

# NATURE'S PLACE

Human Population and the Future of Biological Diversity

RICHARD P. CINCOTTA & ROBERT ENGELMAN



*Population Action  
International*



## About Population Action International

Population Action International (PAI) is a research-based advocacy organization that works to increase global political and financial support for effective population policies and programs grounded in individual rights.

The organization seeks to make clear the linkages between population, reproductive health, the environment and development.

At the heart of PAI's mission is its commitment to the expansion of voluntary family planning, other reproductive health services, and educational and economic opportunities for girls and women. Together these strategies promise to improve the lives of individual women and their families while also slowing the world's population growth.

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# Earth's Biological Diversity and Human Population

## Existing Species

Probably between 7 million and 15 million species

## Human Population

World population, 1900: ~1.6 billion<sup>1</sup>

World population, 1950: 2.5 billion<sup>2</sup>

World population, 1999: 6.0 billion<sup>2</sup>

## Threatened Species

	Assessed Species Listed as Threatened <sup>3</sup>	Proportion of total
Vascular plants	33,798	12.5 percent
Mammals	1,096	25 percent
Birds	970	11 percent
Reptiles	253	20 percent
Amphibians	124	25 percent
Fishes	734	34 percent

## The 25 Global Biodiversity Hotspots

World land area (minus ice, bare rock):	134.9 million square kilometers <sup>4</sup>
Original extent of the 25 hotspots:	17.5 million square kilometers <sup>5</sup>
Area in hotspots remaining in natural vegetation:	2.1 million square kilometers <sup>5</sup>
World population, 1995:	5.7 billion people <sup>2</sup>
Population in the 25 hotspots, 1995:	1.1 billion people <sup>6</sup>
World population density, 1995:	42 people per square kilometer <sup>2</sup>
Population density in the 25 hotspots, 1995:	73 people per square kilometer <sup>6</sup>
World population growth rate, 1995 to 2000:	1.3 percent <sup>2</sup>
Population growth rate in the 25 hotspots, 1995 to 2000:	1.8 percent <sup>6</sup>

## Units of Measurement

1 kilometer = 0.621 miles

1 hectare = 2.47 acres

1 square kilometer = 100 hectares = 0.39 square miles

1 kilogram = 2.2 pounds

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6. Population data estimated by Population Action International.



# Key Terms and Definitions

## Ecological Terms

**Biodiversity (or Biological diversity):** the diversity of living organisms and all the interconnections that support life on Earth.

**Biological invasion:** processes by which species become established in ecosystems to which they are not native. These species are commonly called biological invaders, invasive species or invading species. They are often weeds, pests and disease-causing organisms.

**Breeding populations:** groups of individual plants or animals that tend to reproduce among themselves and much less frequently with individuals from other members of the same species. As important sources of migrants and their genetic variability, these separated sub-populations can prove critical to the survival of a species as a whole.

**Domesticated species:** species in which the evolutionary process has been manipulated by humans to meet human needs.

**Ecosystem:** a dynamic complex of plants, animals and micro-organisms and their non-living environment that interact as a unit.

**Endemic species:** those species that occur within a restricted range. Outside that restricted range (such as an ecosystem, island, or within country boundaries) an endemic species is found nowhere else on Earth.

**Extinction:** in this report, the complete, permanent loss of a species to the planet as a whole.

**Habitat:** the particular environment in which a species or breeding population lives.

**Local biodiversity loss:** in this report, the loss of local breeding populations and/or their habitat, and thus the likely loss of genetic variation and reserve individuals.

**Protected area:** a geographically defined area that is regulated and managed to achieve specific conservation objectives.

**Species:** a group of organisms that, because of close genetic and physical similarities, can naturally mate with each other and produce viable offspring (individuals that can also reproduce naturally). Within species are often other levels of similarity, including sub-species, varieties, and breeding populations. Organisms that reproduce only through *asexual* means (such as micro-organisms that reproduce by dividing or budding) are sometimes difficult to separate using the species concept.

**Speciation:** the processes by which new species are established.

**Sustainable use:** the use of components of biological diversity in a way and at a rate that does not lead to its long-term decline, thereby maintaining its potential to meet the needs and aspirations of present and future generations.

**Threatened species:** species that have been assigned to one of three IUCN *Red List* categories—either vulnerable, endangered or critically endangered.

## Demographic Terms

**Population growth rate:** the percentage of the present population by which a population increases or decreases annually.

**Annual growth increment:** the number of people added to a population or subtracted from it annually.

**Population momentum:** the tendency of population growth to follow past growth trends for several decades, despite immediate changes in fertility that could eventually stabilize population or even reverse its direction of change.

**Population density:** the number of people inhabiting an area of land (expressed as people per square kilometer in international publications).

**Total fertility rate:** the average number of children that would be born alive to each woman if her reproductive experience were to turn out the same as that of women of all reproductive ages who are currently members of the population.

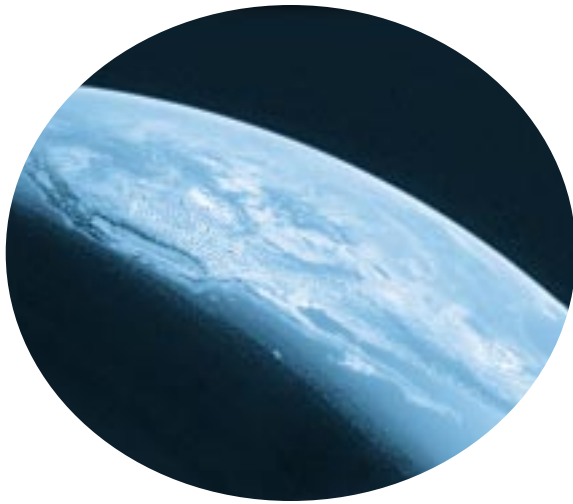
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# Summary



**T**he world's biological wealth is dwindling. Earth—the only location in the universe that we know supports life—is being transformed into a world that is genetically poorer. The loss is irretrievable, and its roots lie in the spectacular success of a single species: us, *Homo sapiens*. The disappearance of species, proceeding thousands of times faster today than in the pre-human past, is still accelerating and is likely to advance even more rapidly in the 21<sup>st</sup> century. No one can know when the process will end, or what the world of nature will look like when it does.

Hopeful signs do brighten this dark prospect, however. Among the most hopeful is that human population may well reach a plateau or peak by the middle of the 21<sup>st</sup> century. The pressure of human activities on remaining habitats could reach a maximum around the same time—and then, perhaps, begin to subside.

Among the most pressing questions are: Does human population growth really matter to species loss? Can policies and programs significantly influence human population trends, and can they do this while upholding the basic human right of couples and individuals to make their own decisions about reproduction, free from interference? The evidence shows that the answer to all these questions is yes.

## Human Activity and Biodiversity

Scientists are becoming increasingly convinced that human beings have caused ecosystem change and species extinction almost since our own species emerged. Between 50,000 and 10,000 years ago, as early populations of humans expanded across the continents, more than 200 species of large animals disappeared forever. Then, between 1,500 and 500 years ago, as human populations reached the farthest oceanic islands, over 1,000 species of island birds went extinct. Today's wave of extinctions, however, is even more extensive. Moreover, it is fundamentally different from its two predecessors in ways that relate strongly to the pervasiveness and size of today's human population:

- **For the first time, human activities are affecting species of all types and habits, at all points of the globe, and pushing many toward extinction.** Scientists project that at least half of all living species could ultimately disappear due to habitat loss alone, creating a mass extinction on a scale comparable to those that have ended past geologic eras.
- **Apart from habitat loss, other agents of human-caused extinction are now at**





**work.** Even more species could disappear as a result of pollution, overhunting, overfishing and inadvertent introduction of exotic species into weakened ecosystems. Hanging over the future of all life is the puzzle of how global climate will change in coming centuries as a result of human influences, and how these changes will affect ecosystems and the species they support.

- **Not all species are at risk, however.** Evolution is resilient. A small percentage of species—from pigeons, to weeds, to microbial parasites—have proliferated beyond their pre-human numbers or ranges. Rapidly evolving pests and disease-causing organisms could swell their ranks. Humanity itself, with more than 30 times the population density it ever could have achieved without agriculture, now appears to have become the central organizing reality around which non-human life will evolve.

## Population and Biodiversity

The full range of connections between local population growth, the influence of distant consumers, changing ecosystems and the loss of species is complex, controversial and in need of more research. Nonetheless, biologists agree on several key points:

- **Population growth is among a handful of underlying conditions determining the type and intensity of human activities that lead to biodiversity loss.** Population size itself is

an important determinant of the *scale* of humanity's use of natural resources—resources upon which other species depend, as well. Population growth, along with increasing per capita consumption, has played a key role in the development of *human-dominated ecosystems* in which the survival of wild species is often precarious. And recent population growth has made biological conservation efforts more difficult, more expensive and more likely to conflict with human needs.

- **The growth of our species' numbers is tightly coupled to rising demand for food and shelter.** Increasing the supply of these essentials, by whatever means, affects biodiversity. Agricultural expansion and urban sprawl play the largest discernible roles in the loss and fragmentation of the world's forests and wetlands, and contribute significantly to river and coral reef siltation. Intensified agriculture and urban concentration are leading contributors to water-borne pollution. And jointly, agriculture and domestic activities account for over three-quarters of all water withdrawn for use from reservoirs and aquifers. These are also the primary beneficiaries of dam-building, which is one of the top two causes (along with biological invasions) of freshwater species extinctions.
- **When considering human population growth, analysts tend to overlook the parallel growth and proliferation of populations of organisms that are closely associated with our**

**species.** These organisms, which include domestic and other species that thrive in human-dominated ecosystems, are themselves often principal agents of ecological disruption and biodiversity loss.

Early stabilization of human population would not by itself act as a brake against the current wave of extinctions. Nonetheless, it is arguably a necessary condition for saving more than 10 percent of the earth's natural ecosystems in perpetuity. And that achievement, ecologists argue, will be needed to avoid losing more than half of the planet's remaining plant and animal species.

## Hotspots: Population Pressures in the Most Biodiverse Places

The emerging technology of *geographic information systems* (GIS) opens up new possibilities for analyzing the distribution and richness of species, including our own species. Several key findings emerge in this first-ever effort to utilize this technology in a Population Action International report:

- **More than 1.1 billion people now live within the 25 global biodiversity hotspots, described by ecologists as the most threatened species-rich regions on Earth.** In 19 of these hotspots, population is growing more rapidly than in the world as a whole. In one hotspot (the Caucasus), population is decreasing moderately. While the hotspots extend across some 12 percent

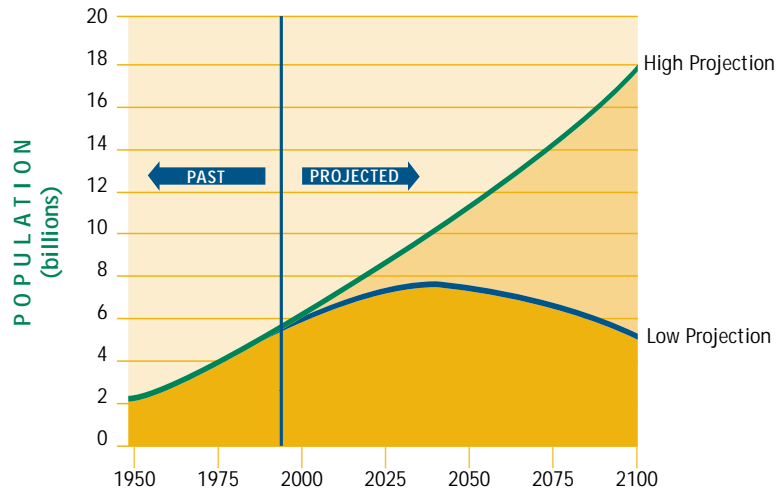


of the planet's land surface, by 1995 they were home to about 20 percent of the world's population.

- **Around 75 million people, or 1.3 percent of the world's population, live within the three major tropical wilderness areas: the Upper Amazonia and Guyana Shield, the**

FIGURE 1

### Possibilities in the Demographic Future



Human population could peak midway through the 21st century, or continue growing with a wide range of plausible outcomes. The path that population takes will likely be strongly influenced by the way in which nations order their priorities during the coming decades, and the progress women achieve toward economic and reproductive self-determination.

Source: Data from UN Long-Range Projections, 1998.

### Congo River Basin, and the New Guinea-Melanesia complex of islands.

All together, these areas cover around 6 percent of Earth's land surface. Population in the tropical wilderness areas is, on average, growing at an annual rate of 3.1 percent, over twice the world's average rate of growth—a product of rapid migration and high rural fertility rates in these regions.

- **In most hotspots located in developed countries, populations are projected to grow for several decades to come.** Past and present migration into these areas is the major factor in this continued growth, specifically in the U.S. states of California, Florida and Hawaii, and in western Australia and in New Zealand. Much of this migration is internal, with more people moving to warmer climates and coastal areas. Significant international migration has also been involved, to varying degrees, much of it with origins in developing countries.

Much of what society and conservationists will need to accomplish to save species will have little to do directly with population change. Population analysis can, however, provide a measure of the risks that most species will face. For as population grows and as additional land, water and waste-absorbing sinks are needed to support these individuals, some conservation options necessarily fall by the wayside.

## Population and Hope

The evidence of recent demographic research suggests that couples the world over, and especially younger women, today desire later childbirths and fewer children than ever before. Both desires—if put into effect—contribute powerfully to the slowing of population growth, now averaging 1.6 percent annually for less developed regions of the world and 0.3 percent for the developed regions. **The growth of our species, once the object of environmental fears, has instead shown itself in the past decade to be among the more resolvable of environmental concerns.**

A plateau or peak in human population by the middle of the new century is possible. But this is likely to occur only if developed and developing countries renew their commitments to the principles—and the shared investments—agreed to in 1994 at the International Conference on Population and Development in Cairo.

An early halt to human population growth will not end human-caused extinctions. Conservationists will continue to contend with our species' unprecedented densities, its geographic range and mobility, its need for natural resources and ways to dispose of wastes, and its use of technologies. The possibility of world population stabilization, in combination with modest decline in some regions, nonetheless offers among the greatest hopes for the future of species and ecosystem conservation on a human-dominated planet.



## Recommendations

Each of us can take action to preserve the planet's wealth of living species. This report's recommendations are addressed to policymakers, to scientists and conservationists, and to the general public. Specifically, they include the following:

- The conservation of biological diversity should be elevated to a high priority by donor agencies, nations and communities. While innovative conservation programs deserve support and funds, there is a pressing need to encourage broader understanding of biodiversity and its value to society. To further this objective, governments and donors should work to expand the ranks of biodiversity scientists and environmental educators in the species-rich tropical countries.
- The Convention on Biological Diversity, an international agreement aimed at maintaining the planet's biodiversity and equitably sharing its benefits, deserves the support of all nations and peoples. Negotiators seeking to improve it and further its progress should consider the interactions between species survival and human population dynamics. Through their impact on population growth and on the capacity of women to manage their own lives, the social investment strategies called for at the 1994 International Conference on Population and Development support and amplify other measures to conserve Earth's complex web of life.
- The public and private sectors should cooperate to diminish the environmental impacts of the expansion of agriculture and housing. Significant investments in research and improved standards in engineering and zoning for these sectors could help minimize the conflict between conserving biodiversity, and much-needed efforts to alleviate poverty and to accommodate the population growth that occurs during the next several decades.
- Where organizations work in remote rural areas to promote biodiversity conservation, conservationists should consider cooperating with qualified providers of reproductive health services. They can do so without jeopardizing their mission in conservation by working as part of broad-based efforts to promote community development, address basic human needs, and improve the management of natural resources that sustain human and non-human life.
- In research publications and other communications, scientists and educators should use the range of future population possibilities—the high and low scenarios projected by the United Nations—rather than the medium scenario alone. There are immeasurable possibilities for unexpected demographic changes, even in the regions where up to now there has been little improvement in women's status and little decline in fertility rates.
- Consumers should learn about and consider the role of their purchases, their pets, and their daily activities in putting biodiversity at risk. They should inform themselves about and consider how their lifestyles and their political choices influence native species and ecosystems.
- Couples and individuals should consider the impact of their reproductive decision-making on the well-being of their communities and of the world as a whole.

The survival of anything like the current panoply of plant and animal species will depend not only on investments made today in biological conservation programs, but also in human development efforts that end up, as a side benefit to their main purposes, slowing the growth of human population.



## Sylphion: A Natural Contraceptive and Its Loss

A single wild herb, a fennel-like plant in the carrot family, could stand as a symbol of the major themes of this report, except for one fact: the plant no longer stands at all, having gone extinct around the height of the Roman Empire.

Roman and Greek chronicles reported that sylphion (*Ferula historica*) once grew in abundance in the hills near Cyrene, a Greek city-state founded in the 6th Century BC along the coast of what is now

Libya. Cyrenian women valued sylphion as an herbal antifertility drug. It was, in fact, the oral contraceptive of the classical world, and contraception was its only recorded use.<sup>1</sup>

As knowledge of sylphion's properties spread throughout the Mediterranean basin, however, the herb was transformed from a home remedy, largely controlled by women themselves, into one of the principal commodities of Cyrene's foreign

trade, controlled by men. Evidence of sylphion's economic importance is its silhouette on the face of Cyrenian four-drachma coins. The 4th century BC physician Hippocrates records Greek and Syrian attempts to cultivate the herb on home ground and cut into the Cyrenian market. The attempts failed, and sylphion remained endemic to Cyrene.<sup>2</sup>

Today, unlike in Roman times, over 3 billion adults and adolescents around the world are in or are entering their reproductive years. The need for a variety of safe and effective contraceptive methods

grows more acute each year. Whatever lessons sylphion might have offered to developers of modern contraception, however, are lost. No one knows what active ingredient in the herb allowed Mediterranean women to manage their own fertility. No one knows how safe or effective it was, or even how the herb was prepared.

All we can be sure of is that many women in the classical world wanted very much to postpone pregnancy and plan their families. Sylphion's value climbed until it was said to have commanded its weight in silver. Without substitutes or the capacity to domesticate or hybridize the wild herb, commercial traders over-harvested it. Around the 2nd or 3rd century AD, sylphion disappeared.

The case of sylphion reminds us that women's interest in managing their own fertility is ancient. The herb's extinction speaks of humanity's longstanding but fragile economic association with biodiversity. It also demonstrates the importance of conserving critical biological resources for ourselves and for our posterity. As in the case of sylphion, we may not know the full price of our loss until it is too late.

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### Greek Colonization 6th Century BC





# Introduction

**N**ever before, in 3.5 billion years of life on Earth, has a single species chipped away large portions of the entire earthly array of life. Yet that is what human beings are doing today, however unintentionally. If most of the trends evident in the 20<sup>th</sup> century continue, it is hard for most biologists to project anything other than a much less diverse—and therefore less wondrous—web of life in the coming century and beyond.

There is one trend, however, that suggests hope for the future of the world's complex mix of species and ecological systems. The growth of the human population is slowing down, faster at the close of the 20<sup>th</sup> century than most demographers had previously expected. Whether and how fast that trend will continue, however, depends critically on decisions made today.

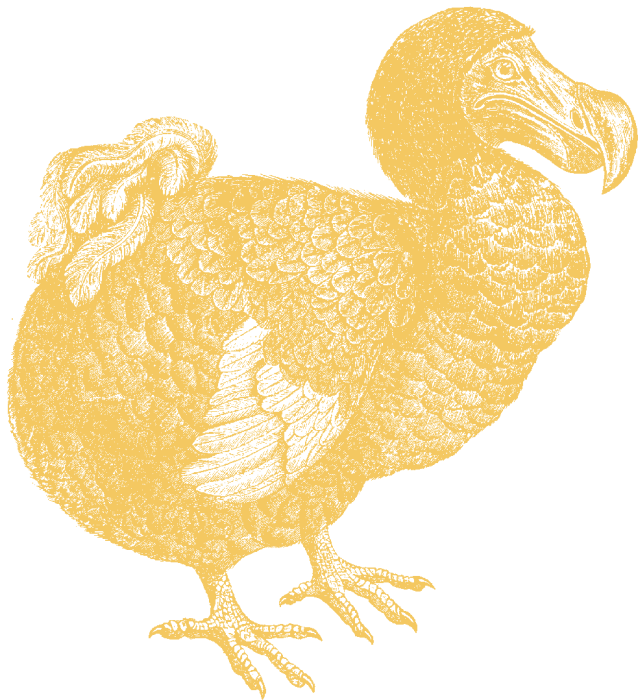
This report, the sixth in a series on population and critical natural resources, considers how population is changing, how society might influence these trends, and what impact future population change might have on the conservation of species. The report surveys the world's highest-priority regions for biological conservation, the 25 biodiversity hotspots and three major wilderness areas. It quantifies each region's human population

density and growth, aspects that will clearly figure in their biological future.

As is the case with most environmental issues, there is some disagreement about the nature and scale of the threat to biodiversity today. Few if any scientists, however, would argue that there is no threat at all. As this report points out, humanity's hand in the extinctions of large land mammals during the late Pleistocene Epoch, and of oceanic island birds during the last two millennia is virtually certain. But never has *Homo sapiens* pushed so many species, of so many types and located in so many parts of the world, toward the biological thresholds of existence. And this push has been rapid. Most populations of these now-threatened species were apparently hardy and viable at the beginning and even the middle of the 20<sup>th</sup> century.

Defying the world's preoccupation with the growth of financial wealth, conservationists around the world work to hold back the relentless erosion of the biological and genetic wealth inherited from eons of evolution. The overarching term for this natural wealth is *biodiversity*, described as the “diversity of life and all the interconnections that support all life on Earth.”<sup>1</sup>

There is little optimism in the scientific and conservation communities that the cur-



## Relative Scarcity: Apes on the Edge



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While our own population is growing steadily, those of our closest biological relatives, the *great apes*—the non-human members of the family Hominidae—have slid precariously toward extinction. Over the past half-century, the population numbers of three out of our four closest relatives—chimpanzees, bonobos and gorillas—have declined by at least half, earning these species an *endangered* status from the IUCN-World Conservation Union<sup>1</sup>. The orang-utan's population has slipped between 20 percent and 50 percent over a similar period. Considered *vulnerable to extinction* in IUCN's 1996 appraisal, the orang-utan is now even worse off—possibly down to half its 1996 numbers—following the past two particularly destructive years of forest fires on the islands of Borneo and Sumatra, and the economic crisis and political unrest that continue to plague Indonesia.<sup>10</sup>

Population sizes of the various species of great apes are tiny fractions of our own. Even the most abundant species, the chimpanzee, now numbers well below 200,000 in the wild.<sup>6</sup> In the United States alone there are 78 cities with populations greater than that figure.<sup>2</sup> The other three great apes—the bonobo (a genetically distinct species formerly known as the pygmy chimpanzee), the orang-utan and the gorilla—are even

less numerous. No more than a few tens of thousands of individuals exist, about the equivalent of human population in a medium-sized town. In fact, the number of human beings born each day—some 350,000—is greater than the current populations of all other great apes combined.

