Keith Roby Memorial Lecture in Community Science (1985)

“Extinction: The Implications of the Loss of our Biological Heritage”

Lecture delivered by: Paul R Ehrlich, Professor of Population Studies and Professor of Biological Sciences at Stanford University, on October2 1985 at Murdoch University

It is a great honour to be here at Murdoch University to deliver the third Keith Roby Lecture. I did not know Dr. Roby personally, but I am a long-time friend and colleague of his friend, Charles Birch, the inaugural Roby lecturer. It is clear from what Charles has told me, and from what .1 have read about Dr. Roby, that we shared many common thoughts about, and goals for, humankind. And I also know that Keith Roby inspired many colleagues and students who keep his memory fresh by working towards those goals.

It is fitting that the modern view of our topic this evening traces back to another scientist with a very broad view of the world - Charles Darwin. Darwin did more than convince the world that new species originated from pre-existing ones - he also brought to public attention the necessity of extinction. Before Darwin, most educated people thought that animals and plants had been created once and for all by God in a sequence of increasing complexity, at the pinnacle of which were upper-class Englishmen (at least in the view of upper-class Englishmen.

There was no more room for the disappearance of existing species from the sequence than there was for the appearance of new ones. Darwin, once he had developed his scheme of evolution by natural selection, recognized the inevitability of extinction: ". .. as new forms are continually and slowly being produced, unless we believe that the number of specific forms goes on perpetually almost indefinitely increasing, numbers inevitably must become extinct." *(Origin of Species,* First Edition, p. 109).

Ironically, Darwin's view, which is shared by all modern biologists, is now sometimes used as an excuse by the ignorant for the wholesale destruction of the products of the evolutionary process.

For example, in an editorial in the *New York Times* no less an expert than Sam Witchell, a "financial and corporate public relations consultant" concluded that there was no reason to be worried about the current extinction epidemic. Witchell stated, in a piece entitled *Give Me the Old-Time Darwin,* "The Darwin people tell us that species come and go, that this is nature's way of experimenting with life. The successful experiments survive for a time; the failures disappear to no one's detriment."

There unfortunately is part of the "Darwin people's" story that Witchell and his ilk seem not to have heard: that in recent times the "going" of species has been accelerating at an alarming rate, while if anything, the "coming" has slowed down. Witchell is like a man watching water spurting through an ever-widening crack in the face of a giant dam, who says to the folks downstream, "Don't worry - water has always come over the spillway anyway." In short, it is that *rate* of extinction that we now have to be worried about.

It is difficult to estimate the magnitude of the rate problem, but it appears that between 1600 and 1975, the rate of extinction of species of birds and mammals was in the order of 5 to 50 times the average rate for the last 50 million years or so. Of even greater concern is that the rate of extinction for the period 1975 - 2000 is projected to accelerate to some 40 to 400 times "normal". By the end of the century, perhaps 15 to 20 percent of the world's present complement of species will have been lost, and the rate of extinction will still be increasing unless determined action is taken to lower it.

Why does it matter?

Should Australians be concerned about this loss of organic diversity? After all, as the Witchell-minded are fond of pointing out, the dinosaurs went extinct and "nobody misses them". That statement is incorrect on a number of levels (e.g., they did not all go extinct; some people miss those that did). But the most important point is that dinosaurs are not much mourned because other organisms evolved to replace them. The extinction of most dinosaurs occurred when the mechanism for generating diversity was fully capable of functioning - and function it did, as the existence of ourselves and of some 4,000 other species of mammals attests.

Extinctions that are occurring today and that can be expected in the future could constitute a far more serious episode than the mass extinctions of the distant past. First of

all, unless action is taken, contemporary extinctions seem likely to delete a far greater proportion of Earth's biotic diversity than did earlier extinction events. Of course, previous catastrophic extinction episodes occurred long before *Homo sapiens* was around, and thus, unlike the one starting now, could not have immediate consequences for humanity. Furthermore, the same human activities that are causing extinctions today are beginning to shut down the process of allopatric speciation, by which diversity can be regenerated.

