit understanding of what prospects face species in developing regions, and would have a clearer recognition of their role in the situation. This would be in marked distinction from the present position, where the community in advanced nations has little opportunity to appraise its contributions—both negative and positive—in clear-cut terms. Moreover, the entire exercise would serve as a measure of the readiness of advanced-world citizens to pay for what they often suggest they want; it would permit them to put up or shut up—a response which is not generally available within present limited opportunities for safeguarding species. With refinements through experience, this institutional device could even serve as some sort of proxy pricing system to express people's minimal evaluation of the resources in question: it could develop into a framework that reflects costs and benefits as perceived by the participant parties.

These proposals are advanced as an initial review of opportunities for broad-scale measures to meet the problem of disappearing species. They should be considered in the light of the options available. Difficult as community action would be, the alternative is the present prospect, where support for threatened species amounts to a few fragmentary efforts—a limited response that represents an implicit decision by society to allow species to decline, even though the costs of protecting them need often not be exceptional in comparison with benefits to be derived.

Summary

Assistance for disappearing species is at present too localized and dispersed to make much impact on the problem with its growing dimensions. Species are threatened primarily because of their status as common property. Institutional deficiencies, notably those of free markets and property rights, promote depletion of species. Conversely, present institutional mechanisms offer little scope for society to express its preferences for goods without price or to establish responsibility for common-heritage resources. The situation postulates corrective measures on the part of collective authority at the international level. These measures would require a joint commitment by the developed and developing worlds, on a scale to reflect the increasingly interdependent needs and opportunities of the community at large. Whether the community perceives itself as a community or not, it functions as such in many of its ecological relationships and economic interactions. The community will sooner or later be obliged to respond to the problem of vanishing species: either sooner, through protective measures of sufficient scope, or later, when it finds that the disappearance of large numbers of species represents a loss through which it is indivisibly impoverished.

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30. The World Bank evaluates some of its projects in terms of environmental impact, but the exercise is marginal as concerns species and their habitats. See World Bank, *Environment and Development* (International Bank for Reconstruction and Development, Washington, D.C., 1975).
31. *The Impact of Multinational Corporations on Development and on International Relations* (ST/ESA/6, Department of Economic and Social Affairs, United Nations, New York, 1974); *International Codes and Regional Arrangements Relating to Transnational Corporations* (E/C.10/9, Commission on Transnational Corporations, United Nations, New York, 1976).
32. T. N. Gladwin and J. G. Welles, in *Studies in International Environmental Economics*, I. Walter, Ed. [Wiley (Interscience), New York, 1976].
33. R. Marris, Ed., *The Corporate Society* (Macmillan, London, 1974); J. W. McKie, Ed., *Social Responsibility and the Business Predicament* (Brookings Institution, Washington, D.C., 1974); R. Nader, Ed., *The Consumer and Corporate Accountability* (Harcourt Brace Jovanovich, New York, 1973).
34. See also S. MacLeod, *IUCN Environ. Policy Law Pap. No. 6* (1974).
35. For a comprehensive presentation of the need for compensatory mechanisms at community level, see K. E. Boulding, *The Economics of Love and Fear: A Preface to Grants Economics* (Wadsworth, Belmont, Calif., 1974).
36. For a discussion of the principle of community action in a context of this type, see J. Buchanan, *The Demand and Supply of Public Goods* (Rand McNally, Skokie, Ill., 1968); E. T. Haefele, Ed., *The Governance of Common Property Resources* (Johns Hopkins Press, Baltimore, 1974).
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