Much of what science has learned about human physiology and behavior comes from observations of primates, particularly of the apes. This is hardly surprising; more than 98 percent of human DNA is identical to that of chimpanzees and bonobos.<sup>3</sup> Yet like selfish big brothers in a dysfunctional family, humans are these animals' greatest threat. Some experts believe that the growing *bushmeat* trade—the uncontrolled harvesting of wildlife, and the butchering and marketing of their meat—could eliminate all viable populations of African apes within the next 50 years.<sup>4</sup> Despite the acute problem of hunting pressure, the clearing of forest may yet prove the ultimate undoing of efforts to save ape species.

Today *Homo sapiens* is the greatest of the great apes. Humans share the greatest responsibility for these species' demise, and can reap the greatest benefits for conserving them. But unless we fully understand this greatness, a day may come when—beyond the walls of zoological parks and laboratories—we are the only living member of our Hominid family.

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FIGURE 2

## Population and Status of the Great Apes, 1999

The degree of extinction threat increases from *vulnerable*, to *endangered* and then to *critically endangered*—the latter category holding the most seriously threatened species on IUCN's *Red List*.

Species, <i>Scientific Name</i> subspecies, <i>scientific name</i>	Population Size (~ = approximately)	Degree of Extinction Threat
<b>Bonobo</b> <i>Pan paniscus</i>	10,000 - 25,000 <sup>5</sup>	Endangered
<b>Chimpanzee</b> <i>Pan troglodytes</i>	100,000 - 150,000 (~2,500 in captivity)	Endangered
eastern chimpanzee <i>Pan troglodytes schweinfurthi</i>	More than 5,000 in the Democratic Republic of the Congo (former Zaire); ~8,000 in Uganda, Rwanda, Burundi and Tanzania <sup>6</sup>	Endangered
central chimpanzee <i>Pan troglodytes troglodytes</i>	~80,000, chiefly in Gabon and Congo. Parts of habitat still not surveyed. <sup>6</sup>	Endangered
western chimpanzee <i>Pan troglodytes verus</i>	No more than 12,000 <sup>6</sup>	Endangered
<b>Gorilla</b> <i>Gorilla gorilla</i>	40,000 - 65,000	Endangered
mountain gorilla <i>Gorilla gorilla beringei</i>	~650 <sup>7</sup>	Critically Endangered
Grauer's gorilla <i>Gorilla gorilla grauerii</i>	~17,000 (8,600 - 25,500) <sup>8</sup>	Endangered
western lowland gorilla <i>Gorilla gorilla gorilla</i>	30,000 - 40,000 <sup>7</sup>	Endangered
<b>Orang-utan</b> <i>Pongo pygmaeus</i>	* ~38,500 * estimated prior to 1997-98 fires; (present population could be from 25,000 <sup>9</sup> to as low as 15,000 <sup>10</sup> )	*Vulnerable
Sumatran orang-utan <i>Pongo pygmaeus abelii</i>	* ~7,500 <sup>11</sup>	(subspecies not evaluated)
Borneo orang-utan <i>Pongo pygmaeus pygmaeus</i>	* ~31,000 <sup>11</sup>	(subspecies not evaluated)
<b>Human</b> <i>Homo sapiens</i>	~6.0 billion	The IUCN-World Conservation Union classifies humans as members of the family of species referred to as the <i>Hominidae</i> —or the <i>great apes</i> , as they are more commonly known. No other ape, nor any primate, can claim near the geographic range or population that humans can. And all species of great apes, except our own, are listed as threatened with extinction.





Unlike most other forms  
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rent threat to biodiversity can be eased any time soon. In a recent Harris Poll, nearly 70 percent of biologists polled said that they believed a mass extinction is under way. A similar proportion predicted that up to one-fifth of all living species could disappear within the next 30 years.<sup>2</sup> When scientists consider current rates of land and aquatic conversion from non-human to human uses, they estimate that thousands of species blink out each year.

Most of the plants, insects, aquatic and marine creatures, and microbes that vanish do so before scientists can record their existence. But every few months, one (or more) of the high-profile species—a bird, mammal, amphibian or reptile known to science—is officially dropped from the catalogue of earthly inhabitants. Only a few cases of extinction are well documented. The extinction of 12 of Guam’s 14 remaining land bird species, which succumbed to the predation of the exotic brown tree snake during the past 50 years, is such a case. The elimination of over 200 freshwater fish species in East Africa’s Lake Victoria is another.

Since Earth first spawned life, global biodiversity has been depleted and renewed several times. The record left by fossils tells us that several million years of evolution can generate sufficient diversity to fill the ecological niches abandoned by the extinct. But this is meaningless to societies that strain even to look a matter of years or decades into the future. Unlike most other forms of

environmental degradation, extinction of a species is a loss no future can remedy. It is, for that life form, a one-way trip to oblivion, despite the fantasies of recent popular cinema.

## Why This Study?

Just as few scientists doubt the threat to non-human species is real, few would argue that the threat is unrelated to the recent growth of human population and its contribution to the scope and scale of human activity. Yet little research has so far explored the complex connections between the threat to biodiversity and the size and growth of human population.

This report is designed to help fill that gap, to distill the evidence and literature for policymakers and other non-scientists, and to contribute original analysis to the issue. In the analysis, we employ *geographic information systems* (GIS) technology, an approach to geography that uses digital information made possible by surveys, remote sensing and other means. The central portion of this report uses GIS to make first-ever estimates of population size and growth rates in the world’s most biodiversity-rich hotspots. The data that result provide an idea of where progress in sound population and other human development policies will be needed to bring human population trends into balance with the world’s most diverse and valuable ecosystems.

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# I. Biodiversity in Brief

*[We are] conscious of the intrinsic value of biological diversity and of the ecological, genetic, social, economic, cultural, recreational and aesthetic values of biological diversity and its components, conscious also of the importance of biological diversity for evolution and for maintaining life sustaining systems of the biosphere.*

Opening words of the preamble to the  
*Convention on Biological Diversity,*  
*Rio de Janeiro, June 5, 1992*



**B**iological diversity—or *biodiversity*—is the sum total of life’s physical expression and genetic potential, embodied in the array of organisms now alive. In a practical sense, biodiversity is the living savings bank for Earth’s successful genes, a bank that holds some 3.5 billion years of life’s solutions to the problems of surviving and competing on our planet.

Those genetic savings alone make biodiversity an exceedingly valuable asset—but there is more to this natural resource. With it come cellular processes that reshuffle and alter the expressed and hidden genetic variation produced during evolution, processes that are essential to meeting challenges yet to be posed. Biodiversity also encompasses the physical, chemical and behavioral relationships that have evolved between co-existing species, and the ecosystems and biotic cycles that embody these relationships, protect them and promote their continued evolution.

To assess biodiversity in any one locality, biologists often run surveys to determine how many species live there. A simple count, however, can be misleading. For example, a large portion of the species we encounter are *biological invaders*, exotic species, many of them adapted to environmental disturbance—as are a majority of the common backyard birds, rodents and insects that inhabit our garbage and invade our homes,

along with plants that survive in suburban parks, on roadsides and on lawns. These species contribute little to the global pool of genetic variability. In fact, they generally detract from it. Biological invaders are blamed for pushing out native species and disrupting the flow of energy and vital nutrients through both natural and agricultural ecosystems.<sup>1</sup> A recent study calculated that alien weeds, introduced animals (mostly insects) and infectious diseases of foreign origin cost the United States well over \$100 billion a year.<sup>2</sup>

If merely counting species is an inadequate indicator of biodiversity, then what defines local biodiversity? The short answer is: the status of *native* species. In conserving the complement of native species, biologists assume that each contributes, in some large or small way, to the complex properties of the ecosystem in which it resides—the ecosystem’s web of food relationships, its ability to capture energy and be productive, its ability to cycle nutrients and water, to exclude exotic species, and to recover from droughts, storms, infestations or pollution.<sup>3</sup>

Ecologists express concern about activities that upset the mix of species, eliminate breeding populations and increase the risk of extinction. These scientists rarely can predict the long-term implications of removing or replacing each species from any one ecosys-



tem. Surveys and field experiments have demonstrated that the removal of certain *keystone species*, often large predators that keep other species' populations in check, can radically change ecosystems. In other cases, however, species have been eliminated with little observed short-term ecological disruption. Just one in a hundred transplanted exotic species go on to produce major biological invasions—and there are few clues alerting biologists as to which one that will be.<sup>4</sup>

Unlike physics, whose laws we take

to be universal, ecological studies have yielded only a handful of basic principles that can be successfully applied from one ecosystem to the next. In the present winnowing and rearrangement of the biological world, surprises are common and often very costly, as illustrated by the over \$100 million in damage already wrought by invading zebra mussels on North American waterways.<sup>5</sup>

## How Many Species Are There?

The *species* is biodiversity's "currency." It is the lowest level of classification at which there are good chances that organisms with different descriptive names will also possess very basic genetic differences. About 1.5 million species have been named and described in museum collections.<sup>6</sup> The most current scientific estimates of total living species range between 7 and 15 million, though estimates higher than 30 million species emerge from justifiable assumptions and estimations. Around 10 million is a reasonable guess for the present, and reasonable guesses will have to do. Currently scientists are finding and describing about 15,000 species a year. So if 10 million species indeed exist, it would take over 6 centuries, at current assessment rates, just to make a proper inventory.<sup>7</sup>

So far, some 250,000 extinct fossil species have been described. But the fossil record presents a notoriously small and unbalanced sample of the earth's biological past. Based upon educated guesses of what types of species would have been present to fill out ancient

ecosystems but are missing from the fossil record, paleontologists guess that something like 5 billion species have lived on Earth.<sup>8</sup> Only two in every thousand of the world's ever-existing species, however, share the planet with today's 6 billion human beings.

From the pre-human fossil record, paleontologists estimate that a mass extinction has unfolded on average once every 26 million years. Five major mass extinctions and roughly another 20 minor pulses of extinction have occurred since animals emerged in the fossil record around 600 million years ago. These were geologically brief periods during which from 15 percent to as much as 90 percent of animal species disappeared.<sup>8</sup>

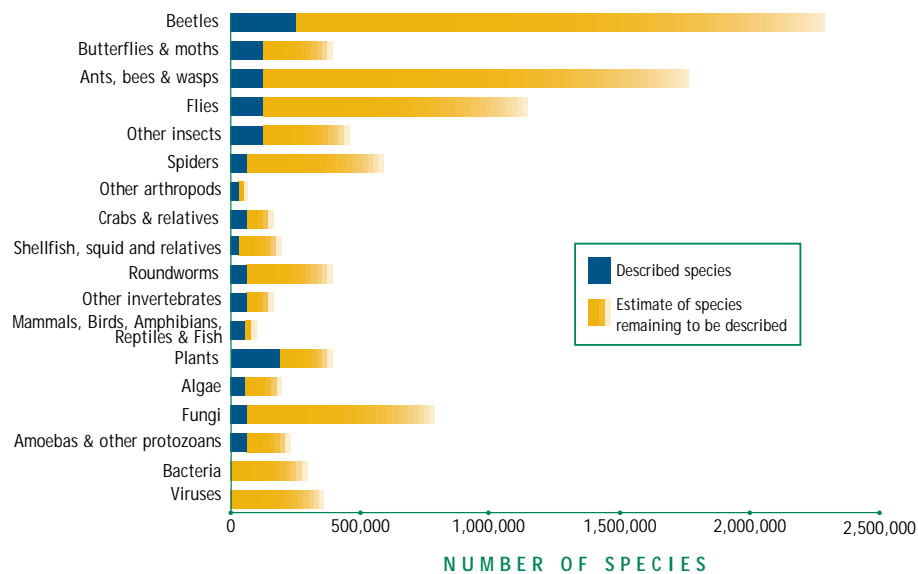
Mass extinctions are presently thought to have been caused by radical changes in sea level, abrupt climate shifts, and collisions with comets or other cosmic debris. All told, these pulses account for roughly 60 percent of extinctions.<sup>8</sup> The last major mass extinction, 65 million years ago, saw the end of dinosaurs and large marine reptiles, and permitted the evolution of a new assemblage of species, including our own.

## What Species Are Alive Today?

From a geological perspective, we live our lives in the Cenezoic Era, often called the Age of Mammals. In fact, mammals and all other *vertebrates* (that is, animals with backbones) presently account for only around 40,000 species, or fewer than 1 percent of all species. Plant life, consisting of flowering plants, conifers, mosses and

FIGURE 3

### Counting Earth's Species



According to the latest scientific estimates, the number of Earth's species range from 7 million to 15 million. In this graph, a total of around 10 million species is assumed. Less than 1.5 million have been identified, and relatively few of these have been studied to any depth.

Source: Adapted from N.E. Stork, 1992.



ferns, probably make up fewer than 5 percent of all species, or about 300,000 species. Arthropods—a group that includes the insects, crustaceans, spiders, mites, centipedes and their relatives—are by far the most diverse and widespread of all groups of organisms, and they are not well studied. They make up around 40 percent of living species.

Biologists still have a world of discovery awaiting them in invertebrate diversity. There are enough undescribed mollusks, echinoderms, jellyfish, worms and their relatives and other backboneless creatures to fill a few hundred museum cases and bookshelves. And there are likely significant payoffs for describing many of the hundreds of thousands of species of fungi, protozoa, algae, bacteria and viruses that remain unknown.

## Where Are They?

Life has spread to virtually every corner of our planet. Species of archaeobacteria thrive at near-boiling temperatures in hot springs in North America, while related species live in the cracks of ice-bound Antarctic lakes. Thousand year-old *welwitschia* plants bloom on the dunes of the African Namib, one of the hottest and driest of Earth's deserts. At the same time, foot-long Jericho worms and bacteria-eating brachyuran crabs feed at the mouths of volcanic vents four kilometers beneath the ocean surface under hull-crushing pressures, bereft of any sunlight and bathed in the searing acidity of concentrated hydrogen sulfide.

Relatively small percentages of today's

species, however, live in such extreme environments. Many more inhabit savannas, the tundras, or live in the open seas. Still higher concentrations of species spend their lives in the grasslands and coniferous forests of temperate latitudes; and even more survive in marshes and swamps, rivers and lakes, in ocean tidal zones and around nutrient-rich marine shoals. The largest concentrations of terrestrial biological diversity live where it is warm and humid, and where such conditions are seasonally quite stable: in the rainforests of the tropics. Though comprising only 2.3 percent of the entire surface of the earth,<sup>9</sup> rainforests probably hold more than 50 percent of all species.<sup>10</sup>

Tropical coral reefs—sometimes called the “rainforests of the oceans” for their richness of species—may run a close second. Worldwide there are about 600,000 square kilometers of reefs, comprising roughly 0.1 percent of Earth's total surface. As many as 950,000 species may inhabit coral reefs globally, though as few as 10 percent have been described.<sup>9</sup>

## How Fast Is Earth Losing Species?

As a rule, extinctions happen. Paleontologists estimate the *background rate of species extinction*—the long-term extinction rate exhibited prior to humanity's influence—at between 1 and 10 extinctions each decade among every million fossil species. Assuming 10 million species are alive today, scientists can expect 1 to 10 species to go extinct *each year* from all forms of life, visible and microscopic. In fact,

species are exiting much faster. Based on records of extinction among the best-studied types of animals, British ecologist Stuart Pimm and colleagues calculated extinction rates during the past century to range from 100 to 10,000 species per year (again, assuming 10 million species exist). That rate is between 100 and 1,000 times faster than the background rate of species extinction.<sup>11</sup>

What if all species presently listed as threatened by IUCN-World Conservation Union were to go extinct in the next century? Then extinction rates would multiply another 10 times over current rates, to 1,000 to 100,000 species per year.<sup>11</sup> This alarming projection matches other projected rates, by leading ecologists, based on recognized mathematical relationships between habitat loss and species loss.<sup>12</sup> Several decades of biological losses near the high end of this range would probably put at risk the planet's major biological and geochemical cycling systems.

## How Many Species Will Remain?

How many of today's species survive the current wave of extinctions depends on how quickly nations recognize the values of biodiversity, and how assiduously governments, organizations and individuals work for its conservation. It also depends critically on the future of human population and human behavior. The highest UN population projections—and even they assume declines in human fertility from present levels—suggest a world of humanity that arguably could spare little

Though comprising only 2.3 percent of the entire surface of the earth, rainforests probably hold more than 50 percent of all species.





If only 10 percent of each type of natural habitat eventually remains . . . around 50 percent of all species are projected to survive.



room for nature without the widespread use of extraordinary technology, and the implementation of environmentally-enlightened governance of unimaginable capacity.

If only 10 percent of each type of natural habitat eventually remains (and that appears to be an optimistic projection for many moist tropical forests), around 50 percent of all species are projected to survive. If that habitat is *fragmented*—left in small isolated pieces (and much of the remaining habitat already is)—then there could be less. If species invasions continue, and they appear to be increasing with globalized trade and weakened ecosystems, then perhaps our descendants will encounter even fewer survivors, and even fewer still from over-harvesting, pollution and the myriad effects of climate change.<sup>13</sup>

### Can Biodiversity Be Regained?

Despite the apparent fragility of individual species, fossil evidence also demonstrates that life itself is an extremely robust and resilient feature of our planet’s surface. Even as prior mass extinctions wiped out millions of species, it opened new opportunities for the survivors. Exposed to less vigorous competition and predation, survivors proliferated and *speciated* (evolved to form new species), filling the gaps left by the extinct.

Can we rely on evolution to recover from the present extinction? Evidence from the geologic record tells us that full recovery from past mass extinctions—recouping not

only the number of species, but the number of diverse groups of plants and animals, each distinct in form from one another (what biologists call *genera* and *families*)—required at least 5 million years, and in some instances up to 100 million years.<sup>14</sup> *Homo sapiens* has been around for some 250,000 years. Nature recovers, but not on a time scale relevant to human society.

### And What is Biodiversity Worth?

Accounting for annual economic productivity of commercial fish species or timber species, or even for certain genes used in crops or in pharmaceuticals is a straightforward exercise. Much of biodiversity’s services, however, never trade in the marketplace. Still we know they are valuable. Some—for example, the generation of our atmosphere’s oxygen, the purification of water, the pollination of crops, the formation of organic soil components, and the cycling of soil nutrients—are essential to human life and seemingly irreplaceable on a large scale.<sup>15</sup> Another, even less tangible category includes biodiversity’s aesthetic contributions to the human experience, and its role as an essential ingredient in the quality of life.<sup>16</sup>

Some economists have argued bluntly that to save a reasonable portion of biodiversity, society will have to come up with ways to make the value of nature’s amenities explicit, or simply risk losing them all. This school of ecological eco-

nomics thinking, a meeting of biological and economic mindsets, argues that the global economy, swelled by population growth and increasing per capita consumption, has grown so large, so demanding and technologically capable, that virtually nothing can escape it.

As economist Herman Daly and ethicist John Cobb have observed, “natural selection is giving way...to economic selection.”<sup>17</sup> What is not recognized as a valuable service in the marketplace, or is not valued by regulation and enforced protection, will ultimately be traded for or substituted with something afforded a higher value. This call-to-arms has prompted several estimates of nature’s values. According to one recent study by biologist David Pimentel and colleagues, biodiversity contributes annually about \$2.9 trillion in goods and services to global human welfare.<sup>18</sup>

Perhaps a more instructive way to ask the thorny question—What is biodiversity worth?—is to imagine that nature’s business is mediated by a group of environmental trustees. For a price, the trustees dispense biodiversity’s services, and with their returns they maintain and invest to promote those services.<sup>19</sup> How much could they charge? And which aspects of nature would we willingly pay to maintain and protect? For which would we settle for poor substitutes, and which might we let slip away forever, never knowing their value to our descendants? These will be critical questions for coming human generations.



## Relating Habitat Area to Species Numbers

Most projections of future extinctions are derived from trends of habitat loss. Over decades of field research, ecologists have shown that the relationship between habitat loss and eventual decline in species numbers, for most groups of organisms, follows a distinct pattern. [See Appendix 1c for the equation describing the relationship.] Presently, many ecologists believe that, if present rates of deforestation and wetland drainage continue, only between 5 and 10 percent of all species-rich habitats is likely to be saved. From the graphed relationship between species and habitat area, it is possible to deduce that losing 90 percent of habitat would likely result in a loss of around 50 percent of the original species.

Besides their value in predicting biodiversity loss, *species-area curves*—as they are called—tell an important story about extinction. The curve [see figure] predicts that as the first bits of original habitat are lost, species disappear slowly. The first to drop out are the *habitat specialists*—species with very specific habitat requirements and just a few breeding populations. Even more rapid species loss, however, occurs after habitat area has been reduced to its last 25 percent. By then most species are vulnerable, having dwindled to just a few breeding populations. Further shrinkage of habitat tends to result, eventually, in dramatic losses of species.

Using the species–area relationship also has its drawbacks. For example, it focuses policymakers' attentions narrowly on habitat

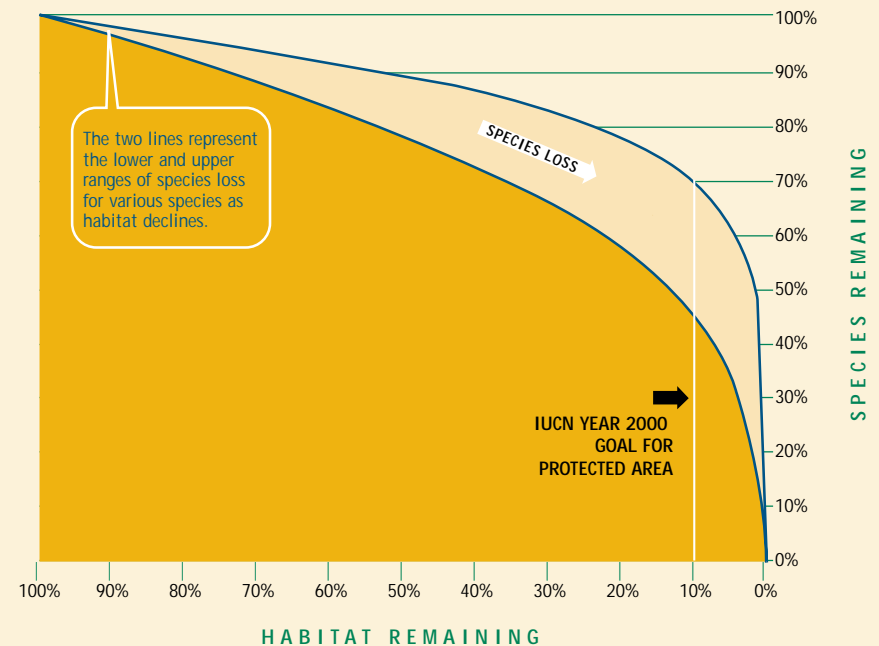
scarcity and species numbers, overlooking the fact that breeding populations are being eliminated at all stages of habitat loss. Losing breeding populations whittles away at species' genetic variability and their capacity for survival.<sup>1</sup> Neither does the species–area relationship adequately capture the importance of habitat interconnectedness and habitat quality. As a rule, habitats that are *fragmented*—broken into small pieces with barriers to movement in between—can maintain fewer species, while large interconnected habitats in good condition can be expected to retain several more species than the curve might predict.