The ranges of organisms are being progressively reduced and environments made increasingly homogeneous. In addition, large mammals are more and more being restricted to reserves and zoos, among which transfers of individuals .will be increasingly necessary to reduce the effects of inbreeding and to avoid stochastic extinctions. All of these factors tend to reduce the isolation of populations and the differential selection pressures that are the major mechanisms of speciation. Therefore, entire new groups of organisms are unlikely to evolve as replacements for those lost if Earth's flora and fauna are decimated now.

But what does it matter if no new species evolve to replace those lost? Why should people care if enormous numbers of plants and animals disappear from the planet? There are three basic reasons why everyone should care.

Esthetics. The first is the argument from esthetics and ethics. It is basically that other species are beautiful, interesting, and have a right to exist. The beauty of many organisms - birds, butterflies, and flowers, for instance - is widely recognised. But biologists know that many other organisms have great, if unexpected, beauty when examined microscopically - the delicate scaling on the wings of malarial mosquitoes, for example. And all organisms have a beauty of intricacy and design. At a meeting I once attended, the great French anthropologist Claude Levi-Strauss correctly stated that "any species of bug that people spray with insecticides is an irreplaceable marvel, equal to the works of art which we religiously preserve in museums".

Indeed it is sad that in rich nations like Australia, where so much effort goes into providing "entertainment" for bored human beings, these attributes are relatively unrecognized. The insects alone can supply precisely the kind of variety and esthetic values that captivate horse fanciers, airplane, train and car buffs, stamp collectors, sci-fi and computer freaks, bibliophiles, and so on.

Ethics. But in my view, more important than these human-oriented values of other species are the ethical reasons for not driving our fellow passengers on Spaceship Earth to extinction. David Ehrenfeld put the argument very well in his provocative book, *The Arrogance of Humanism.* He enunciated the "Noah Principle", named after the best-known historical practitioner of conservation. According to the Noah Principle, species and communities should be conserved

". . . because they exist and because this existence is itself but the present expression of a continuing historical process of immense antiquity and majesty. Long-standing existence in Nature is deemed to carry with it the unimpeachable right to continued existence".

This is essentially a religious argument. There is no way to "prove" scientifically that non-human organisms (or for that matter, human organisms) have a right to exist. It is clear, however, that there has been a trend in human cultural evolution to extend rights beyond the boundaries of *Homo Sapiens.* A century or so ago, it was permissible for an owner to beat a horse to death. It no longer is. Indeed, compassion for other species has been a major factor in helping to preserve some of them. The whales are an excellent case in point. A grass-roots international movement has greatly reduced the assault on those magnificent mammals, and some human beings have even risked their own lives to protect whales from pirate whalers.

The esthetic-ethical arguments are to me, and to many others, among the strongest for the preservation of Earth's biota. But most people find homocentric arguments more persuasive. The second and third arguments are therefore focused on the needs of people rather than those of other species.

Economic Values. The second argument is that other species should be preserved because they are a potential source of great direct economic benefit to humanity. Few people truly appreciate the enormous riches our species has already received from nature. For example, a large fraction of the thousands of medicines employed by humanity are derived from the chemicals that plants have evolved to poison herbivores. In 1979 the sales of a single such compound, the anti-cancer agent vincristine (derived from a Madagascar periwinkle plant) amounted to some $35 million worldwide.

Human beings, of course, derive all of their food from other organisms, domesticated or wild. And an enormous array of other products are harvested from the same source: timber, rubber, leather, a wide variety of oils, waxes, furs, spices, fibres, preservatives, and insecticides, to name just a few.

The important thing, though, is that great as the bounty from nature has been, it represents a mere scratching of the surface. The benefits that potentially could be extracted from other species are obviously vastly greater than those already gained. For example, according to one estimate, only about 5,000 plant species - about 2 percent of the total - have ever been screened for alkaloids, one medically-important group of plant chemicals. Moreover, the screening that has been done has certainly not beenadequate to uncover all the potentially-useful compounds. It is well known that the presence of plant biochemicals varies from time to time in the same part of the plant, from part to part, from plant to plant, and from population to population in the same species.