In 1992, national delegates to IUCN's Fourth World Congress on National Parks and Protected Areas agreed to a non-binding goal of protecting 10 percent of each major habitat type by the year 2000.<sup>2</sup> While some countries have taken this goal seriously, still less than one-third have protected 10 percent of their land surface.<sup>3</sup> Currently, experts consider saving 10 percent of each habitat type to be an optimistic expectation, and yet far less habitat than is needed.<sup>4</sup>

Most ecologists would want to save at least 25 percent of each major habitat type. And that hope has nearly been realized in Costa Rica, where government looks toward the country's innate biological richness both as a valuable economic resource and as an important aspect of national identity.

FIGURE 4

### Species Numbers and Habitat Area



As habitat declines greater proportions of species living within those habitats tend to become extinct. Research over three decades has shown *species-area curves* to be reliable predictors of declines in species numbers when habitat area is lost. The curves for most groups of species that have been studied tend to pass through the region in the graph bounded by the two blue lines. For example, when only 10 percent of the original habitat remains (vertical line), scientists expect between 45 percent to 70 percent of the species to remain. And while IUCN's goal to help secure protection for 10 percent of each natural ecosystem is laudable, it is clear that meeting this benchmark will not be enough to avoid significant losses of native species. **Source:** Adapted from A.P. Dobson, 1996.

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## Squandering the Red Queen's Dowry

Plant life has provided modern medicine with some of its most important pharmaceutical products. More than half of today's prescription drugs are synthesized products modeled on naturally occurring compounds. In the United States, one-quarter of all prescriptions contains active ingredients obtained directly from plants, or chemically modified from plant compounds. By the mid-1980s, the annual commercial trade in plant-derived drugs exceeded \$40 billion worldwide.<sup>1</sup>

In terms of human welfare, the potential value of plant diversity is incalculable. For example, several decades ago researchers identified two valuable alkaloids in the Madagascar periwinkle that suppress white blood cell production in humans. One, vinblastine, is used in treating Hodgkin's disease, the other, vincristine, in treating childhood leukemia.<sup>2</sup>

Unfortunately, we are evidently losing other life-saving medicinal plants before they have been catalogued and assayed. According to the IUCN, almost 34,000 out of an estimated 270,000 known species of vascular plants are threatened with global extinction. The proportion of threatened plant species is even higher in the United States, where almost three in ten of the country's 16,000 plant species risk extinction.<sup>3</sup> The growth of human population, its mobility, and the nature and intensity of its activities are major factors in this risk.

It is no coincidence that plants hold so many compounds of therapeutic value to our own species. Humanity has simply appropriated chemicals from a genetically distant group of organisms, species whose immune systems are the products of successive adaptations to disease after disease over many millions of years.

Biologists expect to find these cumulative effects. Their presence is consistent with the *Red Queen hypothesis*,<sup>4</sup> an accepted evolutionary theory named after a character in Lewis Carroll's *Through the Looking Glass*. In the Red Queen's world "it takes all the running you can do, to keep in the same place."<sup>5</sup> Similarly, in order simply to maintain their competitiveness in ecological communities, plant species have evolved and accumulated chemical defenses to ward off attacks by bacteria, viruses and a range of other pathogens, parasites and predators—which themselves keep evolving, too, as if locked into a deadly biochemical arms race.

Plant chemical diversity—the Red Queen's dowry—is precious. But the repercussions of unprecedented growth and mobility of human populations have already narrowed plant genetic variability dramatically. Paradoxically, these same two human population variables—growth and mobility—are known to promote the transmission of emerging infectious diseases.<sup>6</sup> We appear to be squandering the Red Queen's dowry, at a time when we need it most.

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## Banking on Genes to Feed the Future

By the year 2030, the United Nations projects that world population will have grown beyond its present numbers by anywhere from 1.4 billion to 2.8 billion human beings. Even at the low end of this range, the increase in food demand over the next three decades will be unprecedented in human history, the more so if much-needed progress is made to reduce the malnutrition that now weakens some 800 million human beings.

While there is still potential to expand cropland in a few places in the world, agricultural experts agree that the vast majority of humanity's future sustenance will be harvested from essentially today's cropland.



Population Action International

Yet in the last decade or so, crop yields have leveled off for the chief commercial grains, despite huge increases in fertilizer use worldwide, especially in developing countries. Efforts in genetic improvement of crops, despite the hazards and controversy surrounding them, may be among the few options available that help farmers keep pace with the growth of food demand.

Much of the pressure will be on *crop breeders*—"gene-shufflers" who cross-breed and inbreed plants in search of novel combinations that could substantially boost crop performance. For many crops, however, the genetic deck is missing key cards. For example, North American staple crops like hard red winter wheat, which descends from just two Eastern European varieties, and soybeans, the offspring of a dozen Chinese strains, offer little prospect on their own for genetic improvement. And genetic uniformity increases their vulnerability to pest outbreaks and to emerging diseases.

Where are good genes when you need them? For crop breeders, the newest sources of genetic creativity, it turns out, are the old sources—DNA banked in the cells of wild ancestral species of crops and in their close relatives, and among remaining crop varieties cultivated by indigenous peoples.<sup>1</sup>

More of these plants contain useful traits than geneticists had previously expected. For example, introduction of genes to commercial tomatoes from a tiny wild relative with small off-colored fruits increased yield by nearly 50 percent while improving nutritional qualities and even fruit color. In China, crop yields jumped by almost a sixth after low-yielding wild relatives were cross-bred with farm varieties. Recent research suggests that about half of the most valuable hidden genes can only be found among the particular wild species in which they were discovered.<sup>2</sup>

Once common in the ancient centers of crop origin and production [see figure], these potentially valuable wild relations of common crop plants are now threatened by heavy grazing, rapid urbanization, wetland drainage, deforestation and mechanized agriculture itself. All of these are characteristic of human-dominated ecosystems that have grown in extent and intensity along with increases in human population and in per capita consumption.

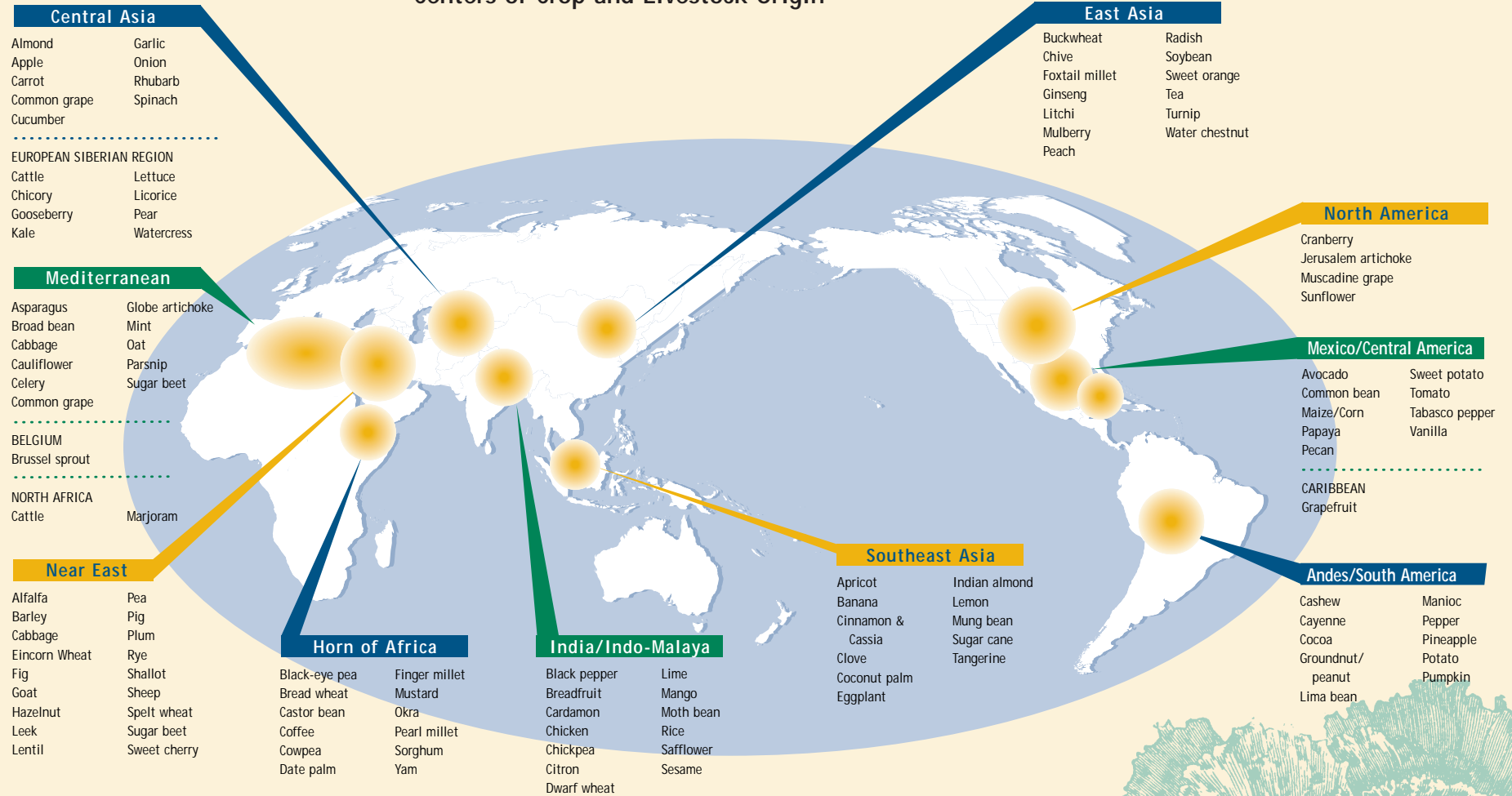
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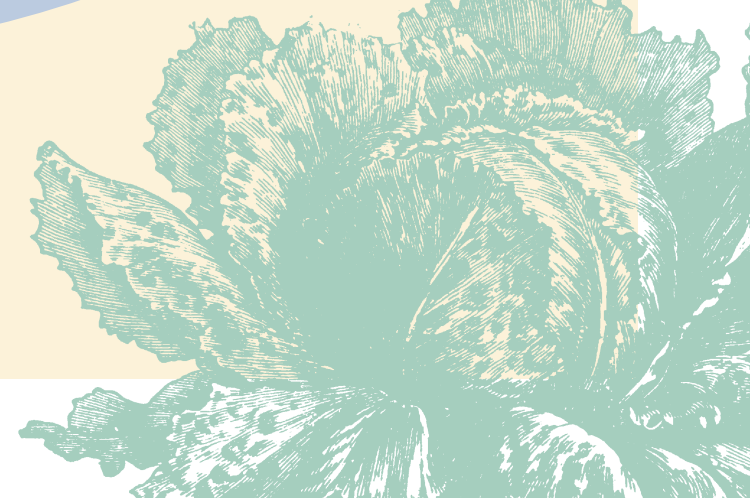


FIGURE 5

## Centers of Crop and Livestock Origin



The potential hidden among wild gene pools and crop varieties used in subsistence farming first came to scientific attention through the work of Russian botanist Nikolai Vavilov in the late 1930s. With his students, Vavilov first mapped the original geographic centers of major domestic crops, a system which now bears his name—the *Vavilov centers of crop origin*. Most of these centers of origin overlap areas of dense or rapidly growing human population. **Source:** Adapted from N. Myers, 1990.



# II. Four Waves of Human Influence

*[We] live in a zoologically impoverished world, from which all the hugest, and fiercest, and strangest forms have recently disappeared.<sup>1</sup>*

*Alfred Russel Wallace, 1876*

*Naturalist and evolutionary biologist*

**H**uman-caused extinction has a long history, predating our demographic and technological dominion over the earth. There is evidence that human hunters played a role in extinctions as far back as 10,000 years ago, and perhaps even 50,000 years before the present.<sup>2,3</sup> Back then, during the late *Pleistocene Epoch*, there may have been only 5 million humans, equipped with primitive technologies—a far cry from the 6 billion of our species that inhabit today's high-tech world.

The results of extensive archaeological and paleontological research over the past four decades leave little doubt that prehistoric human hunting of large mammals and flightless birds, as well as some early disturbance of habitat and importation of exotic species, have actually shaped most of the world's modern-day communities of species. The assemblages of wild animals that children learn so quickly to identify are in fact a profoundly diminished inheritance, a pale shadow of the far richer fauna that early humanity encountered as it first spread from Africa to the far ends of the globe.

## The First Wave: Losing the Big Ones

For nearly a century, scientists believed that climate warming was solely to blame for the Pleistocene extinctions. But by the mid-1960s, paleontologist Paul Martin and colleagues had pieced together enough archaeological and fossil evidence to show convincingly that the demise of populations of large animals (which biologists call *megafauna*) followed closely the migration of human hunters who, about 12,000 years ago, crossed the Bering Straits from Asia into North America on a land bridge linking the two continents.

In just a thousand years, North America



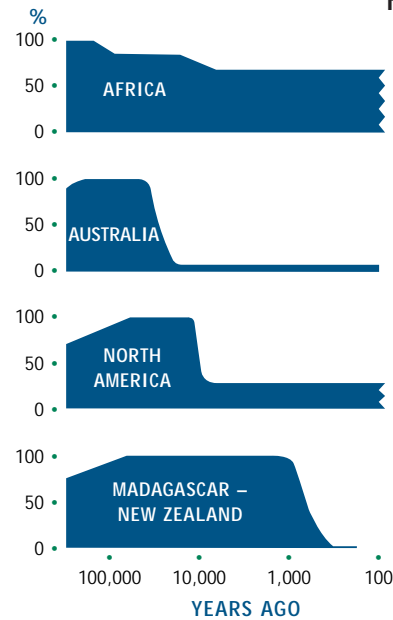
The Great Auk (*Pinguinus impennis*) in a woodcut by Danish artist Johannes Larsen (1867-1961), based on a stuffed specimen. By 1844 the Great Auk was extinct.

lost at least 57 species of large mammals<sup>4</sup>—73 percent of all large animals on the continent. These included types of horses and camels, giant sloths, glyptodonts (looking like giant armadillos), mammoths and mastodons. Their remains line the flooring and garbage pits of Pleistocene human settlements.<sup>5</sup>

Because these were the largest animals, they were also slowest to reproduce and mature, and thus needed the longest recovery periods to survive frequent hunting. And because these species had evolved without humans, they may not have become wary in time to survive. Predators and scavengers—such as dire wolves, lions and an assorted array of carrion feeders—that relied on these grazing and browsing species for their food disappeared along with them, in a tumultuous re-shuffling of the food chain. When humans crossed into South America, the scenario was replayed. About 80 percent of that continent's large mammals succumbed to extinction.<sup>2</sup>

While some researchers dispute Martin's *megafaunal-overkill* hypothesis, holding on to the climate-change hypothesis as the probable cause for North American Pleistocene extinctions, most biologists today accept that humans played a pivotal role in the extinctions. Without the human influence, this shift to a warmer, more arid climate would probably not, by itself, have caused such ponderous losses to biodiversity. These same assemblages of large animals had survived roughly 27 previous ice ages with several warming shifts before and after each one.<sup>2</sup>

*Homo sapiens'* arrival on the Australian



Source: P.S. Martin, 1984.

Large animal species have suffered extinctions that coincide with the presence of modern humans. The left-hand figure shows the percent survival of large animal species on three continents and two large islands.

continent some 50,000 years ago had an even more dramatic impact than did our arrival in the Americas. Australia lost 86 percent of its marsupial mammals, including several giant kangaroos, as well as marsupials resembling rhinoceros, tapirs, and ground sloths, plus a couple monotremes (egg-laying mammals) and a lizard larger than any alive today. Out of at least 48 highly varied large land animals, only four kangaroo species survive today.<sup>6</sup>

In Eurasia, Pleistocene losses were roughly comparable to those in North America. On the walls of caves in northern Spain and in the Dordogne River valley of southwestern France, wondrously

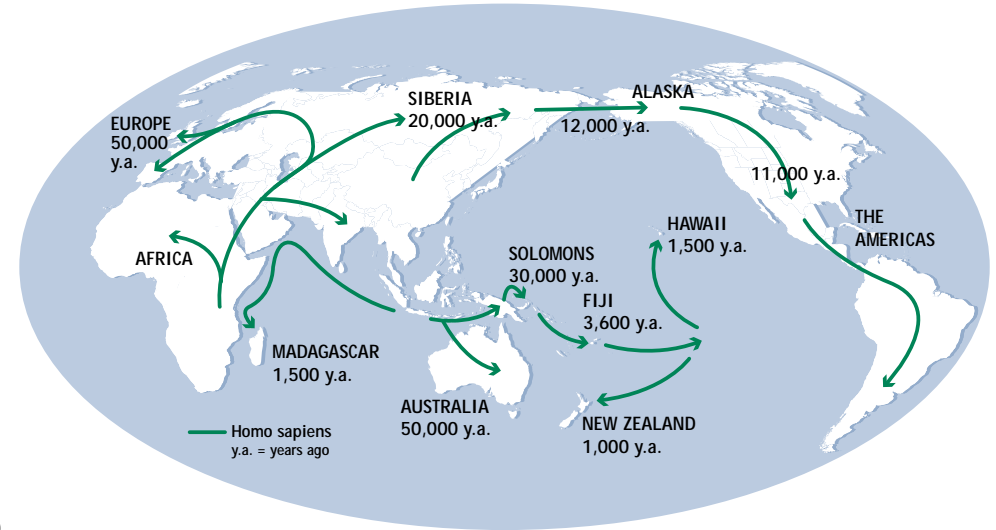
colorful paintings of large mammals and human hunters—most more than 14,000 years old, at Vallon-Pont-d'Arc at least 31,000 years old<sup>7</sup>—foretell the dawning of human art and civilization. But for the great herds that then roamed the Mediterranean Basin and the Eurasian forests and steppes, the paintings foreshadow the dusk of their existence.

## The Second Wave: Island Bird Extinctions

When the first human visitors to New Zealand landed on its shores about a thousand years ago, they encountered a

FIGURE 6

## Human Colonization and Associated Species Loss



Source: Adapted from J. Diamond, 1992.



The ongoing third wave of human-caused disruption to biodiversity is fundamentally different from its predecessors.



diverse array of moderate to large-sized animal species well-adapted to a variety of local ecosystems, just as on the continents. There were large grazers and browsers, predators and scavengers. But, quite unlike the animals of the continents, these creatures were all birds. By the time that Captain Cook circumnavigated New Zealand in 1769, the 50 tribes that are now collectively called the Maori had grown to over 100,000 people, but scarcely a trace of the wondrous birds remained.

By the mid-19th century, archeologists in New Zealand were publishing discoveries of bones of several species of large flightless birds—called *moa* in Maori oral tradition—which passed into extinction prior to European settlement.<sup>8</sup> There were 13 species in all. One is estimated to have grown as large as 250 kilograms (550 pounds).

The evidence—over a half million moa skeletons linked with ancient Maori settlements—has led scientists to conclude that human hunters pushed the moas to extinction. The hunters were equipped with nothing more than Stone Age hunting technology and abetted by the widespread disturbance created by the pigs, dogs and rats that they had introduced to New Zealand. Archaeology suggests that the Maori depended heavily on the moa for food, clothing and ritual items. Even moa eggs were blown out and used as water vessels.<sup>9</sup>

What happened in New Zealand played out as well in various forms on Madagascar and Cyprus, in the Azores and on the Caribbean islands. Wherever

flightless or weakly flying bird species evolved, and whenever these species were restricted to a few breeding populations, most disappeared within a few centuries after humans arrived on the scene. In the Pacific Ocean, this occurred on each of nearly 800 smaller islands to the north and east of New Zealand. In fact, archaeologists have yet to uncover fossil evidence of bird extinction in the South Pacific during the long period before human contact.

Polynesian settlement alone eventually led, estimating conservatively, to the extinction of more than 1,000 oceanic-island bird species—though estimates go as high as 2,000 lost species. Thus, extinction claimed between one and two bird species in every ten then alive on Earth.<sup>10</sup>

## The Ongoing Third Wave

After reading of the already staggering toll of human-caused extinctions, one well might wonder, “what group will be next, and why?” Fair questions, for most of the plant and animal species threatened with extinction today coexisted with humans for tens of thousands of years. Many were regularly hunted and harvested. And until between 50 and 100 years ago, most were surviving in good order.

The ongoing third wave of human-caused disruption to biodiversity is fundamentally different from its predecessors. Today, breeding populations are disappearing from species of all evolutionary forms and sizes, from the largest trees to the tiniest soil microbes. And they are disappearing from all regions and habitats. Though

winning fastest on isolated islands and in lakes, the present wave of extinction is running its course throughout the vast continents, on coral reefs and in the great oceans as well.

There is another difference. Those species extinguished during the first and second waves of disruption owed their demise largely to innate vulnerabilities, namely to slow reproductive rates, flightlessness or their existence in small, isolated breeding populations. Most of today’s threatened species were not innately vulnerable, but were made so by human activity. Only recently were these species reduced to small, isolated breeding populations whose reproductive potential is suppressed by degraded habitat and pollution—and thus assume aspects of the vulnerabilities exhibited by the large mammals and island birds that disappeared before them.

Already IUCN-World Conservation Union estimates that about one-quarter of all the world’s mammals and more than a tenth of its remaining birds are at a high risk of extinction. One-fifth of all reptile species, a quarter of all amphibians, and as much as 34 percent of all fishes, mostly freshwater species, are in similar jeopardy. And these proportions refer only to species already described by science. In the less studied taxonomic groupings, IUCN estimates that more than 500 insect species, 400 crustaceans, and 900 mollusks are threatened as well.<sup>11</sup> Among plants, about an eighth of the world’s flowering species is on the edge of survival.<sup>12</sup>

Moreover, time scales for human-caused extinction have shortened. Whereas Pleistocene mammals withstood several





## The Nature of Islands



Sally Ethelston

Ever since the voyages of Charles Darwin and Alfred Russel Wallace over 150 years ago, islands have fascinated evolutionary biologists, and for good reasons. Oceanic islands have been hotbeds of both *speciation* (the formation of new species) and recent extinction. For example, before the arrival of humans some 90 percent of the original

plant species and all of the native terrestrial birds of the

Hawaiian Islands were *endemic*—completely unique to these islands, having evolved from just a few species that landed there over the past several million years.

Following the original Polynesian settlement, during which pigs and rats were introduced, the Hawaiian Islands lost roughly half of their endemic bird species. Since 1778, when Captain Cook first visited their shores, the islands have lost an additional 18 bird species and the fate of another 12 Hawaiian birds hangs in the balance. Out of the 980 native plants identified in early collections, 84 are now extinct, and 133 are represented by less than 100 individuals in the wild.<sup>1</sup>

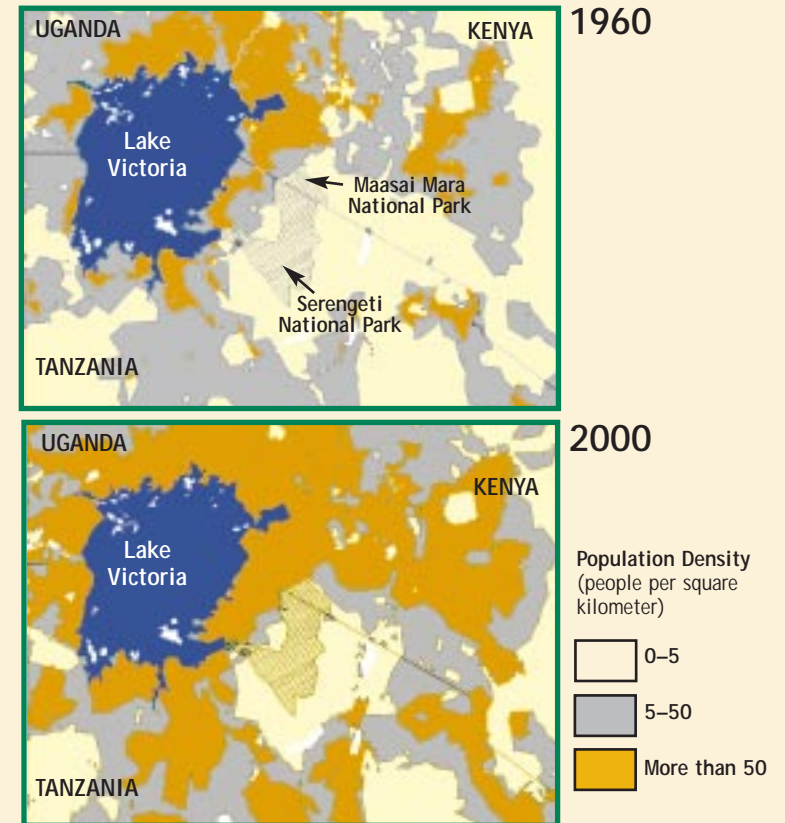
As it turns out, repeated studies of island species, principally of birds, confirm that species confined solely to small, isolated islands face high risks of extinction. This lesson from island ecology has even greater significance for 21<sup>st</sup> century conservation. Natural habitats, where they exist as reserves and national parks, are now mostly small *habitat islands*, isolated from one another by a sea of human settlement and activity. As farms have intensified, suburbs grown, road networks expanded and vehicular traffic increased—each related in some large or small way to continued population growth—habitat area has diminished and successful movements of organisms between protected habitats has become less and less likely. What were once vulnerabilities associated primarily with fragile oceanic island species, are now characteristics of numerous species on the continents.<sup>2</sup>

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FIGURE 7

### Islands of Nature: Population Growth and the Isolation of Protected Areas



Once stopovers for grazing animals migrating through East Africa's Rift Valley, Tanzania's Serengeti National Park and Kenya's Maasai Mara have become, over the past 50 years, isolated by agricultural settlement. Isolation could increase the vulnerability of wildlife populations to periodic drought, promote inbreeding among some species, and intensify interactions between wildlife, agriculture and surrounding people. To maintain the Serengeti's mix of plant and animal species under conditions of increasing population density will likely demand greater efforts and financial resources. And much of the funding needed will probably have to come from abroad.

Source: R.S. Reid and others, 1999.



... the fourth wave of human-caused disruption of biodiversity is a wave of proliferation rather than extinction, involving a small minority of species whose success is intimately tied to our own.



thousand years of hunting, and many island birds survived several centuries of harvests, species now can pass from hardy, viable populations to the threshold of extinction in a matter of decades.

The roots of current extinctions actually go back 6,000 to 10,000 years, to a time when the habits of human hunter-gatherers were going through change. Pressured by the upward momentum of its own numbers and a related scarcity of game animals, *Homo sapiens* turned to domesticating plant and animal species, gradually took to farming and livestock raising, and forged a new relationship with Earth's ecosystems.<sup>13</sup> Using fire and primitive tools, humans learned to purposefully shape the course of natural events, and then, slowly at first, to radically refashion entire ecosystems—to create what scientists now call *human-dominated ecosystems*. Today these ecosystems appear as a highly varied set of landscapes, from swidden farming to dense metropolitan centers, each intended to meet the needs and designs of members of our own species, generally at the expense of the needs of wild species.

On top of that, our extraordinary mobility facilitated the transport of exotic plants, animals and diseases, transfiguring previously isolated ecosystems. It is these changes—and the limited capacity of today's species to adapt to them—that are at the crux of recent and pending extinctions. And these changes, though motivated by a complex mix of factors, are clearly writ large by population growth.

How far have these trends gone? Well over 70 percent of Earth's habitable terres-

trial surface is fully or partially disturbed by agriculture, natural resource use or construction.<sup>14</sup> Humans now claim for their own use around 40 percent of each year's *terrestrial net primary productivity*—the total organic material produced by photosynthetic plants on land.<sup>15</sup> Nearly four-fifths of all native forests that covered our planet at the close of the last ice age has been cleared, fragmented, modified or degraded,<sup>16</sup> and half of that cover has completely disappeared. At least 10 percent of the world's coral reefs are severely degraded. Another 30 percent are considered in a "critical state," and thus likely to be lost within the next two decades.<sup>17</sup>

Clearly the additions to human population projected for at least the next half-century will require further appropriation of Earth's ecosystems. Such growth, coupled with expected growth of consumption and further globalization of trade and much-needed improvements in the living standards of the world's poor, is bound to put at further risk much of the world's remaining biodiversity.

## The Fourth Wave: Nature Altered

Many species will surely survive us. Some are becoming more numerous and even extending their ranges. This is especially true of biologically invading species transplanted beyond the reach of competitors, predators and diseases that once constrained them. Other species, adapted to nutrient-rich conditions that were previously rare, are also spreading, thanks to a profusion of fertile urban and agricul-

tural wastes. The toxic microbe *Pfiesteria* is just one example. Observed blooming in higher than normal marine concentrations of nitrogen and phosphorous, *Pfiesteria* has been responsible for massive fish kills in coastal waterways in the United States several times in the 1990s.<sup>18</sup>

Some higher animals have made clever behavioral adjustments. Among these is the black kite, a Southeast Asian hawk and successful urban predator that has become as adept at snatching sandwiches from lunching students as it is at plucking rodents from rooftops. The chimney swift, a small insect-eating bird native to North America, today builds its nest on the inner walls of chimneys rather than inside the dead, hollowed-out trees that were once a ubiquitous feature of the northern hardwood forest. And troops of Hanuman langurs, a South Asian primate, reside in train stations and in temples and frequently migrate with religious pilgrims.

Many of the organisms finding such success are not so harmless. A significant number are economic pests, such as weeds, house rodents and crop-eating insects. Some spread disease. And others directly cause infectious diseases upon which billions of dollars are spent annually for control and eradication. Whatever their habits and genetic origins, these species are wonders of rapid adaptation, organisms that have become hugely successful by integrating themselves into relatively homogenous and nutrient-rich human-dominated ecosystems.<sup>19</sup>

These make up what might be called the *fourth wave* of human-caused disrupt-



tion of biodiversity—a wave of proliferation rather than extinction, involving a small minority of species whose success is intimately tied to our own. Among them are a virtual handful of domesticated plants and animals that, according to some biologists, could be considered the biggest evolutionary winners in the race to keep pace with human-caused global change.

The demographic success of domesticated species parallels our own [see figure 8]. As our fortunes—and our populations—increase, so do theirs. Along with their numbers, their demands for energy, nutrition, space and waste disposal grow apace. In the United States alone, livestock produce more than 900 million metric tons of manure every year, over 4.5 tons of manure for every person. The U.S. Fish and Wildlife Service identifies livestock waste as the principal pollutant of 1,785 bodies of water in 39 U.S. states.<sup>21</sup>

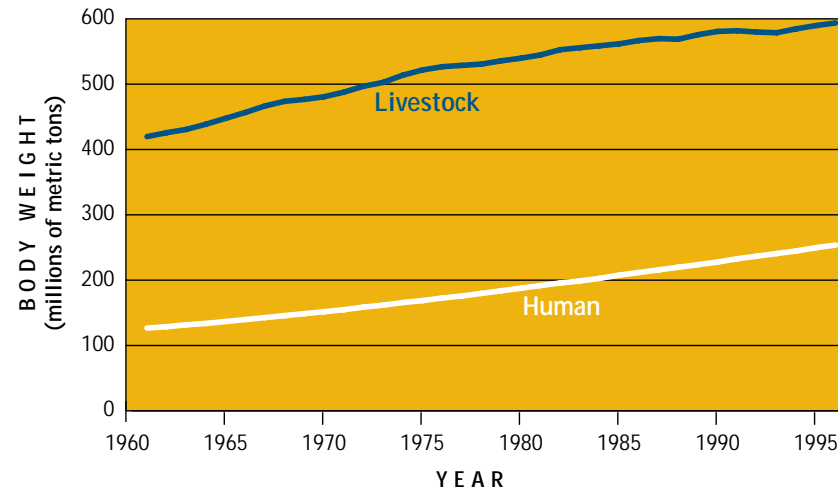
How many other species are acclimated or have become acclimated to some type of human-dominated ecosystem through genetic change or learning? There appear to be no scientifically-determined estimates. For Europe and North America, a survey by Population Action International of published guidebooks to flowering plants, birds and mammals suggests that between one and two in every 20 of these larger, well-studied species is now associated with farmland, suburban areas and other human-dominated ecosystems [see Appendix 1e], although some of these species are declining because of pesticides and changes in farming methods.

In tropical rainforests that harbor many specialized and interdependent organisms, the number of species likely to adjust to fully human-dominated ecosystems probably make up a far smaller portion of the total number.

For smaller species, there is much less information. How many fourth-wave organisms are insects and other invertebrates? How many are fungi, bacteria, viruses and other microbes? If evolution has its way, there could be many, for

FIGURE 8

### Domesticated Demographics: the Growth of Livestock Populations



The growth in livestock, shown above by their accumulated body weights, has kept pace with human population growth. Increases in disposable income globally are likely to step-up growth among these few species, and thus increase livestock waste discharge and other environmental changes these species promote.

**Source:** Livestock numbers from FAO-STAT, 1998; other sources and assumptions, see Appendix 1d.

these are small organisms that reproduce prolifically, and mutate frequently. Their recent evolutionary accomplishments—including bacterial resistance to antibiotics, malarial resistance to quinine-like drugs, and adaptations of crop-eating insects to chemical pesticides—have diminished the significance of many of humanity’s earlier achievements in biochemistry and medicine.<sup>22</sup>

Scientists see no end to this evolu-



## An Epoch in the Making

The global environmental change the earth went through 10,000 years ago was quite literally epoch-making. Geologists define that time as a boundary that ended the 2-million-year-long *Pleistocene* epoch and launched the *Holocene* in which we live today. Within a thousand years of the Pleistocene-Holocene boundary, ocean temperatures warmed. Shellfish

on the ocean floor shifted their distributions. Atmospheric carbon dioxide leveled off at roughly 280 parts per million, where it remained until the Industrial Revolution.

On land, average temperatures rose by 2.3 degrees Celsius. The massive glaciers that had spread into the mid-latitudes and across the continents over the preceding 40,000 years began to melt away slowly. And as they did, the great majority of large mammals vanished from North and South America—a process to which humans surely contributed.<sup>1</sup>

Today it is increasingly obvious that our species is responsible for fundamental changes to Earth's surface that are comparable to those of the Pleistocene-Holocene transition. In some locations, persistent soil erosion and the disposal of hazardous and nuclear waste are leaving legacies of ecological change that could persist for million of years. Over the next few millennia sea level rise wrought by human intensification of the greenhouse effect could literally reshape the world's coastlines. Increases in temperature and shifts in the water cycle could bring new patterns of vegetation to the world's landscapes, and reprogram the paths and volumes of oceanic currents. Finally, and perhaps with the

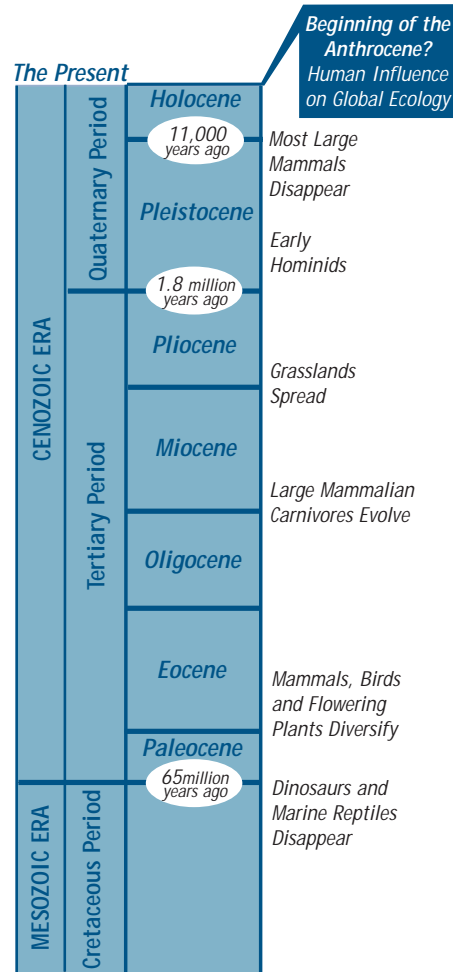
greatest long-term impact, species extinctions linked to human activity from the late Pleistocene through the next few centuries may well resemble mass extinctions of the pre-human past—each of which defined the boundaries of geological epochs.<sup>1</sup>

Indeed, a case could be made that Earth has entered a new epoch. Call it the *Anthrocene*, a period initiated and defined by *Homo sapiens'* unprecedented population and its capacity to influence the planet's global cycles. If scientists poke into the planet's crust thousands or millions of years from now, they may be able to identify the opening of the Anthrocene by a layer of lead, mercury and other relatively rare metals released from buried plastics and the settling smoke particles of fossil fuels. Probing polar ice and peat bogs, researchers will find trapped air bubbles with unusually high concentrations of carbon dioxide—now above 360 parts per million and rising—along with trace levels of industrial gases that were new to the planet when human beings invented them. In the surrounding media, scientists may find particulate ash from tropical forest burning, tilled soil and fertilizers blown from the world's agricultural regions,<sup>2</sup> and more heavy metals left by industrial processes hundreds of times above background levels.<sup>3</sup> The plastic detritus of modern civilization could be as sure a marker of human dominance of the earth as the layer of iridium left over from a coating of meteorite dust 65 million years ago is a marker of the passing of the dinosaurs.

What will life be like for our descendants, living later in the Anthrocene? Much will depend on the success of efforts to halt the four major interacting global transitions—human population growth, species extinctions, tropical deforestation, and global atmospheric and climatic change. Each of these epoch-making transitions has accelerated greatly in the last 50 years, less than a human lifetime. There is no way to know how far each trend will proceed, but their destinations will depend in large part on decisions human societies make in the early years of the 21<sup>st</sup> century.

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tionary tit-for-tat. By some estimates, viruses are “a million times more likely to mutate” than human cells and can, in some cases, produce a thousand copies in about an hour.<sup>23</sup> Though less prolific than microbes, insects seem well suited for evolution in human-dominated ecosystems. For example, researchers in London recently identified a new species of mosquito in the city’s underground transport system. A descendent of an aboveground species that taps into birds, this one obtains blood from the tunnel’s rodents and train workers.<sup>24</sup>

In the early 1970s, advances in vaccines suggested to many clinicians that the age of infectious disease was over. Since then clinicians have recorded at least 28 newly recognized diseases—HIV/AIDS, hepatitis C, D and E, Ebola and mad cow disease most prominent among them—and have had to battle dozens of resurgent infectious diseases.<sup>25</sup> Logically, some of the success of parasitic organisms could be related to amounts of accumulated body mass and energy now available in human-dominated ecosystems, and the ease at which these organisms can travel between distant hosts.

According to PAI’s estimates [Appendix 1d], there are roughly 250 million metric tons of human mass globally, and well over twice that in livestock. It is not unreasonable to suggest that humans, and the ecosystems they remake, are becoming the principal organizing reality for organic evolution. Indeed, a half-century of unprecedented human population growth may have helped give evolution a

**FIGURE 9**

**Newly Emerging Diseases**

Disease	Year of emergence or re-emergence	Country
HIV/AIDS	1975	probably Gabon or the Congo
Legionnaires disease	1976	United States
Cryptosporidiosis	1976	United States
Ebola haemorrhagic fever	1976	Dem. Rep. of the Congo (then Zaire)
Hantavirus	1977	Republic of Korea
Creutzfeldt-Jakob disease (CJD)	1979	United Kingdom, Canada
Human T-cell lymphotropic virus-I	1980	Japan
Hepatitis D	1980	Italy
Escherichia coli O157:H7	1982	United States
New variant of CJD (related to mad cow disease)	1986	United Kingdom
Salmonella enteritidis PT-4	1988	United Kingdom
Hepatitis C	1989	United States
Venezuelan haemorrhagic fever	1991	Venezuela
Brazilian haemorrhagic fever	1994	Brazil
Vibrio cholerae	1992	India
Human and equine morbillivirus	1994	Australia

Source: Adapted from D. Pimentel and others, 1998; WHO, 1996.

new start and some new directions.

Ultimately, massive education and public health campaigns, poverty alleviation, new technologies and human behavioral change may help control the diseases that have recently emerged and those that may be evolving.<sup>26</sup> And methods such as integrated pest management and careful

use of biological controls will no doubt help us deal with emerging crop pests. But given human population, the prevalence and neglect of poverty, and upward trends in consumption and in travel and trade, we can be sure that the battle of “wits versus genes” will continue.<sup>27</sup>



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# III. Nature Replaced: Prospects for Our Species

*... the world's nations by their actions or inactions will choose from among a range of alternative demographic futures.<sup>1</sup>*

*Programme of Action of the 1994 International Conference on Population and Development Approved by 179 nations Cairo, 1994*

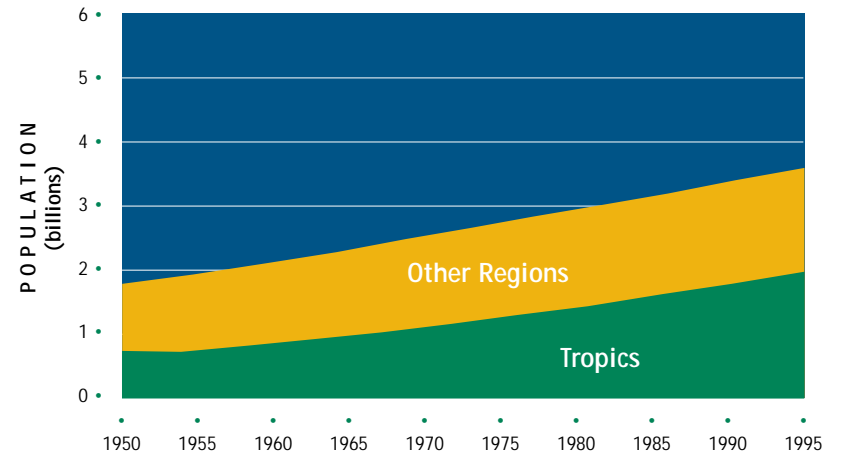


**A**s the second millennium draws to a close, roughly 6 billion people are alive on the planet. The number is unprecedented and imposing, but hard to place in perspective. No other species in the planet's past or present has combined the large body

size, the large and rapidly growing population, and the global distribution of *Homo sapiens*. Nor has any species evolved such intelligence and a capacity for innovation comparable to our own. There are, in fact, no models to guide our course. Yet we have plenty of demographic statistics to consider.

FIGURE 10

Population Growth in the Species-Rich Tropics



Source: Estimates by Population Action International.

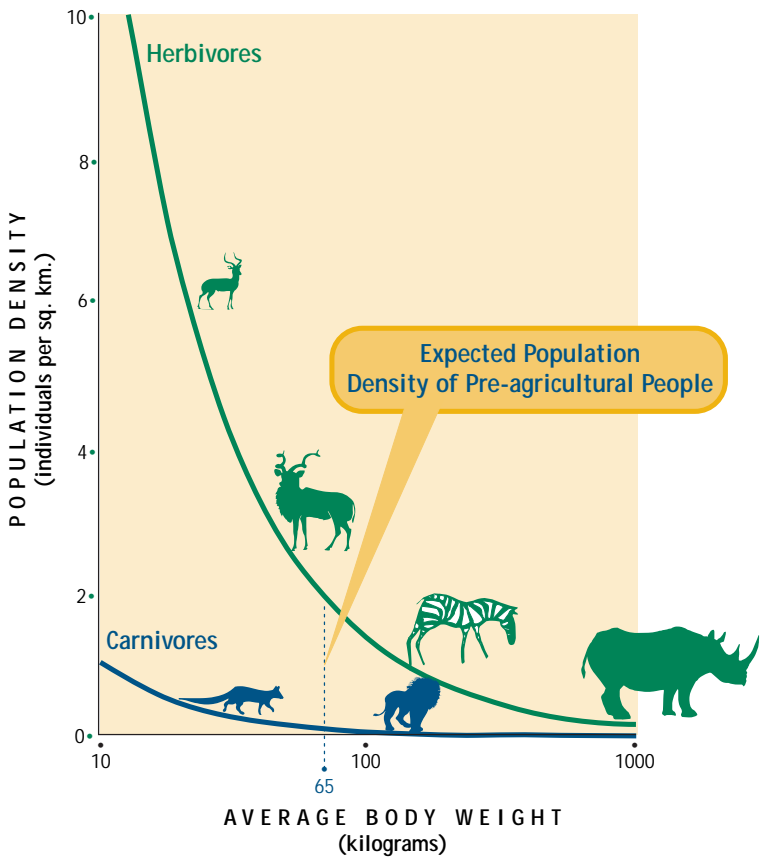
Since 1950, human population has more than tripled in the tropics, home to probably two-thirds of Earth's biodiversity. During the same period, the tropical share of world population grew from 28 percent to 36 percent and by 1995 comprised over 2 billion people. Today human population is growing by around 78 million people annually. Population Action International estimates that 51 percent of this growth now occurs in the band between the two tropics. [See Appendix 1i.]