To my knowledge, no single plant species has yet been adequately screened for all possible useful biochemicals. The same is true of animals - especially marine species, which seem to have high potential as sources of useful drugs. This is one potent reason for not restricting conservation efforts to the preservation of species, but to include the preservation of the unique populations that make up species of sexually-reproducing organisms and the genetic variability within those populations.

Human utilization of plants as food sources has also been surprisingly limited. Only about 150 species of crops have been grown commercially, and only 3,000 or so (about 10 percent of the total plant species) have ever been used as food. Today human nutrition rests on a narrow base of some 20 major crops, of which three species of grasses - rice, wheat and corn - are by far the most important.

Enough is known about the food potential of plants now commercially grown to make it clear that humanity has a great deal to gain nutritionally by not wiping out plant populations and species. As a single example, the Seri Indians of the west coast of Mexico have long made flour from seeds of one of the eighteen species of eel grasses that grow in the sea. Here is a potential crop that would need no fresh water, pesticides, or fertilizers; a crop that might prove an enormous bonanza in many hungry nations.

It is important to note, however, that successfully developing new crops and maintaining established ones both depend on the preservation of genetic variability for plant breeders to work with. For instance, the average useful life of a new cultivated wheat variety in the northwestern United States is about five years. Then rusts adapt to the strain, and a new resistant one must be developed. Without a reservoir of genetic diversity for artificial selection to operate on, such development is impossible.

Especially since the development of high yielding, fertilizer-sensitive crop varieties (HYV's) and their dissemination around the world, the reservoirs of genetic diversity of major crops have been rapidly dwindling. HYV's have been replacing numerous indigenous strains in poor nations, greatly constricting the genetic base of such crops as rice and wheat. Furthermore, an additional source of germ plasm for crop maintenance - populations of wild relatives of the cultivated plants - are being exterminated in many parts of the globe. Therefore, although plant species now supply humanity with much of its food directly (and the remainder indirectly), both the ability to maintain production of current crops and to develop new crops are in jeopardy because of extinctions.

And the situation with respect to animal food sources is similar. Relatively few animals have been domesticated and some wild ones have high potential for domestication. For example, cultivation of mixed herds of antelope and other native herbivore species seems capable of outproducing cattle in certain parts of Africa, while not degrading the range as cattle do. But, of course, the *sine qua non* of developing such polycultures is the preservation of the native species themselves.

The potential for extracting new non-food products from other organisms, especially plants, is also very large. It is possible that certain plants of the family *Euphorbiaceae* might be genetically improved to give a very high yield of petroleum-like hydrocarbons. "Gasoline farming" is not out of the question in the future if the appropriate species and populations are preserved.

Thus nature is, in essence, a vast "genetic library" from which humanity has just begun to withdraw useful items. Unhappily, though, all too few people are aware of the existence of the library or of its importance. As a result, *Homo sapiens is* on the verge of burning it down.

Life-Support Services of *Ecosystems.* Indispensable as are the direct benefits humanity receives from other species, they are only part of the story. Equally important are the indirect benefits supplied through ecosystem services. The ecological systems of Earth, the planet's living organisms interacting with each other and with their physical environment, provide free public-service functions on which civilization utterly depends. These services include maintenance of the quality of the atmosphere, control of the climate, operation of the hydrological cycle, generation and maintenance of soils, disposal of wastes and recycling of nutrients essential to life (including agriculture), control of over 95 percent of potential crop pests and carriers of disease, provision of food from the sea, and maintenance of the genetic library just discussed.

Breakdowns of these services on a local scale have often been observed. For example, in the Canete Valley of Peru, farmers sprayed large quantities of DDT and other persistent pesticides beginning in 1948. At first they obtained good control of cotton pests - so good in fact that they increased the spraying. By the mid-1950s the results were utter disaster. Yields dropped well below the levels obtained before spraying had been initiated. Cotton pests quickly became resistant to the pesticides, and , more importantly from our point of view, brand new insect pests appeared. These insects were "promoted" to pest status because they were less susceptible to the pesticides than were the insect predators that normally controlled them. The killing of those predators disrupted the ecosystem's pest-control function and "released" new plagues.

It is important to remember that populations of other species are vital working components of ecosystems and that they are usually not interchangeable. The predators that were decimated in the Canete Valley, if driven to extinction, could not be replaced with just any predator. The replacement predators would have to fit the physical and biological requirements of the niche vacated by the extinct predators - and in most cases a sufficiently close fit would be impossible.

Deforestation provides another example of the consequences of disrupting ecosystem services. Floods occur in river valleys below denuded watersheds; nutrients are lost from soil and the soils themselves are often washed away; and local climates become more severe. In areas of limited rainfall, deforestation may be the first step toward desertification. If deforestation is sufficiently extensive around the world -- and it is proceeding rapidly - at least regional, if not global, climate changes are likely to ensue due to changes in the Earth's reflectivity.

Deforestation may also contribute to the increasing concentration of carbon dioxide in the atmosphere, and that may eventually have profound effects on worldwide climate.

These are but two examples of the consequences to society of disrupting or destroying ecological systems. Because the organisms within an ecosystem are its functioning components, the loss of any population is at least potentially disruptive of that system. In addition, the accelerating disappearance of population after population around the world is indicative of the damage people are inflicting on ecosystems everywhere - damage we inflict at our own peril, since those ecosystems support our lives as well. Furthermore recent studies indicate that, in most cases, services lost through extinctions can not readily be restored by substituting other species or populations for those that have been extirpated. Thus it is their role in supplying ecosystem services that I believe provides the

most compelling argument against deliberately exterminating any population or species that does not present a clear and present danger to Homo *sapiens.*

The Rivet Poppers. We can illustrate the argument with a simple analogy. Suppose you are about to board an airliner, and you notice a man on a ladder busily popping rivets out of the wing. Curious, you approach him and ask what he's doing.

"I'm taking these rivets out of the wing," he replies.

"Why?"

"Growthmania Airlines, which own the plane, sells them for $1.00 each, and I get $0.50 from them for each one I pop."

"Are you crazy? The wing will be weakened and sooner or later it'll fall off!"

"Don't worry, there's a lot of redundancy built into the wing - I've popped out a lot of rivets, and nothing has happened yet. Besides, I'm going to ride on this same flight, so you can be sure it's safe."

At this point, you would doubtless return to the terminal, report the man and Growthmania Airlines to the Department of Civil Aviation, and book a flight on a different airline - hoping that the Growthmania aircraft does not encounter any severe turbulence before the DCA grounds it.

The assault that humanity is mounting on Earth's ecosystems is in many ways parallel to popping the rivets out of an airliner's wing. The ecosystems and airlines have built-in redundancy. The precise role of each population in an ecosystem is usually unknown, just as is the precise role of each rivet in an aircraft's wing. Equally, the results of popping a single rivet or deleting a single population cannot be predicted with great precision- especially since future stresses on the system are unpredictable in detail. But what is known with precision is that the end result of either continuing to pop the rivets or to exterminate populations or species. Both will inevitably lead to a failure - of the wing in the first case; of the ecosystem in the second.

Failure of the ecosystem services would be fully as disastrous for the passengers on Spaceship Earth as the failure of a wing would be for those on an airliner. For instance, it is possible that the destruction of the forests of the Amazon and the rich complex of

species it contains would help trigger changes in global climatic patterns. Agriculture remains heavily dependent on stable climate, and human beings remain heavily dependent on food. By the end of the century, the destruction of the forest in the Amazon basin, leading to the extinction of several million species - could entrain famines in which as many as a billion human beings perished. And, if our species were very unlucky, the famines might lead to a thermonuclear war, which, as "nuclear winter" studies have indicated, could extinguish civilization.