FIGURE 11

### Expected Population Densities of Mammals



Standard curves predict the densities at which mammalian herbivores (leaf-eaters) and mammalian carnivores (meat-eaters) of different body weights can live in undisturbed habitats. According to the United Nations, in 1999 humans averaged about 44 people per square kilometer, substantially above these curves. Such unusually high density, over 30 times what is predicted for a mammal of our size with a mixed diet, would not be possible without modern agriculture.  
 Source: Relationships from R.M. Peters, 1983.

In comparison to the recent past, today's world population is large indeed. Our species' numbers have multiplied nearly 4 times since the beginning of this century, when the world's population was around 1.6 billion, and it has doubled since 1960. These figures are impressive, yet they still fail to illuminate how we compare as a species to the rest of life on Earth. There is, however, a scientific method based on animal body size that provides some biological perspective to human numbers.

### Population From An Ecological Perspective

Recognizing that species with larger body sizes have greater nutritional requirements and therefore must range farther for food, the late Canadian ecologist Robert Henry Peters compared species' average body sizes to their documented abundance. For mammals, Peters found statistical relationships that predicted numbers of *carnivores* (meat-eaters) and *herbivores* (plant-eaters) in natural ecosystems [see Appendix 1d].<sup>2</sup> These relationships can be used to estimate how many humans would have survived if we had remained, in effect, just another primate—a species that lived by gathering seeds, tubers and fruits, and hunting or scavenging meat, without the benefits of agriculture.<sup>3</sup>

Peters' equations predict 0.12 individuals per square kilometer for a carnivorous mammal the size of modern *Homo sapiens*, averaging roughly 65 kilograms (142 pounds), and 2.1 per square kilometer for a herbivore of the same weight.

Pre-agricultural human diets, however, fell in between carnivorous and herbivorous diets. A liberal estimate of the average population density our species would likely have maintained **without agriculture** is around 1.0 to 1.5 individuals per square kilometer, similar to the average density at which hunter-gatherers lived until relatively recently. Compare this with modern densities, such as that of Bangladesh with over 880 people per square kilometer, and the Netherlands averaging 384 people per square kilometer.<sup>4</sup>

**If, on this principle, pre-agricultural humans at densities around 1.0 to 1.5 persons per square kilometer were to exploit every corner of Earth's habitable terrestrial surface (about 130 million square kilometers),<sup>5</sup> the world would conceivably support around 130 million to 200 million pre-agricultural people.** According to several estimates, world population surpassed 130 million in the early years of the Roman Empire (before 400 BC), and reached twice that population, or two people per square kilometer, around AD 200.<sup>6</sup> The United States alone surpassed 130 million just prior to World War II,<sup>7</sup> and by mid-1999 claimed over 270 million inhabitants.

Even some scientists in the biological disciplines are unaware of how ecologically unprecedented the scale of human numbers is—not just *present* numbers, but those of the last two millennia as well. No other mammal of comparable body weight has ever attained anywhere near such abundance, nor has any other similar-sized terrestrial animal demonstrated such reproductive success.



The range of one to two people per square kilometer has added significance. It reflects how dense human populations can get, on average, before our species must modify the ecosystems we inhabit for our own survival. And it suggests how dramatically we must now control our competitors, predators and parasites, in order to maintain our numbers. It is these modifications and controls, writ large by the scale our populations and economies have achieved, that now pose the principal threat to biological diversity.

## The Reproductive Revolution

Today, despite our still growing population, we find ourselves somewhere in the middle of a revolution in reproductive behavior. On average, family size has decreased by roughly half, from more than six children per woman in many countries to fewer than three today. And contraceptive technologies are becoming more accessible, more affordable and more widely accepted. Gaps in access to family planning services and information, nonetheless, continue to exist in many parts of the world, especially in developing countries in sub-Saharan Africa, South Asia, and parts of Latin America and the Middle East.<sup>8</sup> Recent surveys suggest that even in the United States, nearly half of pregnancies are mistimed or unwanted. In the world as a whole, nearly two out of every five pregnancies are unplanned, suggesting the impact that improved access to safe and effective family planning services could have on population growth, not to mention on the well-being of women and their families.<sup>9</sup>

Shifts occurring in women's roles, access

FIGURE 12

### Human Fertility Change in the Highly Biodiverse Countries

	Total Fertility Rate (average number of births per woman)	
	1960 - 1965	1995 - 2000
Australia	3.3	1.8
Brazil	6.2	2.3
China	5.7	1.8
Colombia	6.8	2.8
Democratic Republic of the Congo (formerly Zaire)	6.0	6.4
Ecuador	6.7	3.1
India	5.8	3.1
Indonesia	5.4	2.6
Madagascar	6.6	5.4
Malaysia	6.7	3.6
Mexico	6.8	2.8
Papua New Guinea	6.3	4.6
Peru	6.9	3.0
Philippines	6.6	3.6
South Africa	6.5	3.3
United States	3.3	2.0
Venezuela	6.7	3.0

The countries listed are 18 selected by Conservation International as *megadiversity countries*. These countries are home to an inordinately large share of biodiversity, probably between 60 percent and 70 percent of the global total, including terrestrial, marine and freshwater species. In several of these countries fertility has declined dramatically over the past 30 years. Others remain considerably above replacement-level fertility, which is slightly above an average of 2 children per woman of reproductive age in populations where there is relatively low infant and child mortality.

Source: Data from UN Population Division, 1998.



## Bordering on Uncertainty: Considering the UN Population Projections

Like other PAI reports, this publication uses the low population projection as a rough semblance of the kind of demographic future we might expect with sound and well-funded population policies around the world. The high projection, by contrast, may represent a world in which governments and leaders have neglected or misapplied the health-related

and other social strategies that slow population growth and improve human well-being in many other ways.

The high and low scenarios do not represent margins of error in the conventional statistical sense. UN demographers do not suggest how probable any projection is. These low and high scenarios simply represent two distinct but extreme sets of assumptions that UN demographers apply, with slight variations, to every country. The low variant, in which fertility levels off at 1.6 children per woman, mimics the path of

fertility change that has occurred in most of the European countries (including Italy, Spain, Norway and Greece) and in several East Asian countries (Japan, South Korea, Taiwan and Thailand). In these countries, when fertility dropped from high levels it ultimately dipped below replacement fertility to levels of 1.2 to 1.8 children per woman over the last two decades.

The high variant, in which fertility rates are assumed to level off at 2.6 children per woman, mimics a number of Central and South American countries where fertility rates have momentarily stabilized at higher than replacement.<sup>1</sup> For example, total fertility rates of both Uruguay and Argentina have

fluctuated erratically below 3.5 children per woman for at least 50 years without ever having dropped to replacement levels. In Costa Rica and Chile, fertility declined rapidly during the 1970s, but stalled at similar levels.

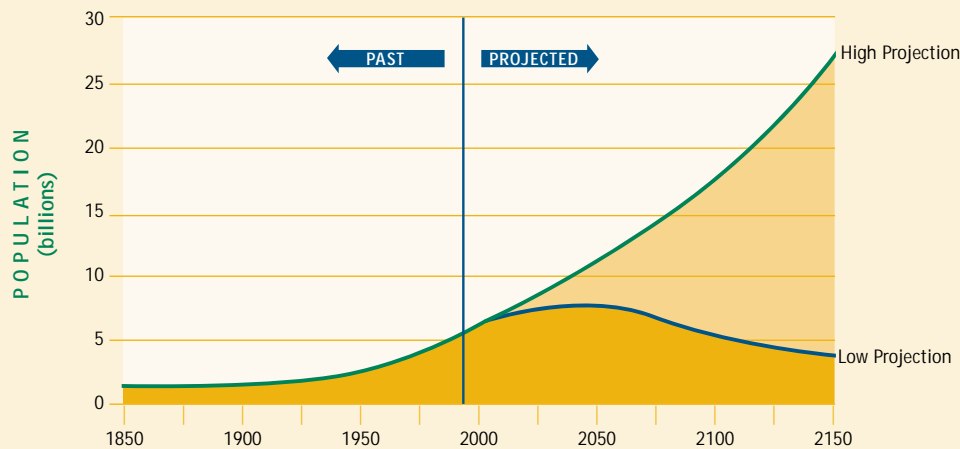
For parts of these regions and much of the world, predictions of fertility are especially difficult. In sub-Saharan Africa women still bear on average more than five children. In Pakistan, northern India, much of the Middle East and parts of Central Asia, women bear around four children. For these countries, demographers have few clues as to when further changes in reproductive behavior and women's roles will occur and how small future families might be. No indicator appears in the projections for global efforts to change human development policies that would influence population growth. Yet it is clear that the size of world population in 2050—whether 7.3 billion or 10.6 billion people, or some number in between—will depend in large part on the choices that governments, foreign aid donors, businesses and non-governmental organizations make in the coming decades.

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FIGURE 13

World Population: Past and Projected



Source: Data from UN Long-Range Projections, 1998.



to education, and economic and social mobility in almost every society are important elements in the transition to lower fertility. Changes in social norms, increasing costs and higher expectations for children, and growing demands on parents' time, all share in the mix that has increased demand for family planning services. How much and how often each has contributed are the subjects of continuing debate.<sup>10</sup>

Currently, throughout the developing world, women are seeking to have smaller families than their mothers and even their older sisters, and they increasingly have the means to achieve the family size they seek. Several good examples can be gleaned from East and Southeast Asia. During the mid-1960s, South Korea, Taiwan, Singapore, Thailand and former Hong Kong Territory began effective programs to lower infant and maternal mortality, establish easy access to family planning services,<sup>11</sup> and increase primary school enrollments and educational attainment.<sup>12</sup> Three decades later, average fertility in each of these Asian states is below two children per woman (the average in the United States). Other developing countries, including Mexico (2.8 children per woman), Brazil (2.3), Indonesia (2.8), Tunisia (2.6) and Sri Lanka (2.1), also are experiencing downward trends in fertility. Meanwhile, in more than 30 countries in Africa, women can still expect to bear five children or more during their lifetimes.<sup>13</sup>

During the late 1960s and '70s, nearly all the European countries fell below the approximately two-child-per-couple aver-

age necessary, in the absence of net immigration, to replace each generation with the following one. In the industrialized countries fertility rates may well remain low for some time, or they could rise again if the tradeoffs and costs of childrearing decline or if larger families regain social approval. Realistically speaking, we just don't know.

## Divergent Futures

According to the most recent long-range population projections, by the end of the 21<sup>st</sup> century global human population could reach as high as 16 billion. Or it could peak at less than 7.5 billion around 2040 and return again to below 5.5 billion by the century's end.<sup>14</sup> Between these two extreme projections lies a vast array of possible futures, including everything from continued exponential growth to early stabilization and even eventual decline. The outcome of this range of possible population trajectories, now uncertain, could make a critical difference to the prospects for conserving the remainder of our biological diversity in the coming century and beyond.

Could there be demographic surprises? Indeed, there already have been several. During the mid-1970s, annual net additions in world population actually decreased temporarily, reflecting devastating effects of earlier famine and political upheaval on the age structure of China's huge population.<sup>15</sup> Few demographers predicted the early declines in fertility in developing countries like

Indonesia, Tunisia, Colombia, Thailand and Bangladesh—or that Spain and Italy would eventually experience the lowest fertility rates in the world.

## Regional Trends

Many of the assumptions for future declines in population growth—even for the UN high-growth scenario—depend on a relatively complete diffusion of access to family planning services and better education for girls in sub-Saharan Africa, in parts of the Middle East, and in northernmost South Asia, where fertility rates are still high. And there is still considerable uncertainty as to whether declines in fertility will continue in Latin America.

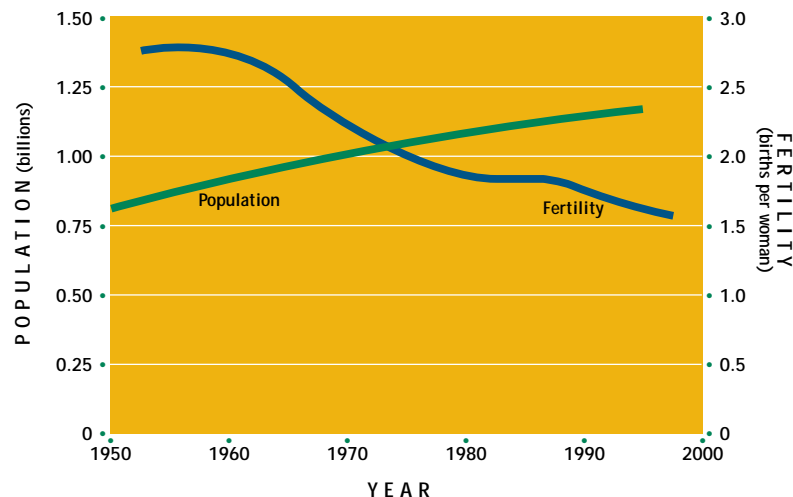
The UN Population Division projects that rising mortality from HIV/AIDS could have significant demographic impacts in some sub-Saharan African countries by early in the new century. Deaths from this virulent disease, most of which occur among adults in the prime of their productive lives, could stall educational progress, decimate the able and trained, and set back economic development for generations to come. In the long term, Africa's HIV pandemic could slow the continent's eventual transition to low fertility. With 780 million people today, Africa is projected by the UN to attain somewhere between 1.5 billion and 2.1 billion people by mid-21<sup>st</sup> century, a projection that accounts for some of the expected AIDS mortality.

In no small way, the survival of many of today's species, large and small, is linked to the well-being of the female of our own species.



FIGURE 14

## Population in the Industrialized Countries



Whereas fertility in industrialized countries is, on average, presently below the level at which couples can replace themselves, population continues to grow slowly from population momentum and immigration. Even among these countries—what the United Nations calls the more developed countries—population growth is uneven. Industrialized countries that have experienced decades of low fertility, such as Latvia, Portugal and Italy, are now reporting slow declines in population. The United States, Australia and New Zealand, however, continue to add about another 1 percent each year to their populations.

**Source:** Data from UN Population Division, 1998.

## Realities and Uncertainties

Even under the low-growth scenario, human numbers will continue to climb for many years, though at a slowing rate. Setting aside the possibility of catastrophe, most demographers expect that at least another 1.5 billion people, and probably more, will be added to today's total of 6 billion before growth halts its upward trend. If world population peaks early, conservation opportunities may arise. While these effects will surely be mediated by other economic and technological factors, less competition for land, reduced poverty, less road-building and less pollution are possible outcomes of an earlier-than-expected end to population growth that could aid the survival of species by the second half of the 21<sup>st</sup> century. In no small way, the survival of many of today's species, large and small, is linked to the well-being of the female of our own species. What is exciting about the state of the world's population is not the certainty about its future direction—there can be none—but the clarity of its present trends. At a time of rising concern about mass extinctions of wild species and the loss of natural ecosystems, it can only be good news that humanity's growing

enthusiasm for later childbirths and smaller families is opening up the possibility of bringing to an end the long history of our species' population growth.

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## Population Momentum

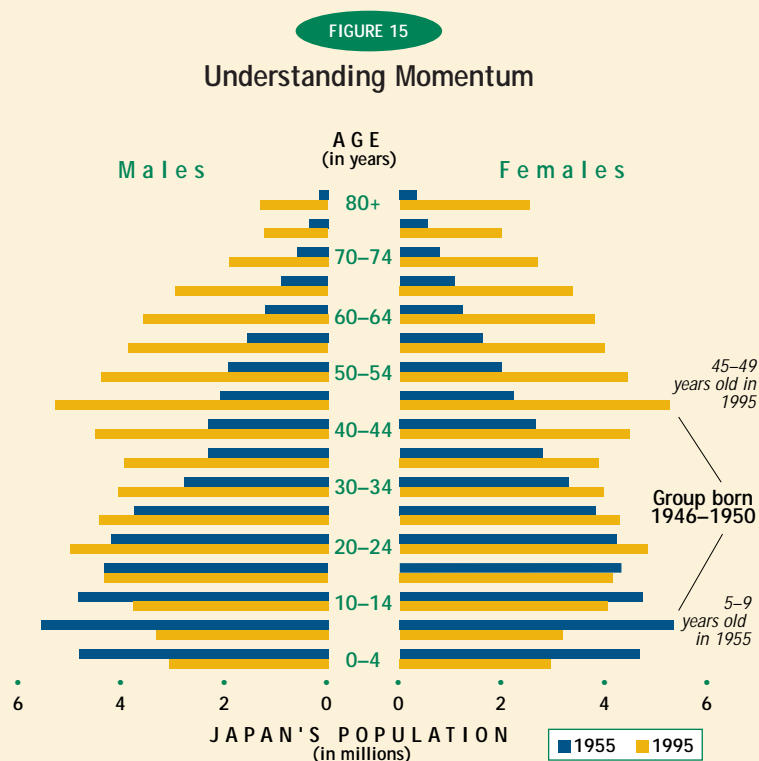
Demographers at the United Nations calculate that if average fertility in India were to have dropped abruptly to replacement-level fertility (slightly above two children per woman) during 1995 and had remained precisely at that level, India's population, then at 927 million people, would have continued to grow rapidly, reaching 1.45 billion by 2050.<sup>1</sup> This additional growth, occurring after fertility declines to replacement level, is caused by *population momentum*.

Growth due to population momentum occurs during the decades when a low-fertility population with a youthful age structure—a characteristic left over from years of high fertility—gradually fills out to a more uniform age structure, one that typifies a population that is not growing (a *stationary population*). For some rapidly growing countries, this "filling out" could take more than 50 years and double the existing population.<sup>2</sup>

This effect, however, does not mean that an extra half-century or more of population growth is inevitable in countries that attain the two-child family average. Momentum is reduced when average fertility falls well below replacement, and when the average age of women at childbirth rises.

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Due to population momentum alone, Japan's present population (gold-colored bars) is about one-third larger than the population it attained almost four decades ago, when it reached the level of replacement fertility (slightly over 2 children per woman). Japan's population is still growing modestly today. Demographers at the United Nations Population Division, however, project that trend to shift during the early 21<sup>st</sup> century to a slowly decreasing population.

**Source:** Data from UN Population Division, 1998.



# IV. The Role of Population Growth

*The more fundamental causes [of biodiversity loss] are rooted in the contemporary human condition, especially as they are amplified by the explosive growth in human numbers in the last three centuries.<sup>1</sup>*

Michael Soulé, 1991

Conservation Biologist



Stephanie Koontz

In the late 1970s, American ornithologist Thomas Lovejoy and colleagues began in Brazil a biological experiment planned to last a century. Taking advantage of a Brazilian law that required rainforest settlers to leave at least half of their deeded land forested, Lovejoy convinced several Brazilian farmers to leave their rainforest in square tracts of varying sizes, from 1 to 1,000 hectares (from one-hundredth to 10 square kilometers). The changes that have so far been documented in the Forest Fragments Project provide the most complete evidence to date of how human-caused forest fragmentation operates on biological diversity. And while ecologists expect the numbers and types of species in these habitat fragments to continue changing for decades, and perhaps for centuries, effects were observed within the first several years of the experiment.<sup>2,3</sup>

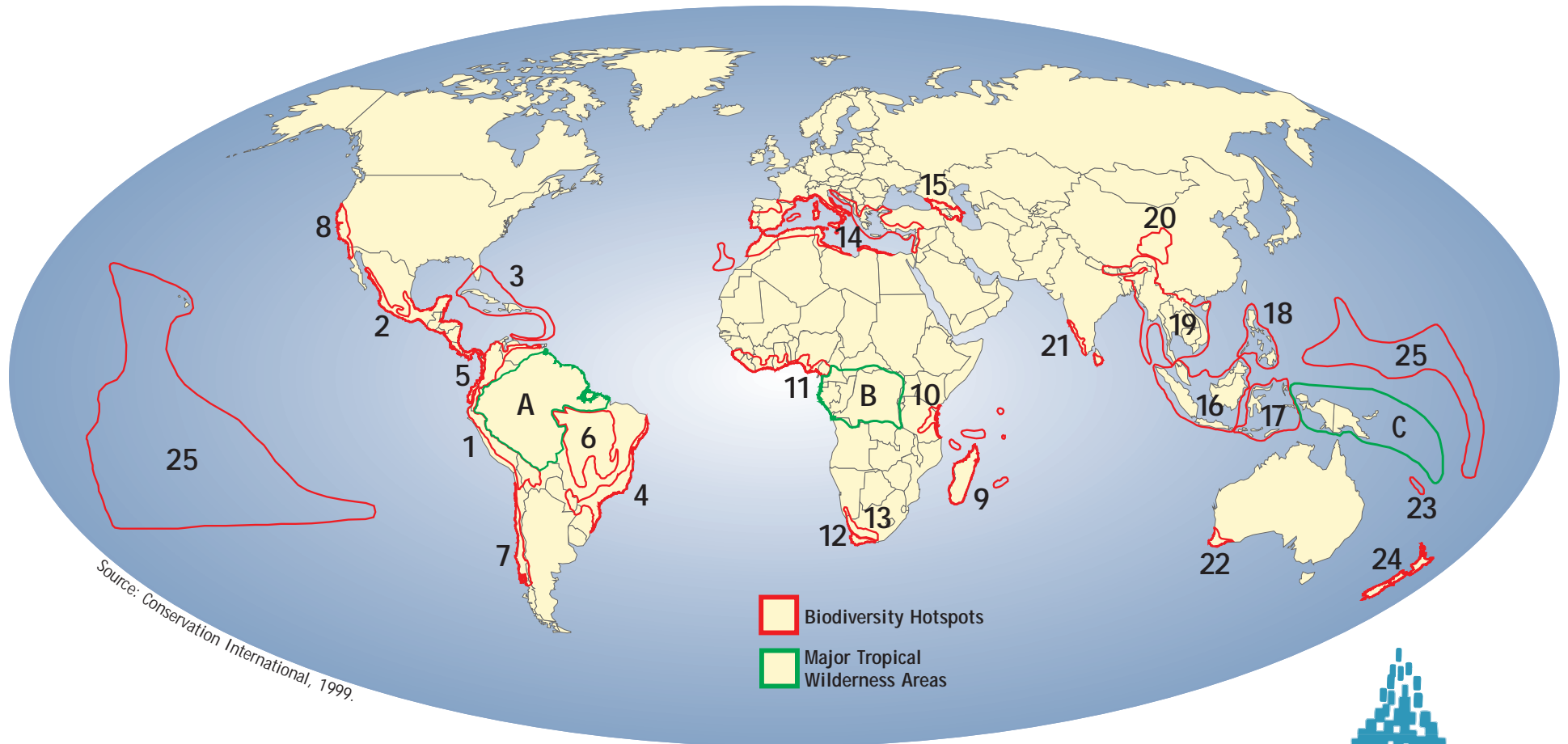
The earliest changes occurred in the smaller forest tracts. In these patches, numerous mid-size plant and animal species dwindled in a matter of years, then disappeared. Closer study disclosed that many of the missing species were casualties of *biodiversity chain reactions*. For example, colonies of army ants were lost from woodlands of 10 hectares or smaller. Then came the loss of ant-birds, which prey on insects taking flight to escape marauding ants. Vegetation along forest bor-

ders dried and was soon supplanted by non-rainforest plants. Bee populations plummeted, even in the 100-hectare plots, placing at risk tens of species of orchids and other flowering plants that depend on them for pollination. The big mammals with extensive home ranges and big appetites—jaguars, pumas and peccaries among them—simply picked up and left the area, abandoning even larger tracts. Without peccaries digging wallows, which fill with rainwater, three species of frogs failed to breed and disappeared. If fundamental ecological theories hold true, further biodiversity chain reactions can be expected to follow the loss of the big rainforest predators.