At best, humanity is capable of only partially substituting its own mechanisms for lost natural ecosystem services. And many services - including the climate-regulating function of the Amazon forest and the waste-disposal and nutrient-cycling functions - society couldn't begin to replace. Even if we knew how, the magnitude of the effort would be beyond our capabilities. Humanity is already paying the price of ecosystem disruption in many parts of the world. The alarming rate of desertification is one clear example. The need to install flood-control works in many areas and to resort to irrigation in others is usually the result of deforestation or other ecosystem degradation. And such degradation is virtually always accompanied by losses of populations and species.

The Forces of Extinction

There are two basic ways by which humanity pushes populations and species over the brink of extinction. One is by direct endangering - primarily by overexploitation; harvesting individuals of a population more rapidly than they can reproduce themselves. It is a tried-and-true method, dating back at least to Pleistocene times when hunting pressure from human beings helped erase a whole spectrum of large mammal species. The extermination in historic times of the dodo, great auk, passenger pigeon, and most populations of American bison followed the same tradition. Today, direct endangering threatens, among many others, several species of whales and rhinos and numerous populations of wild cats, elephants, reptiles, and cacti.

Some endangered species are hunted for food, but most are at risk because of other products: rhino horn (with reputed aphrodisiac properties), ivory, fur, tortoise shell, and so on. A surprising number of species of birds, reptiles, and plants are threatened because their rarity or beauty makes them the target of collectors. And depredations carried out in the name of medical research and zoos are helping to decimate the already far reduced populations of gorillas, chimpanzees, and other primates.

But serious as this direct endangering of populations and species is, it is a relatively minor cause of extinctions in comparison with the alteration and destruction of habitats - the

ecosystems of which species are components. Such indirect endangering has been in the past, and will be in the future, the principal way in which Homo sapiens erode organic diversity.

Habitat Destruction - Paving Over. One major source of loss is the paving over or other development of habitat in urban areas. For the past 20 years, our group has been studying the ecology and population genetics of checkerspot butterflies. The array of populations under investigation is now probably the best known group of natural populations, and the most intensively-studied population is an ecotype that is restricted to islands of serpentine grassland in the San Francisco Bay region. Populations of that ecotype are subject to periodic natural extinctions (we have observed several) and eventual recolonization from other islands.

Gradually, however, development has been removing islands from the mosaic. In 1979. a crucial colony at Woodside that we had been working with for two decades disappeared under a housing development. Enough of the habitat has now been destroyed that the ecotype as a whole is in danger of extinction, but its listing as an endangered species is being opposed by an arrogant defense contracting corporation, afraid that it might have to spend a few thousand dollars to protect the butterfly on land that it owns. It has intervened through the Department of Defense in the listing process.

The destruction of the Woodside checkerspot population is only the latest-known butterfly extinction caused by urbanization of the Bay area. As long ago as 1880, the Sthenele Brown disappeared under the spreading city of San Francisco, and in 1943 the last individual of the Xerces Butterfly was taken. Then it, too, went extinct as San Francisco spread over the Xerces' sand-dune habitat. And the San Francisco story is being repeated all over the world as urban areas expand. The butterflies, of course, are only prominent representatives of the multitudes of populations of unsung organisms - inconspicuous plants, small mammals, reptiles, amphibians, and invertebrates - that succumb to urban sprawl.

Ploughing Under. As serious as habitat destruction through urbanization is, it is minor compared to that accompanying the spread of agriculture. Entire ecosystems are converted into stands of one or a few plants, and heroic efforts are made to exclude all herbivores. Other ecosystems are dramatically modified by the introduction of exotic herbivores - cattle, sheep, and especially goats. Since agricultural areas are vastly greater than urban areas, the extinctions caused by agriculture are proportionately greater.

The first victims of agriculture are native plants, which are either ploughed under or devoured by grazers. For example, most of the Mediterranean basin is already a "goatscape", long since largely stripped of its native vegetation by deforestation and overgrazing. In the midwestern

United States, the few remaining relatively-undisturbed native prairie plant communities occupy only tiny threatened enclaves; and in the overgrazed hills of California's Inner Coast Range east of Oakland, almost all the visible plants are introduced weeds. Indeed, California's flora was so completely changed by the grazing of cattle and by competition from Mediterranean species introduced by the Spanish that botanists are not sure what the original flora really was like. China's native flora was already so reduced by agricultural development 50 years ago that, when famed entomologist Gordon Floyd Ferris searched for scale insects on their native hosts, his labours were virtually confined to temple courtyards where a few stragglers of once-abundant plant species persisted. And, of course, in much of Australia overgrazing by sheep has transformed the flora and fauna.

When humanity embarked on the agricultural revolution 10,000 years ago, it also embarked upon a slaughter of Earth's natural flora that continues to this day. Undocumented billions of plant populations and numerous plant species have been exterminated. The seriousness of this loss of plant diversity is greatly multiplied because of the foundation position of plants in food chains. Peter H. Raven, Director of the Missouri Botanical Garden and a leading plant scientist, has estimated that, because of the specialized feeding habitats of most organisms that attack plants, every plant species that goes extinct takes an average of 10 to 30 species of other organisms with it. He wrote: ". . . the diversity of plants is the underlying factor controlling the diversity of other organisms and thus the stability of the world ecosystem. On these grounds alone, the conservation of the plant world is ultimately a matter of survival for the human race." (In J. B. Simmons, *et al., Conservation of Threatened Plants,* Plenum, New York, 1978).

Agricultural destruction of habitat has also had dramatic effects on larger animals - from the recently-discovered Iriomote cat of Japan to many of Africa's spectacular game animals. Indeed, animals that require large unbroken stretches of habitat to maintain their populations are threatened over most of the world by the continuing conversion of natural ecosystems into farms and grazing land.

Activities associated with agriculture moreover can lead to extinctions far from the farms themselves. Diversion of water for irrigation always alters and often destroys the aquatic habitats at the source, and the organisms, terrestrial and aquatic, that depend on them. And pesticides intended for farms often find their way into other habitats and have severe impacts on non-target organisms. Predatory birds are the most famous victims of persistent pesticides, which wiped out peregrine falcons in the eastern United States and were implicated in the decline of the bald eagle. But from the standpoint of ecosystem functioning, the impact of pesticides on predatory insects, pollinators, and soil organisms

may well be more significant. Unhappily, the impacts of insecticides on ecosystems have rarely been documented in detail; still less is known of the effects of massive applications of herbicides. But there is little question that both are significant factors in causing extinctions.

Poisoning. Many of the toxic substances implicated in extinctions are not sprayed purposely in the course of agriculture, but are released inadvertantly. These include such chemicals as PCBs (which are structurally similar to persistent pesticides of the DDT family), heavy metals, radioactive materials, and many others.

Spewing. Among the most important products spewed into the environment by industrial civilization are oxides of sulphur and nitrogen. In the atmosphere, these are converted into sulphuric and nitric acids --and as a result rains over eastern North America and Europe are 100 to 1,000 times as acid as rains from unpolluted skies.
Acid rains have already destroyed all the fish populations in 300 Adirondack lakes, are helping to destroy the spawning rivers of Atlantic Salmon, and have made breeding impossible for Spotted Salamanders in upper New York State. Their impact on soil organisms (and thus on the nitrogen cycle, among others) and on forest trees are still a matter of dispute - but only the most dedicated pollyanna would find the prognosis anything but grim. Recently, for example, a German scientist has concluded that acid rains may have already irreversibly doomed Europe's forests, although other scientists there blame the deterioration of the trees on a virus epidemic.

Getting Energy. Humanity's search for minerals and energy also has wide-ranging deleterious effects on habitats. Strip mining for coal totally destroys large areas and many mine wastes contain toxins that find their way into bodies of fresh water and kill all or part of the organisms present. Tailings ponds of vast extent are often required by modern mining operations. They destroy the ecosystems where they are sited as thoroughly as would paving them over; and they often have far-flung impacts because of the fugitive dust and water pollution they generate. And strip-mining, of course, is possibly the most biologically destructive human activity outside of thermonuclear war. More than 4,000 square miles had been strip-mined for coal in the United States by 1980 - and the natural ecosystems that once occupied those square miles are irretrievably gone. Projected destruction in the Rocky Mountain states under current plans to turn them into an energy colony for the two coasts will dwarf what has already been done in eastern states such as Kentucky.