The Forest Fragments Project was designed with a specific objective: to determine how much rainforest is needed to maintain 99 percent of native species for a century. In fact, the project does much more. Considered broadly, the results can help us better understand population's role in biodiversity loss—how common patterns of modern human settlement and natural resource use tend to reduce, fragment and isolate natural habitat; and how these activities affect a wide range of species in complex, long-term ways, despite our best intentions to save some portion of nature.



# People and Biological Diversity



## The Global Biodiversity Hotspots and Major Tropical Wilderness Areas

### Hotspots

1. Tropical Andes
2. Mesoamerica
3. Caribbean
4. Atlantic Forest Region
5. Chocó-Darién-Western Ecuador
6. Brazilian Cerrado
7. Central Chile
8. California Floristic Province
9. Madagascar and Indian Ocean Islands

10. Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya
11. Guinean Forests of West Africa
12. Cape Floristic Province
13. Succulent Karoo
14. Mediterranean Basin
15. Caucasus
16. Sundaland
17. Wallacea
18. Philippines
19. Indo-Burma

20. Mountains of South-Central China
21. Western Ghats and Sri Lanka
22. Southwest Australia
23. New Caledonia
24. New Zealand
25. Polynesia/Micronesia

### Major Tropical Wilderness Areas

- A. Upper Amazonia and Guyana Shield
- B. Congo Basin
- C. New Guinea and Melanesian Islands



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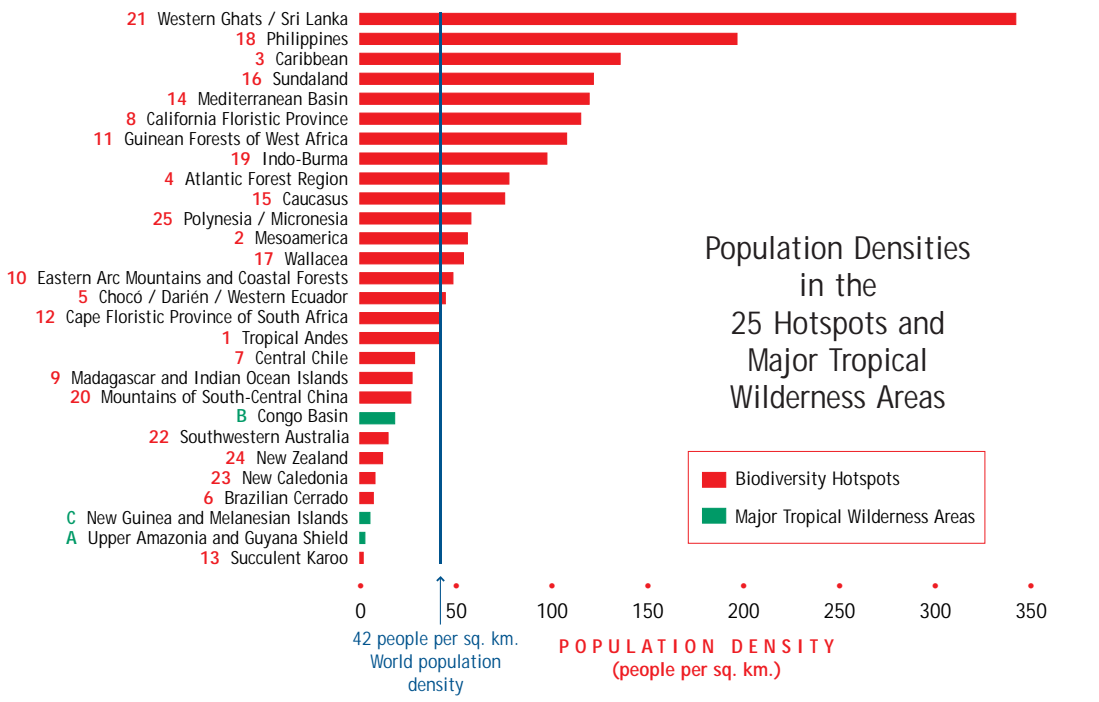
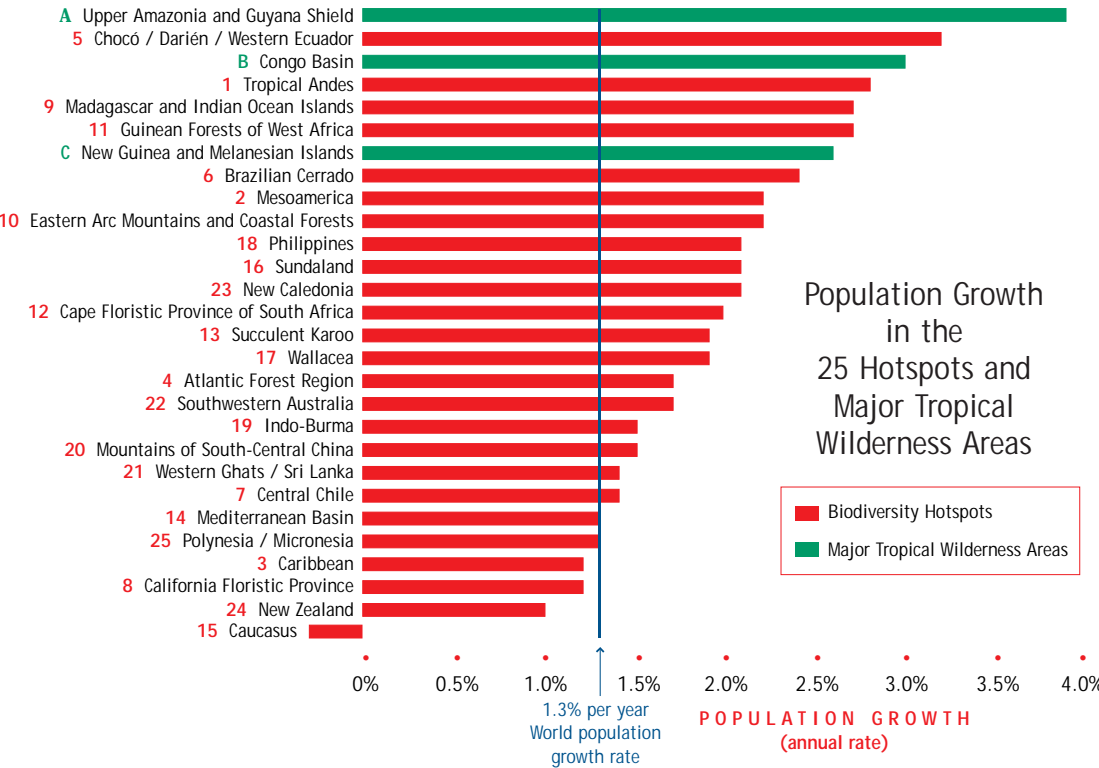
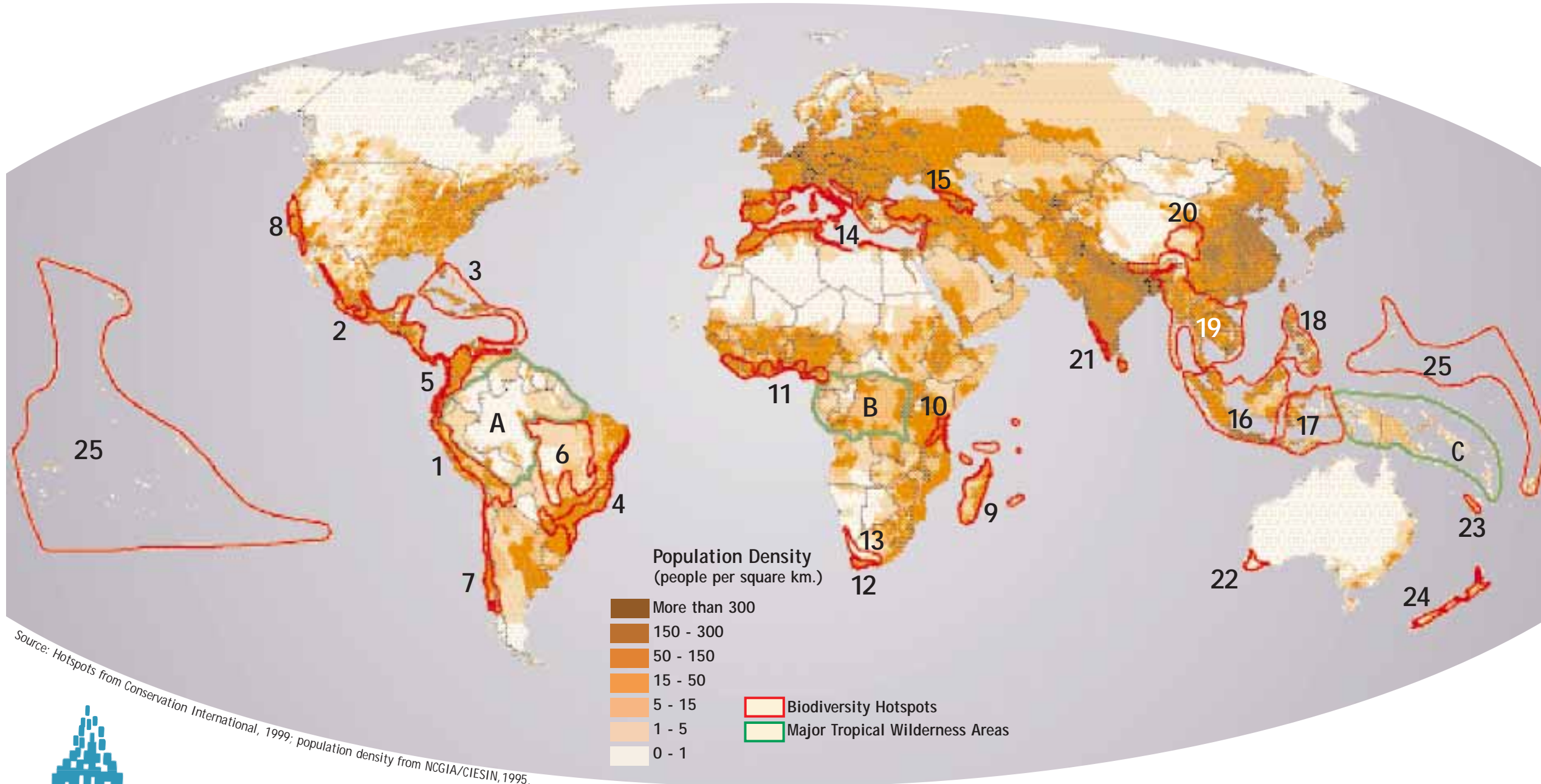


# People and Biological Diversity: Population in the Global Biodiversity Hotspots, 1995

The 25 *global biodiversity hotspots*, mapped by ecologist Norman Myers, Russell Mittermeier and scientists at Conservation International, are considered to be the most threatened of all biologically-rich terrestrial regions of the world. Within the hotspot boundaries, biologists estimate, live at least half of the world's terrestrial species. Recent human population growth and migration into these species-rich regions have made biological conservation efforts more urgent, more difficult to conduct and often more likely to conflict with human needs.

As of 1995, more than 1.1 billion people were living in the global biodiversity hotspots. While hotspot boundaries enclose some 12 percent of the planet's land surface, these biologically diverse regions were then home to about 20 percent of the world's human population. All but one of the 25 hotspots are still experiencing net population growth.

By 1995, an additional 75 million people were already living within the three *major tropical wilderness areas*, the last great expanses of tropical forest. Population growth in these regions has been proceeding at two and a half times the rate of the world's population as a whole. If present deforestation rates continue unabated, these vast native forests could be reduced to a handful of isolated woodlands in the coming decades.





FIGURE

## The 25 Global Hotspots

Hotspot	Hotspot Area (thousands of sq. km.)	Human Population, 1995 (thousands)	Population Density, 1995 (per sq. km.)	Population Growth Rate, 1995-2000 (percent per year)	E N D E M I C S P E C I E S					Extent of Original Vegetation (thousands of sq. km.)	Original Extent Remaining Intact	Original Extent Protected
					Plants	Birds	Mammals	Reptiles	Amphibians			
1 Tropical Andes	1,415	57,920	40	2.8	20,000	677	68	218	604	1,258	25%	6.3%
2 Mesoamerica	1,099	61,060	56	2.2	5,000	251	210	391	307	1,155	20%	12.0%
3 Caribbean	264	38,780	136	1.2	7,000	148	49	418	164	264	11%	15.6%
4 Atlantic Forest Region	824	65,050	79	1.7	6,000	73	160	60	253	1,228	8%	2.7%
5 Chocó-Darién-Western Ecuador	134	5,930	44	3.2	2,250	85	60	63	210	261	24%	6.3%
6 Brazilian Cerrado	2,160	14,370	7	2.4	4,400	29	19	24	45	1,783	20%	1.2%
7 Central Chile	320	9,710	29	1.4	1,605	4	9	34	14	300	30%	3.1%
8 California Floristic Province	236	25,360	108	1.2	2,125	8	30	16	17	324	25%	9.7%
9 Madagascar and Indian Ocean Islands	587	15,450	26	2.7	9704	199	84	301	187	594	10%	1.9%
10 Eastern Arc Mts. & Coastal Forests	142	7,070	50	2.2	1,400	22	16	50	33	30	7%	16.9%
11 Guinean Forests of West Africa	660	68,290	104	2.7	2,250	90	45	46	89	1,265	10%	1.6%
12 Cape Floristic Province	82	3,480	42	2.0	5,682	6	9	19	19	74	24%	19.0%
13 Succulent Karoo	193	460	3	1.9	1,940	1	4	36	4	112	27%	2.1%
14 Mediterranean Basin	1,556	174,460	111	1.3	13,000	47	46	110	32	2,362	5%	1.8%
15 Caucasus	184	13,940	76	-0.3	1,600	3	32	21	3	500	10%	2.8%
16 Sundaland	1,500	180,490	121	2.1	15,000	139	115	268	179	1,600	8%	5.6%
17 Wallacea	341	18,260	54	1.9	1,500	249	123	122	35	347	15%	5.9%
18 Philippines	293	61,790	198	2.1	5,832	183	111	159	65	301	8%	1.3%
19 Indo-Burma	2,313	224,920	98	1.5	7,000	140	73	201	114	2,060	5%	7.8%
20 Mountains of South-Central China	469	12,830	25	1.5	3,500	36	75	16	51	800	8%	2.1%
21 Western Ghats and Sri Lanka	136	46,810	341	1.4	2,180	40	38	161	116	183	7%	10.4%
22 Southwest Australia	107	1,440	13	1.7	4,331	19	7	50	24	310	11%	10.8%
23 New Caledonia	16	140	8	2.1	2,551	22	6	56	0	19	28%	2.8%
24 New Zealand	260	2,740	11	1.0	1,865	68	3	61	4	271	22%	19.2%
25 Polynesia / Micronesia	46	2,900	58	1.3	3,334	174	9	37	3	46	22%	10.7%

Sources: Conservation International, Population Action International.



## Linkages in the Literature

The most systematic reviews identify at least a half-dozen major *underlying causes* for current declines in species, wild breeding populations and natural ecosystems. In each review, population growth—which can include global and local natural increase and migration—is listed as one of these primary root causes.<sup>4</sup>

It is important to note, however, that none of these reviews suggest that the impacts of human activity on biodiversity are driven solely by population growth or by population density alone. It is generally accepted that several underlying causes are at work, some applying pressures that can alter ecosystems and deplete species, the others undermining natural and social means that could limit or reverse those changes. Even in local case studies where researchers found the growth of nearby human populations to be the most apparent locus of biodiversity loss, these same authors consistently indicated that, on close analysis, a complex mix of interacting conditions and failed remedies were involved.<sup>5</sup>

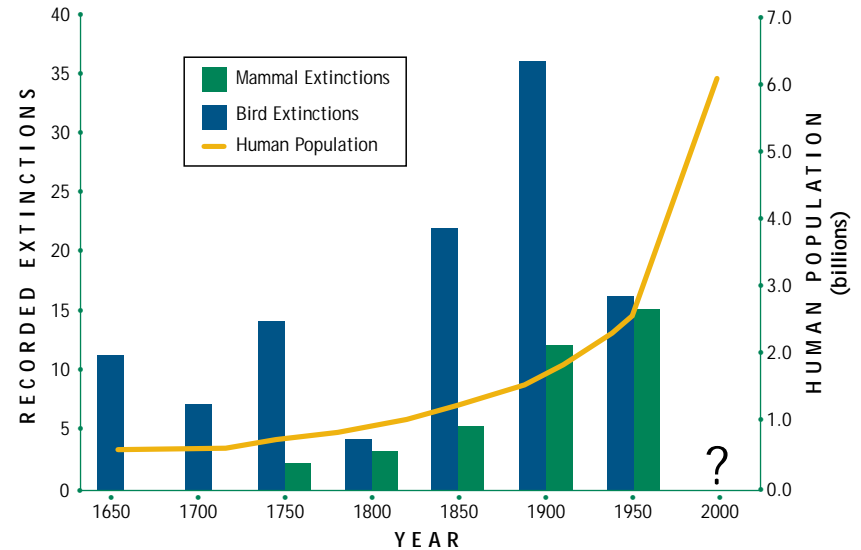
How important is population growth and population density—the product of past growth—to current global biodiversity loss? There is no credible numerical answer to that question. A recent analysis that relied on several measures of root causes (including population density) to mathematically predict proportions of threatened species in over 107 countries was only partially successful.<sup>6</sup>

Nor does the literature on individual species provide many clues to the linkage. Understandably, these studies have focused on the *direct causes* of decline in breeding populations—the effects of habitat distur-

bance, fragmentation and loss; biological invasion; pollution; over-hunting and, in a few recent cases, climate change—rather than measures of human population. But there are a few exceptions. In a recent study, over half of the deaths of African wild dogs were associated with direct human contact and infectious diseases obtained from domestic dogs.<sup>7</sup> Similar relationships could explain wild carnivore declines worldwide.<sup>8</sup> And recent research indicates that above a human population threshold, usually between 15 to 20 people per square kilometer, elephants move out of certain parts of Zimbabwe. The authors suggest that this threshold may represent the patterns of farming and natural resource use that result from this population density, rather than elephants' aversion to human numbers *per se*.<sup>9</sup>

Lack of hard evidence for the linkage has not deterred scientists from drawing conclusions based upon fundamental ecological theories. Several senior ecologists assert that continued rapid population growth in the tropics is undermining the integrity of biodiversity-rich ecosystems, and that present demographic trends bear strongly upon what biodiversity will look like in the future.<sup>10</sup> Yet none of these scientists suggest that population stabilization alone would be sufficient to return extinction rates to background levels. And even after population stabilization is achieved, conservationists will likely face challenges related to the *residual state* of our human-dominated planet, such as: human distribution and population density, the long-term viability of remaining species populations, global trends in per capita demand, existing

FIGURE 16  
Trends in Extinction



Though by no means a simple cause and effect relationship, recent analyses conclude that population growth is among a handful of underlying causes of biodiversity loss. In the bar graph, bird and mammal extinctions were summed for 50 year periods. The year appearing on the bottom axis is the mid-point of that period.

Source: Data from WCMC, 1992; adapted from graphs by Goudie, 1986.

levels of pollution, trends in human-induced climate change, and the inroads already made by invading species.<sup>11</sup>

## Links to Direct Causes

This section focuses on evidence connecting human population growth (both global and local) to the direct causes of biodiversity loss. Connections that are non-demographic, though very important in the overall loss of biodiversity, are not given the coverage they would deserve in a more extensive review. After this section, another entitled *Considerations* reviews further complexities in the rela-



FIGURE 17A

### Causes of Human-Induced Extinction

#### Underlying Causes

##### Population Change

- \* Growth
- \* Density
- \* Migration

##### Poverty and Inequity

- \* Pressing needs for food and shelter
- \* Lack of education
- \* Lack of options

##### Policy Failures

- \* Environmentally-destructive subsidies
- \* Poor controls on species trade and movements
- \* Lack of environmental awareness
- \* Poor protections for property

##### Market Failures

- \* Lack of information on species dynamics
- \* Lack of information about biodiversity's present and potential value

#### Direct Causes

##### Habitat Loss and Fragmentation

- \* Deforestation
- \* Large dams
- \* Coral reef destruction
- \* Roadways
- \* Wetland drainage

##### Biological Invasion (Invasive Species and Diseases)

- \* Competition from invasive species
- \* Emerging diseases

##### Pollution

- \* Synthetic pollutants
- \* Nutrient overloads

##### Over-Harvesting

- \* Overhunting
- \* Overfishing
- \* Over-collecting/pet trade
- \* Unsustainable logging

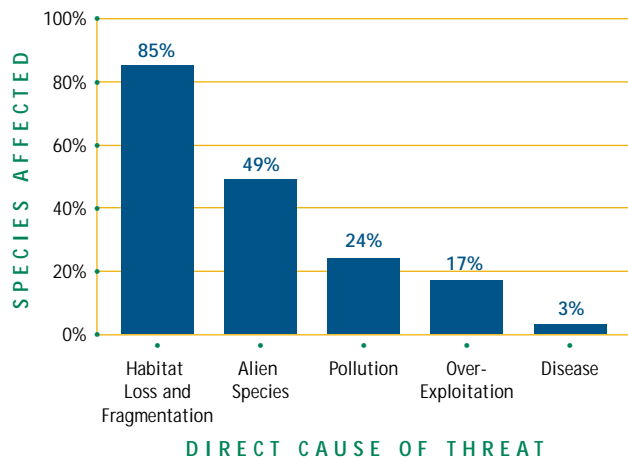
##### Human-Induced Climate Change

- \* Shift in geographic range
- \* Susceptibility to diseases

Studies tend to separate the causes of biodiversity loss into *direct causes*, the factors most immediately linked to extinction, and *underlying causes* which are often called root causes. Generally working in combination, these underlying causes control the type, frequency and intensity of the more direct causes of biodiversity loss.