Oil spills are another inadvertant assault on habitat associated with humanity's attempts to mobilize energy. Their impacts seem to vary a great deal from spill to spill, depending on the kind of oil, physical conditions, and the ecosystem affected. But they are clearly putting pressure on some marine birds such as the South African blackfooted penguin and have deleterious effects on a wide variety of smaller marine organisms.

Damming. In the United States, dam building is perhaps the most notorious energy-related activity on the extinction front. This is because two dam projects - both outrageous boondoogles - have recently threatened two obscure organisms. One was the relative of the snapdragon, the Furbish lousewort, populations of which are threatened by the Army Corps of Engineers' Dickey-Lincoln Dam in northern Maine. The other, more famous case was that of the snail darter, an obscure species of fish, the then only known population of which was endangered by the Tellico Dam in Tennessee.

The confrontation of the snail darter and the Dam was a classic case of pork-barrel politics. The Tellico Dam was acknowledged to be an ill-conceived and destructive project by a long series of governmental reviewers. More was clearly to be gained by not completing it than by completing it - even if its completion would not exterminate the snail darter. Nonetheless, completion of the dam was finally forced through Congress by legislative guile, presumably in order to enrich a few contractors in Tennessee. It is the first known instance of the deliberate extermination of another species for economic gain; whether transplanted populations will survive remains to be seen.

Tropical Deforestation. The human activity that seems certain to cause by far the greatest number of extinctions in the next few decades is the destruction of tropical rain forests. Rain forests are by far the greatest reservoir of organic diversity on Earth. Their destruction will impoverish our planet more than the loss of any other habitat type, because about 40 to 50 percent of Earth's species occur in rain forests.

Rain forests are now under an escalating, multipronged attack; they are being destroyed by expansion of farming, lumbering, ranching, and to a lesser extent, cutting for firewood. One major assault comes from farmers attempting to wrest a living from the poor soils of the tropical forests. Exploding populations of these farmers, growing either crops for their own subsistence or cash crops for local or foreign markets, are quickly converting vast tracts from sustainable slash-and-burn rotation patterns to permanently destructive clearing.

More and more, the world is looking toward tropical forests as a source not only of solid lumber but of wood pulp to be used in producing newspapers, books, cartons for Japanese radios, and the like. Recent technological advances have made it possible to convert the diverse tropical forests to pulp, hardwoods and all. This has greatly escalated the attack on southeast Asia's forests; as Japan, hungry for pulp, has turned in that direction to meet its needs. The outlook for those forests and their inhabitants, from the orangutan and the Sumatran rhino on down, is dismal indeed.

In the Western Hemisphere, an important force in the destruction of rain forests is the demand for beef in rich countries. This is causing the conversion of large areas of forest to rangeland for the grazing of cattle. In twelve years ending in 1978, 30,000 square miles of Brazilian Amazonia were cleared to make room for 336 ranches running six million head of cattle. In Central America, the area for rangeland more than doubled between 1950 and 1975, and almost all of the increase was gained by clearing virgin forests.

Transporting. A form of habitat alteration that has already caused many extinctions has been the transporting of organisms. Moving plants and animals from the ecosystems in which they evolved into ecosystems where other plants and animals have no evolutionary experience with them has often had catastrophic effects on the recipient community. These effects have been especially severe on islands, where plants and animals normally have to contend with fewer predators and competitors than do their mainland relatives. When exotic organisms - rats, mongooses, goats, weeds - are introduced to islands, they often make quick work of the native species. Under the impact of exotic organisms, more plants and animals are known to have gone extinct on Hawaii than in all of North America.

Although the most dramatic effects of transporting can be seen on small islands, the impacts of imported organisms are also obvious on larger land masses. The native floras and faunas of New Zealand and Australia have been ravaged by imported plants and herbivores. The beautiful Eastern Bluebird of North America has gone into a decline in the past 50 years because of heavy competition for nesting holes from two introduced birds - the starling and the house sparrow. A fungus, the chestnut blight, accidentally imported into the United States from Asia on nursery plants, has virtually exterminated American chestnut trees.