FIGURE 17B

### Threats to Species in the United States



Despite the increasing threat of species invasions and pollution to biodiversity in the United States, habitat loss and fragmentation remain the major source of threat to imperiled species. Because many species are subject to multiple threats, percentages add up to more than 100 percent.

Source: D.S. Wilcove and others, 1998.

tionship between population growth and biodiversity loss.

### Habitat Loss and Fragmentation

There is consensus among ecologists, with some supporting evidence from research, that habitat disturbance, *fragmentation* (division and isolation of habitat) and outright habitat loss, taken together, currently constitute the leading direct cause of extinction.<sup>12</sup> Habitat loss, the easiest to measure of this composite category, roughly parallels recent growth of human population. Since 1950, population has tripled and cropland has doubled in the tropics.<sup>13</sup> Today roughly 97 percent of population growth and over 99 percent of agricultural expansion occur in developing regions.

Several global studies show close associations between population growth and the decline of species-rich tropical forests in developing countries.<sup>14</sup> However, these and other studies caution against overly simplistic explanations of changes in forest cover, such as those based upon population growth alone. Accordingly, most analysts of localized deforestation in the tropics describe a complex mix of factors leading to habitat loss. These include various combinations of land inequity and patterns of past settlement, local population growth and migration from growing urban areas and crowded agricultural zones, commercial logging and mining, road-building, settlement schemes, unemployment and poverty, and even political instability and violence.<sup>15</sup>

Linkages also exist between population growth and aquatic habitat loss. Jointly, agricultural and housing sectors account for nearly three-quarters of annual water withdrawals worldwide, and historically these have been major driving forces behind dam building and water diversion.<sup>16</sup> The effects of damming—creating barriers to aquatic migration and altering water dynamics—are, in turn, considered to be among the two leading causes (along with biological invasion, see below) of aquatic extinction.<sup>17</sup> According to the UN



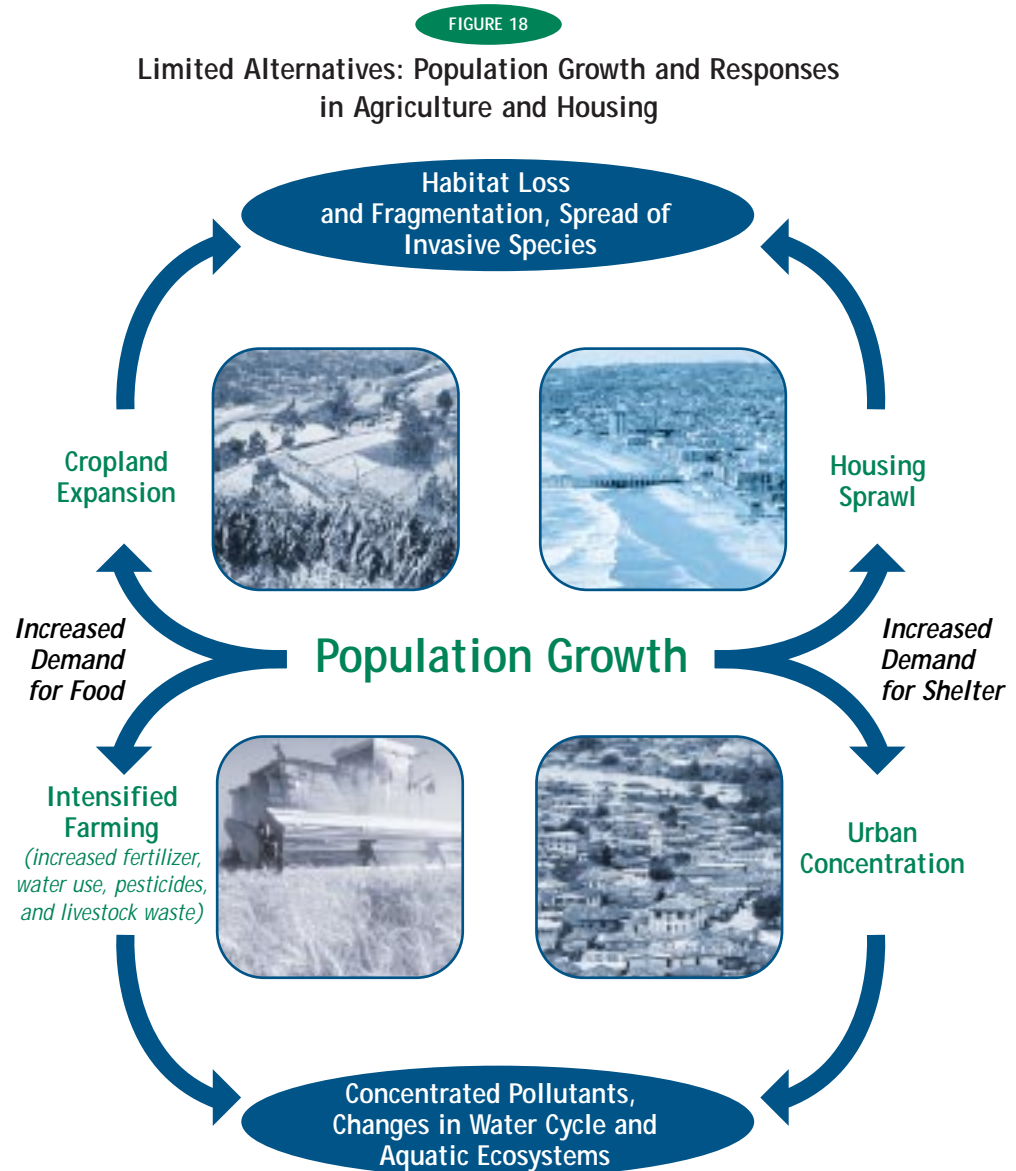
Commission on Sustainable Development, experience indicates that “special attention” is required to keep aquatic ecosystems intact in countries withdrawing more than 20 percent of their fresh water supplies for annual use.<sup>18</sup> Though data quality is relatively poor for this measure, it is estimated that at least 47 countries presently fit this category.<sup>19</sup>

### Biological Invasion

A recent review of global species decline ranks *biological invasion* (processes by which species become established in ecosystems to which they are not native) as the number two cause of global biodiversity loss.<sup>17</sup> A study of threatened species in the United States came to a similar conclusion. Despite international agreements and elaborate border controls set up to prevent biological invasion, the frequency at which invading species are establishing themselves appears to be on the rise. Population growth has probably not been the most critical cause underlying biological invasions. Historically, most invasive species have been unleashed deliberately or carelessly by individuals ignorant of the potential for economic harm. Yet population growth’s effects are nonetheless discernable.

Biological surveys of human settlements illustrate this complex relationship. Several studies report greater counts of bird and plant species in parks, along roadsides, and around rural housing than in comparable forests. Yet high tallies in these areas can often be explained by the added presence of ornamental and invasive species.<sup>20</sup> Port cities tend to act as launchpoints for biological invasion. In San Francisco Bay, for example, one exotic marine species establishes itself on average, every 12 weeks.<sup>21</sup> Denser human settlement means significant shifts in soil chemistry<sup>22</sup> and more frequent soil disturbance. Such basic changes can encourage the proliferation of invasive species.

Population growth expands the scale of trade and transport upon which many countries now depend. By 1990, more than 1.2 million tourists were arriving in foreign destinations each day.<sup>23</sup> Over 86,000 merchant vessels ply the seas, emptying cargo and ballast thousands of miles from their point of origin.<sup>24</sup> The daily movements of people, resources and species across geographic barriers that once isolated them could increase with globalization of trade, population growth, and the inte-



Demand for food and for basic shelter tends to closely parallel human population growth. For a country to meet these basic needs using its own natural resources, it must experience development sprawl or intensification, and most often some combination of the two. Each response can have dramatic consequences for biological diversity. Imports and exports of food also affect the scale of demand. And transportation networks, economic productivity, affluence and public policies tend to shape the geographic patterns of housing and urban growth.





## Places Apart: Military Tensions and Biodiversity

Among the most convincing evidence of population growth's relationship to biodiversity comes from an unexpected source: a collection of unintended experiments that are byproducts of late-20<sup>th</sup> century hostilities and tensions. In the unpopulated Demilitarized Zone that straddles the 250-kilometer border between North and South Korea—no one's idea of a wildlife refuge—researchers recently discovered several species of animals and plants thought to have disappeared from the Korean peninsula. After 50 years of military standoff, the zone's biodiversity is now so much richer than the surrounding countryside that Korean and international environmental organizations are working to turn the area into a cross-border national park.<sup>1</sup>

Similarly, Soviet-Chinese tensions beginning in 1960 discouraged settlement and development in parts of the Amur-Sakhalin region of Siberia, now the last outpost of some of Russia's most threatened species, including the Amur tiger, Amur leopard, Blakiston's fish-owl, and red-crowned and white-naped cranes. Several Russian ecologists have raised private funds and donated their expertise in an effort to protect more than 200 square kilometers of Siberian forest and wetland in this region.<sup>2</sup>

In the United States, huge military reserves and security zones, established around the country's atomic research laboratories at the beginning of the Cold War, have become habitat refuges for threatened species that are otherwise rare or absent from the surrounding human-dominated landscape. For example, some ecological researchers consider Oak Ridge National Laboratory's 14,000-hectare reservation to be more pristine than most U.S. national parks. The Nature Conservancy tracks roughly 400 animal species and 11,000 plant species in this area alone.<sup>3</sup>

Many more of these depopulated areas exist around the world. Turning them permanently into conservation reserves—what conservationists are calling “peace parks”—could provide new hopes for conserving many threatened species and ecosystems.<sup>4</sup>

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White-naped crane, Sergei Smirenski



gration of more of the developing world's people into the global economy.

## Pollution

Today, the earth's biosphere is exposed to tens of thousands of chemicals, including some 600 pesticides, that were absent during all pre-human evolution.<sup>25</sup> For only a few hundred of these chemicals do scientists understand even some of their short-term biological implications. Chemical-intensive agriculture, probably essential at current levels of human population,<sup>26</sup> is a major source of both natural chemical overloads (particularly nitrogen and phosphorus) and synthetic-chemical toxicities in aquatic and terrestrial ecosystems. In the United States alone, estimates suggest that more than 60 million birds are killed annually by pesticides applied to farmland.<sup>27</sup> There is also evidence that nitrogen in rainfall, now between 10 and 100 times the normal rates in North America and Europe, is upsetting relationships in terrestrial plant communities.<sup>28</sup>

Where people concentrate in urban and suburban areas, so do nitrogen and phosphorus-containing compounds—in sewage and organic garbage, in industrial and automobile emissions, and in lawn fertilizers. Exposed soils on road and housing construction sites are also significant sources of pollutant runoff, as dying soil microorganisms release their cell-bound nitrogen into more soluble forms.<sup>29</sup> In a review of 39 of the world's watersheds, researchers concluded that population density is the most powerful determinant of river-borne nitrates, regardless of the size of the watershed or amount of water flow.<sup>30</sup> Nutrient-rich

urban and farmland runoff are thought to be responsible for the development of about 50 coastal "dead zones," marine environments depleted in oxygen by the mass decay of algae and nearly devoid of other sea life. One dead zone near the outlet of the Mississippi River covers 18,000 square kilometers, an area larger than Kuwait.<sup>31</sup> Even larger dead zones are reported in the Baltic and Black Sea.

Today roughly two-thirds of the world's people live within 150 kilometers of coastlines. This proportion is projected to rise to three-quarters by year 2025, adding between 1.4 and 2.3 billion coastal dwellers worldwide in just 25 years.<sup>32</sup> The ecological changes that will accompany such rapid and concentrated growth will very likely pose a major threat to remaining biodiversity-rich estuaries and coral reefs.<sup>33</sup>

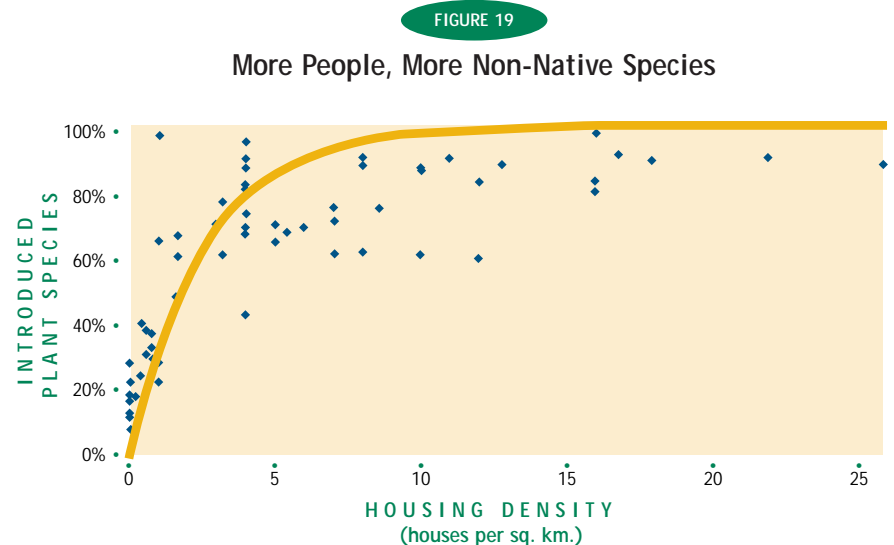
## Over-Harvesting

Overhunting, overfishing, overtrapping, and wild plant collecting continue to represent extremely serious threats to many species. This is particularly true when laws that restrict and control harvesting are absent, weak or not enforced, and where demand for species is high. Perhaps the most well documented example of over-harvesting is collectively called the *bushmeat trade*, a market that moves weapons to forest hunters, and wild animals from tropical forests to the dinner table. Mammals, including primates, are the prime targets of bushmeat hunters. But the trade also includes birds, reptiles and amphibians.

Bushmeat hunting has been documented in each of the extensive tropical forests. Most of the kill feeds logging camps or is

trucked to nearby urban markets. Some bushmeat hunting is associated with forest settlers. The more exotic species end up as far away as Europe and Asia. Indigenous forest peoples, many of whom depend on wildlife for protein, are either being impoverished by the trade or drawn into commercial hunting themselves.<sup>34</sup>

Growing demand for many marketable species is, in part, linked to population growth. For example, Indonesian wildlife managers blame the exotic appetites of large populations in northern Asian countries, particularly those with growing purchasing power, as the principal motivation for Indonesia's bushmeat trade. But on the supply side, population appears less important: a few well-organized and well-armed

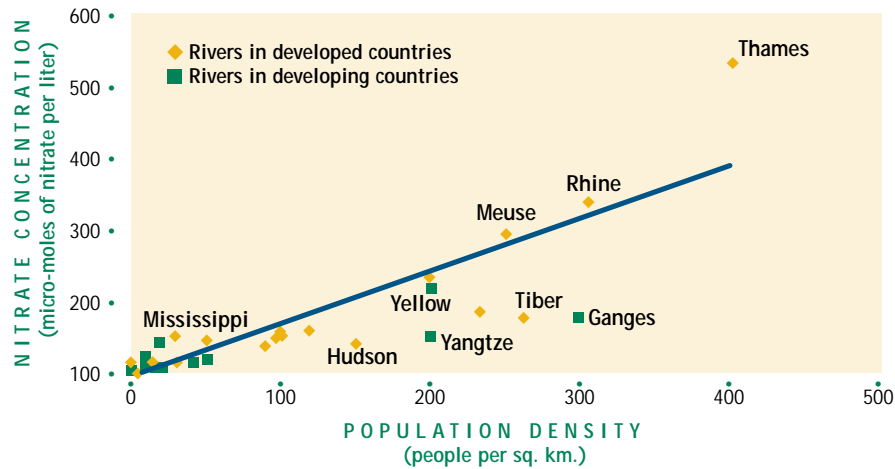


An innovative study in Buenos Aires that sampled in rural and urban areas showed that native plant species were replaced by introduced species—both planted exotics and invasive weeds—as urbanization progressed. **Source:** Adapted from E.H. Rapaport, 1993.

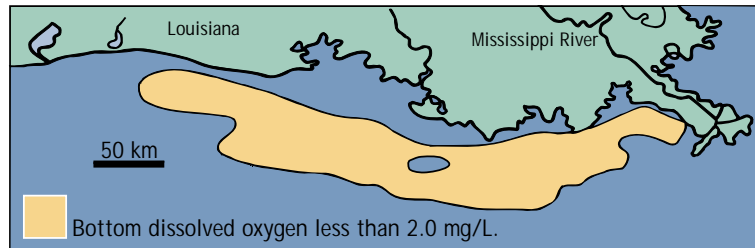


FIGURE 20

### Nitrogen Pollution and Population Density



Researchers have found a close relationship between the density of human population that lives in a watershed, and the amount of nitrates in the watershed's primary river. **Source:** Data from J.S. Cole and others, 1993.



In marine dead zones, such as the one (above) that has developed in the Gulf of Mexico, dissolved oxygen in the bottom layer of seawater is present at levels below 2.0 milligrams per liter. Development of dead zones—where sea life is nearly absent—is associated with the accumulation of large volumes of nitrogen and phosphorous—containing chemicals that are washed from urban centers, farms and livestock into coastal marine environments in which there is limited water mixing. **Source:** *Science*, 1998.

poachers can do the job. And economic hardship may make illegal hunting a more appealing livelihood.<sup>35</sup>

Animal and wild plant-parts also find their way into African and South American tourist curios, or into South and East Asian herbal medicines, while much of the exotic pet and plant trades are destined for North America. Each illegal market poses a formidable threat to particular species—especially primates, colorful mollusks and corals, seahorses, and tropical birds and plants—despite restrictive national and international laws.

In addition, humans are still hunters on the world's waters. The IUCN-World Conservation Union now carries numerous once-commercial fish species on its *Red List* of threatened species. The southern bluefin tuna, the Atlantic halibut, yellow tail flounder and several species of shark are among them. In already over-exploited coastal waters throughout the tropics, desperate fishermen have turned to using small-mesh nets, cyanide and dynamite, thus killing corals and damaging supporting reefs, and pushing hundreds of tropical marine fish and invertebrate species towards extinction.<sup>36</sup>

Humans are also wholesale gatherers of the world's tree species. The IUCN concludes that tree felling is the most important impact on tree diversity, and now lists more than 8,700 tree species as threatened.<sup>37</sup>

### Human-Induced Climate Change

A recent census of a butterfly known as Edith's checkerspot, whose range is shift-

ing northward as southern populations disappear, is perhaps the best documented of many cases where global warming appears to be influencing species distributions.<sup>61</sup> The threat to biodiversity is not so much climate change itself, which has occurred numerous times in the past of every living species, but the added inability of animal and plant species to shift their ranges in response. The unprecedented pervasiveness of human settlement, vegetation change, agricultural activity, road-building and vehicular traffic—all showing upward trends, thanks in part to population growth—precludes such responses in the foreseeable future.

As temperature and weather patterns change, what will happen to those threatened species now cloistered in protected areas, and surrounded on all sides by agricultural and urban development? Could reserves be shifted, re-established under the right habitat conditions and restocked with species? According to one recent study, a 3 degree Celsius increase in global average temperature—well within the range of possibilities over the next few centuries—could eliminate 7 to 11 percent of North America's vascular plant species.<sup>62</sup> Trends in population growth and rapid climate change present a brand new set of conservation challenges.

### Considerations

The following section highlights the complex nature of relationships between population growth and biological diversity. These complexities are principally



due to variations among human social and economic systems, and in their capacities to transform nature and to respond to threats of biodiversity loss. Each topic discussed below should be an important consideration in policymaking, and worthy of further research.

### Indigenous People

Recent research casts doubts on notions that technologically primitive peoples ever lived harmoniously with the full complement of biodiversity that they first encountered. More likely, *Homo sapiens* arrived in new lands and hunted the largest and most easily harvested animal species for food, often driving the majority of them to extinction.<sup>40</sup>

That said, there is ample evidence that many human tribal groups settled into various patterns of co-existence with the remaining, perhaps less vulnerable, plant and animal species. Some indigenous groups continue such patterns today, often holding knowledge that is key to conserving and utilizing the species around them. Substantial evidence suggests that some cultures have actively promoted the abundance of particular species either by periodically burning vegetation to increase game species, by developing sophisticated restraints on hunting, or by adapting forest gardening techniques fostering local native plant and animal species.<sup>41</sup> Patterns of impact of these indigenous people often resemble those of occasional natural occurrences such as fires and storms, to which species have adapted over eons of time. And many landscapes that we label “wilderness” have, in fact, been influ-

enced by human occupancy in the distant and not-so-distant past.

In general, where such co-existence occurs today, indigenous people live at low levels of technology and in relative isolation from the global economy. Moreover, population densities tend to be extremely low in these situations, generally less than five people per square kilometer over their full hunting and gathering ranges. In almost all cases, the survival of these peoples, their languages, knowledge and practices are just as much in jeopardy as the biodiversity with which they are associated.<sup>42</sup>

Since the late 19<sup>th</sup> century and throughout the 20<sup>th</sup> century, there have been numerous cases where indigenous peoples were removed or restricted from tribal lands in order to establish national parks and other protected areas. The wisdom of these displacements has been criticized. Many might not have occurred had equitable rights and just compensation been extended to these peoples. Current trends in conservation ethics encourage biological conservationists to negotiate arrangements that respect both cultural and biological diversity, and share the benefits of conserving species among governments, local people and private companies.<sup>43</sup>

### Migration, Land Inequity and Population Growth

In the short term, migration and natural increase in population are easily distinguishable, and the distinctions are impor-

tant to conservationists. Migration into and around biologically diverse regions is a critical concern for conservation programs worldwide.<sup>44</sup> And for indigenous groups trying to maintain their cultural traditions and customary rights to natural resources, the influx of settlers can mean an end to a way of life and a threat to their very existence.<sup>45</sup>

Migration can be an exceptionally powerful agent of change, especially when added on top of already high rates of natural increase. In the forested Petén region of the Yucatan Peninsula, for example, migration has pushed rates of annual population growth to between 8 and 10 percent, more than three times the growth rate of Guatemala as a whole.<sup>46</sup> Similarly, immigration from mainland Ecuador to the Galapagos Archipelago could double the islands’ resident population in 7 to 12 years.<sup>47</sup>

The question is, why now? Why are the most remote and biologically-rich ecosystems experiencing such pressures from migration? One answer is, arguably, that these ecosystems are all that remain. For example, few migrants would now be moving into these inhospitable and only marginally arable lands if land of greater potential were not already claimed, or if jobs were available. And though clearly important, population growth is not the only factor activating human movement. Today’s cumulative distribution of population—occupying virtually all land of prime agricultural potential and packing habitable coastlines—has been greatly influenced by historic and political pat-

As temperature and weather patterns change, what will happen to those threatened species now cloistered in protected areas, and surrounded on all sides by agricultural and urban development?