The Total Impact. In this partial recitation of the sources of habitat destruction, each individual assault may seem relatively minor. Import goats here, pave a little here, release some more oxides of suphur and nitrogen some other place. In a sense, ecosystems are

being nickel-and-dimed to death. Each of us constantly contributes to their destruction in the course of our everyday activities - buying food grown in the agricultural system, using energy directly, purchasing an enormous variety of goods that have diverse environmental impacts tracing all the way back to the extraction of the original resources from which they were created. Just as the seemingly trivial act of throwing a gumwrapper away can, if done by enough individuals, convert a lovely scene into a rubbish-strewn mess, so seemingly minor actions on the part of all human beings can in the aggregate destroy the ecosystems of our planet - by eliminating their working parts.

The results of habitat destruction are written in the historic record for those willing to read it. Past civilizations - the farmers of the Tigris and Euphrates valleys, the Khmers, the Mayans, the Greeks, the Romans-all paid the price of being insensitive to the long-term ecological effects of their activities. What is so horrifying now, in the light of past localized ecocatastrophes, is the specter of a global civilization travelling precisely the same route - equipped with destructive tools unimaginable to past civilizations, which, in spite of their lack of technological capacity, still managed to ruin their life-support systems thoroughly.

What Can Be Done?

The fundamental solution to the problem of the ongoing impoverishment of Earth's biota is to create a massive system of ecosystem reserves, which must be kept as undisturbed as possible, and to manage the rest of Earth's surface in a manner that makes it relatively hospitable to other organisms. While zoos, botanic gardens and captive-breeding programmes may help to save a few prominent organisms for a time, there simply is no substitute for preserving entire ecosystems and abating planet-wide threats such as pesticide pollution and acid rains. Only in that way can a substantial fraction of Earth's original biological diversity be preserved and enabled to continue evolving. And only by preserving entire ecosystems can civilization continue to receive benefits from them - both useful products and essential life-support services.

What needs to be done, then, is perfectly clear - the tactics for conserving Earth's biota can be outlined in a few sentences. The strategy for accomplishing this is quite another matter. It means, of course, mobilizing the resources of society to control human population growth as rapidly as possible - since resources co-opted by *Homo sapiens* in most cases are not available to support other species. It means transitioning to a sustainable, steady-state economic system with equal alacrity, for it is not just the numbers of people that generate impacts on ecosystems, it is how the people behave. Thus, facing up to a substantial redistribution of wealth between the rich and poor of the

planet will be essential, because the poor cannot be frozen in poverty as the transition to a sustainable society is made. Sharing the wealth is also necessary because many of the biological reserves will have to be carved out of poor tropical nations, where the principal reservoirs of diversity are.

It will not be easy. The strategy will require a virtual end to further development in rich nations - indeed a de-development, a retreat to lower levels of energy use and material throughout (which fortunately can be accomplished with a rise in the quality of life). It will also require very different development goals, what I have called "grass-roots development", in poor nations. It means a revolution in the attitudes of most of humanity about our species' relationship with the entire planet, and especially with the other life-forms with which we share it.

But there is an encouraging side of the picture, too; the signs of change are already upon us. Most people now recognize the need to halt population growth quickly. Those who are not yet alerted are mostly unalertable. The smarter economists are starting to look at steady-state economic systems and to appreciate the physical and biological constraints within which that system must operate. And many people among the "haves" seem to understand that sharing with the "have-nots" is becoming a matter of survival. Whether the job will be done in time is problematical, but at least there is hope that "practical men" can be awakened from their dream worlds in time to change the lethal course they are now steering for civilization. If they do not awaken, our fellow passengers on Spaceship Earth will be decimated, and the handful of human beings that survive the resultant collapse may, if they are lucky, be able to eke out a livelihood hunting and gathering. For make no mistake about it - the bell that tolls for the snail darter and the mountain gorilla tolls also for *Homo sapiens.*