In a sense, we are adapting to ourselves in large numbers, and in some cases we are doing that well. But will most other species survive our success?



terms of conquest, colonization, road building, government-subsidized migration, and, very often, the grossly inequitable distribution of land.<sup>48</sup>

### Agricultural Intensification and Reforestation

Studies suggest that in some farming areas, particularly those with adequate rainfall or irrigation, the declines in per capita arable land and increases in land value that routinely accompany population growth can act as inducements to *intensify farming*—to apply more labor and technology, to abandon grazing for farming, and to produce more food per hectare.<sup>49</sup> A recent review of some 70 case studies, all of them from farming communities in mountain areas in developing countries, found that these communities are often sites of environmental restoration, such as tree planting and water management.<sup>50</sup> The review also points out, however, that planting trees and building terraces, though critical environmental improvements, are not the same as maintaining native forests and their species. Native species and varieties are lost throughout the conversion to farmland and settlement—the most sensitive disappear at the early stages. Agroforestry and erosion control (which often employ non-native species) were never designed to maintain the full complement of native species and natural ecosystems.<sup>51</sup>

In terms of food production, agricultural intensification has been enormously successful. Despite rapid population growth, malnutrition is down slightly from a peak around 1970 when over 900

million people were chronically malnourished. And by one estimate crop intensification has spared—at least temporarily—an additional 27 percent of Earth’s habitable land surface from conversion to agricultural use.<sup>52</sup> Still, intensive agriculture is not an ecologically benign response to population growth or to shifts in per capita consumption. High concentrations of chemical nutrients and animal wastes, the signature of intensive food-production systems, have proved difficult to contain safely, even in industrial countries.<sup>53</sup>

So far humans have met many of the environmental challenges of unprecedented population growth. In a sense, we are adapting to ourselves in large numbers, and in some cases we are doing that well. But will most other species survive our success in this endeavor? That is a very different environmental challenge.

### Housing Momentum: Trends in Urbanization and Sprawl

Like food production, housing construction and home services (water, energy and waste disposal) tend to accommodate population growth. Patterns of concentration and suburban sprawl vary considerably between countries. Suburban sprawl tends to consume agricultural land and its water supplies, including any of the habitat that farmland protected.

Urban concentrations tend to concentrate pollutants, dramatically affecting aquatic and coastal marine ecosystems. The United States is experiencing major housing construction near environmental-ly pristine areas, a trend probably driven

by retirement incomes and factors that allow greater separation between homes and conventional urban workplaces.<sup>54</sup> The trend raises concerns among wildlife managers, not only because of habitat loss, but because of the inevitable growth of predatory pet populations and the spread of invasive plant species.

While industrialized countries currently account for a disproportionately large share of housing, requirements for shelter in developing countries are projected to more than double by the middle of the 21<sup>st</sup> century.<sup>55</sup> This upsurge in housing needs is projected as a result of population growth combined with a gradual shift to fewer people per household. Thus, there is a type of *housing momentum*—a tendency for per capita housing needs to increase even while population growth slows. Today between one-fourth and one-fifth of all households in the industrialized countries are single-person households. A similar trend is expected to occur in developing countries as family size becomes smaller and economies industrialize.<sup>56</sup>

### The Population Pressure Transition: Development and Its Effects on Protected Areas

Governments worldwide have accepted the notion of *protected areas*—the IUCN term for parks and reserves, many of which have the conservation of biological diversity as part of their mandate. Over the past decade, the total amount of terrestrial protected area in the world has increased by nearly 40 percent, most of it

## Suburban Predators

Where there are people, there are pets. And while house pets bring a great deal of satisfaction to their owners, they are, after all, introduced species. As such, their numbers and activities can affect biological diversity, particularly when significant numbers roam outdoors.

Some ecologists suggest that many of our environmental problems with pets stem from pets' abilities to thwart some of nature's most fundamental rules. When prey populations decline in numbers in the wild, so do wild predators—but not populations of cats and dogs, which are protected by feeding and household shelter. Also, predator-pet populations are not as limited by territoriality, as is the case for many wild predators.

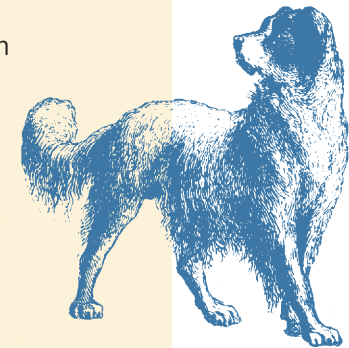
While several pet species are known to affect native species, the case against poorly managed house cats is perhaps the best documented of all. In the United States, domestic cats (of which there are at least 60 million in U.S. homes and perhaps 30 to 40 million more feral) are estimated to kill over a billion native small mammals and, conservatively, 200 million birds annually.<sup>1</sup> To date, domestic cats have been implicated, to varying degrees, in the endangerment of at least six species of North American birds and small mammals, and in the extinction of more than 20 animal species in Australia.<sup>2</sup>

Diseases common among both dogs and house cats afflict related native predators. African wild dog populations, now numbering fewer than 5,000, are threatened, in part, by rabies and canine distemper, and viral infections transmitted to them primarily by domestic dogs.<sup>3</sup> Likewise, the viruses causing feline leukemia and feline distemper have spread from domestic cats into populations of North American mountain lions.<sup>1</sup>

Pet population densities respond to both rising human affluence and population growth. How pets have been managed has clearly affected biological diversity, and will likely influence its future in our human-dominated world.

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Scholars of economic history conclude that institutions tend to work best for those who make their rules—and wild species are, of course, not making the rules.



from increases in the developing world.<sup>57</sup> Despite these gains, the process is controversial. Disputes arise over each new or expanded protected area, and tensions over use and access often persist for generations after boundaries are drawn.

In developing countries, pressures from growing populations have most often been exerted from expanding settlement within and around the edges of parks and reserves. The weakest of these reserves, or “paper parks” as conservationists call them, lack the funding and political commitments to deter illegal resource use and species loss.

Population-related pressures on protected areas do not necessarily fade away with development and enforcement of reserve boundaries. They merely shift. In industrialized countries, impacts are exerted at long distances. For example, boundaries of the Everglades National Park and Audubon’s Rowe Sanctuary on the Platte River in the United States are amply protected, yet both reserves have suffered significant habitat degradation because of irrigation projects and growing urban use upstream. Yearly freshwater flows through these ecosystems register as a mere fraction of what passed through 150 years ago—and it was to these past levels that native plants and animals originally adapted. By comparison, many less policed reserves in developing countries are less threatened.<sup>58</sup>

Thus, despite a century of conservation legislation and litigation in the industrialized countries, thousands of species outside the tropics are threatened with

extinction. Because public reserves in North America and Europe were most often set up to preserve picturesque landscape and historic sites or to control recreational and timber resources, rather than to conserve biodiversity, the industrialized countries face large gaps in species protection. For example, recent studies in the U.S. state of Utah led researchers to conclude that between 25 and 40 percent of the state’s vegetation types are at risk due to a lack of formal protection.<sup>59</sup> Suburban development, growing demand for natural resources and rising land prices could make future land acquisitions and conservation agreements increasingly difficult.

### Global Inequality and Consumption

The world’s wealth is unequally distributed and current trends lean toward even greater inequalities. Presently, the poorest one-fifth of the world’s population average less than a dollar of income a day and account for less than 2 percent of all private consumption.<sup>60</sup> How industrial countries deal with global development, and how the wealthy and educated of each nation deal with the poorest segment of their society, will likely have important implications for the future of biological diversity. Simply put, species loss can create economic risks that are chiefly long-term, while many of the world’s poor face uncertainties about tomorrow’s meals. Poverty forces people to take sustenance from the most unprotected of resources.

The 20 percent of world population

living in industrialized countries account for some 86 percent of all private consumption, and over 80 percent of world trade. In 1998, donor countries provided only 0.23 percent of their combined gross national product to international development assistance, far short of the United Nations’ target of 0.7 percent.<sup>61</sup> Increasing foreign assistance could have major implications for the developing world, for social as well as environmental programs, including biodiversity conservation. While ultimate responsibility for conserving species rests with the countries wherein those species originally reside, there is currently much more interest in industrialized countries in saving certain tropical species and ecosystems (and more financial resources, as well) than currently exists in the tropics themselves.

### Institutions: the Rules of the Game

For conservation scientists, ongoing upward trends in demand for natural resources forebode a bleak future for biological diversity. There is good news, however. Demand is not all that counts. To restrict the flow of natural resources and to control access to them, nations rely on what social scientists call *modern institutions*—rules of law, markets and property rights, and government programs and policies. And the success or failure of these institutions make it difficult to predict precisely how population growth or changes in per capita consumption will ultimately affect natural resources.<sup>62</sup>

There is bad news, too. Scholars of



economic history conclude that institutions tend to work best for those who make their rules<sup>63</sup>—and wild species are, of course, not making the rules.

Government subsidies are a case in point: for example, bringing in the 1994 world fish catch was estimated to cost \$124 billion but was worth only \$70 billion at dockside. Timber harvests, grazing allotments and settlement schemes in many countries, including industrialized countries, receive subsidies that weaken the abilities of markets to limit over-harvesting.<sup>64</sup>

Ours is a world in which species, many teetering on the brink of extinction, have no legal rights to continue existing. Biodiversity's survival in an environment of contentious politics, population growth, economic inequity, and fast-paced global enterprise will, to a large extent, depend on how well laws, policies and the marketplace promote biological conservation. For this reason, the degree to which scientists and environmentalists are able to influence these institutions will be critical for biodiversity's future. Here, developing countries lag.

Presently, the developing world—home to around 80 percent of the world's population and the vast majority of its biodiversity—can claim just 30 percent of the world's scientists and technicians.<sup>65</sup> Of these, a relatively small proportion now work in fields directly relevant to biodiversity conservation, and a disproportionate number of these are concentrated in Brazil, Mexico, India and East Asia.<sup>66</sup>

## Patterns of Loss

The bulk of evidence suggests that there are patterns of biodiversity loss associated with population growth—patterns that are repeated and clear, yet neither simple nor entirely inalterable. Today, ecosystems populated at low densities vary widely in their conditions. Some remain nearly pristine, while others have received extensive damage from natural resource extraction, pollution and biological invasion. In more heavily settled areas, a close association between increasing population density and biodiversity loss appears clearer. Logically, the risks will be greater, and probably more difficult—and thus more expensive—to avoid through regulation and investment.

Ecologist Michael Soulé concludes that failed institutions and rapid population growth have placed powerful constraints around what biological programs can conserve of fading biodiversity. And because of these constraints, there are few places in the world where creating new reserves and passing protective legislation are enough, by themselves, to save native species and ecosystems. Sometimes these simple prescriptions are not appropriate at all. Programs like agro-forestry, shade-grown coffee, privately-owned ventures in ecotourism, and multi-use community property schemes can be key components in national biodiversity strategies. And when political systems are unstable in areas where population pressure continues to build, there may be more hope

for temporarily maintaining some species in off-site facilities like zoos and germplasm banks, than anywhere within their native range.<sup>67</sup>

Population growth is, and has clearly been, an important underlying cause of recent losses to biological diversity. Just as clearly, it is not the sole culprit, nor do pressures from population growth, density or migration work alone. Put simply, human-induced biodiversity loss can neither be fully understood nor can it be resolved, in practice, from this perspective alone. Yet, in the presence of population growth, the notion of sustainability is, as ecologist Edward Wilson puts it, “but a fragile theoretical construct.”<sup>68</sup>

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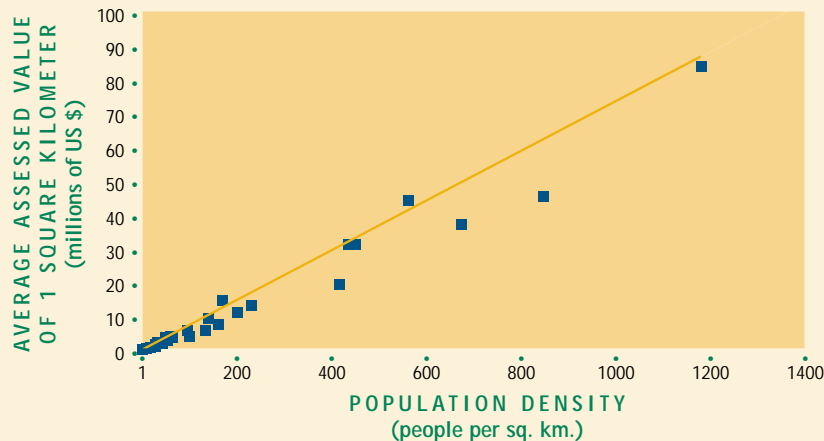




## Biodiversity, Property Rights and Population Growth

FIGURE 21

People and Property Values—California, 1990



Property values tend to increase as local population grows, making it difficult to purchase adequate land to protect species.  
Source: Data from U.S. Census Bureau, 1998.

Over the past two decades, environmentalists have come to realize that marketing biodiversity's many products, and returning the profits to local owners and caretakers, can provide powerful incentives for conserving biodiversity. Still, on balance, biodiversity has fared poorly in the global marketplace. More often than not, *property rights* (rules of use or ownership, and penalties for breaking those rules) are absent for wild species. At best, those rules are vague or hard to enforce. And typically, there is little accurate knowledge about the response of species to harvest and use. Without adequate property rights and knowledge, and without affordable substitutes for evolution's unique products, competition among suppliers has repeatedly overwhelmed conservation efforts and outcries of public concern.

The passenger pigeon, for example, the most ubiquitous North American bird in the early 19<sup>th</sup> century and once a delicacy, owes its extinction in part to markets. Today 69 percent of known fish stocks are in decline.<sup>1</sup> Thirty-seven species of seahorses and pipefishes are on IUCN's *Red List of Threatened Animals*, most of them harvested to low levels to meet the demands of the Asian medicinal trade. And many other species—from the bluefin tuna, now fetching thousands of dollars per individual, to the African white rhinoceros, whose horn is more valuable than gold in parts of Asia—can thank market pressures for their positions on the edges of survival.

So what does population growth have to do with it? Property rights protect productive work and investment, and try to minimize conflicts among resource users. It was likely that an increase in population density first motivated early societies to establish local systems of *tenure*—rights to use land, rivers and their resources.<sup>2</sup> In today's world, with 6 billion people and powerful commercial interests, strict property arrangements are more appropriate than ever. Economists have concluded that without property rights that are clear and enforceable, population growth can lead to greater demand and use of resources, and ultimately to over-harvest and depletion.<sup>3</sup>



Local conservation efforts are also affected. Population growth is among factors elevating land prices, making it expensive to purchase or retain land that is needed to establish and broaden species protection. Even when parks and reserves are established, it is often difficult to keep large animals from harming property or people, or being harmed themselves near or beyond the boundaries of protected areas.<sup>4</sup> And efforts to maintain the boundaries of protected areas in populous localities are often deemed impractical, expensive or politically costly, particularly in the poorest countries.<sup>5</sup>

In the future, conservationists may also need to consider how population growth relates to *community-based resource management programs*.<sup>6</sup> These programs have focused on arranging property rights in ways that distribute benefits of commercial use of biodiversity to local people and thus encourage conservation. Perhaps the most widely recognized example is Zimbabwe's Communal Areas Management Programme for Indigenous Resources (CAMPFIRE), which sets guidelines for community-based wildlife management outside protected areas. This program distributed \$1.6 million in profits to local communities during 1995, over 90 percent of it from hunting fees.<sup>7</sup> Intriguingly, CAMPFIRE participants themselves have recognized the role of population growth in reducing the individual shares of wildlife-related revenues that now maintain local interest in protecting habitat and wildlife.<sup>8</sup>

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# V. Human Population Growth and the Biodiversity Hotspots

*By concentrating on such areas where needs are greatest and where the pay-off from safeguard measures would also be greatest, conservationists can engage in a more systematized response to the challenge of large-scale extinctions.<sup>1</sup>*

*Norman Myers, 1988*

*Ecologist*



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**D**espite the efforts of dedicated conservationists of many different nationalities, significant numbers of today's living species will become extinct in the coming decades. To minimize the loss to future human generations, international environmental policymakers, strapped by limited funds, will have to act quickly, wisely and in the right locations. How will they manage to do this?

In fact, a tool exists. Conceived by British ecologist Norman Myers in the late 1980s,<sup>2</sup> and expanded upon by Myers, Russell Mittermeier and scientists at Conservation International, the *global biodiversity hotspots* call attention to 25 terrestrial regions of the world where biological diversity is most concentrated and the threat of loss most severe. In all of the hotspots, fully intact natural ecosystems have already been reduced to 30 percent or less of their original land surface area. And in nine hotspots—including the Philippines, Madagascar and Brazil's Atlantic Forest Region—intact natural habitats are down to less than 10 percent of their original extent.<sup>4</sup> As presently drawn, the boundaries of the 25 biodiversity hotspots enclose around 12 percent of the Earth's habitable land surface (omitting Antarctica and other areas of bare rock and ice).

Along with the hotspots, three *major tropical*

*wilderness areas* have been identified: the Upper Amazonia and Guyana Shield, the Congo River Basin, and forests of New Guinea and Melanesia. These are the most pristine and least fragmented of all species-rich regions of the world, and among the last places in the tropics where indigenous forest-dwelling peoples have any hope of maintaining their traditional lifestyles. An estimated 75 percent or more of the naturally vegetated habitat remains in each of the three major tropical wilderness areas.<sup>3</sup>

## What Makes the Hotspots So "Hot"?

Analysis of hotspots is based on the number of *endemic species* (species found nowhere else in the world) of *vascular plants*. These are plants with internal vessels to conduct water and nutrients, like grasses, flowering plants, trees and ferns. Although the intact, naturally vegetated ecosystems within the hotspots cover less than 2 percent of the Earth's land surface, over 131,000 species are found within these hotspots as endemics. These account for roughly 44 percent of the world's plant diversity. In addition, the hotspots include habitat for thousands more plant species that are also found outside the hotspots.<sup>3</sup>



Because high plant diversity is, by and large, a good indicator for a richness of terrestrial animal species, the hotspots help set geographical priorities for world animal conservation as well. The hotspots are estimated to contain somewhere around 35 percent of all terrestrial vertebrates (which excludes fish) as endemics. There are also indications that at least 75 percent of all terrestrial animal species listed as threatened by the IUCN-World Conservation Union are found within this relatively small area.<sup>3</sup>

Hotspot analysis is an ongoing process. Revisions to the current list are likely in the future. And the global biodiversity hotspots are not the only world-wide conservation priority system. Others include World Wildlife Fund's (WWF) *global 200 ecoregions*, BirdLife International's *endemic bird areas*, and WWF/IUCN's *centers of plant diversity*.<sup>4</sup>

## Future Risk and Uncertainty

The fate of a significantly large proportion of terrestrial biodiversity is linked to the future of these 28 biologically diverse regions. But what is that future, and what are its risks? Realistically, we cannot know precisely. Economic and cultural factors, both global and local, will matter. So will policy responses to biodiversity loss. And most of these are not measurable, or are presently unavailable for evaluation.

Population density and population growth have been measured. Both imply risks to biodiversity, for both will assuredly play important roles in determining the extent and nature of human dominion over ecosystems, and in the success or failure of

conservation efforts. Rates of growth of human population provide some insight into the future hotspot population, and allude to densities it might achieve in some localities.

In the following analysis by Population Action International, population density and growth rates have been estimated for each of the hotspots and major tropical wilderness areas. The analysis uses geographical data from Conservation International; a map of 1995 population density produced by the National Center for Global Information Analysis, at the University of California at Santa Barbara, California, in the United States; and national and sub-national population growth data from various sources.<sup>5</sup> [See Appendices 1f, g and j.]

This method cannot assess the full range of risks on specific groups of organisms or species. And there are numerous sources of uncertainty, particularly at low levels of human population density. Here, human-caused disturbance can vary dramatically—native habitat could be nearly pristine, inhabited by relatively small groups of indigenous people who subsist with little impact on the environment. Or, significant biodiversity loss may have resulted previous to widespread settlement, from land uses like logging, grazing, mining and hunting that have extracted natural resources, abetted biological invasion or dumped pollutants. That variation diminishes with higher population densities, in which case it becomes harder

to prevent biodiversity loss, even with significant regulation and investment.

## Results of the Analysis

**As of 1995, more than 1.1 billion people were living within the 25 biodiversity hotspots. Population density in the hotspots was, on average, almost twice that of the world as a whole.** Despite declines in human fertility in several regions of the world, this study suggests that population growth, which ranges from 1.0 to 3.2 percent annual growth in 24 of the 25 hotspots, remains an important factor in global biodiversity conservation. On average, population in the hotspots is growing by 1.8 percent annually, 38 percent faster than the world population growth rate of 1.3 percent per year, and even significantly above the developing world's rate of 1.6 percent per year.

Around 75 million people, or 1.3 percent of the world's population, presently live within the three major tropical wilderness areas. These tropical forests cover around 6 percent of the Earth's land surface, an area larger than China. Among Earth's most biologically diverse regions, these forests are experiencing the most rapid growth in human population: 3.1 percent annually, on average, a level over twice the global rate of population growth.

Growth rates for developed country populations situated in hotspots are, in most cases, substantially higher than the worldwide average for developed regions, which is 0.3 percent. Migration, both in present and past decades, is the principal

As of 1995, more than  
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living within the 25  
biodiversity hotspots.



## Global Biodiversity Hotspots

### 1. Tropical Andes

Original extent remaining intact: 25%  
 Original extent protected: 6.3%  
 Location: highlands of Colombia, Ecuador, Bolivia, Peru, Venezuela  
 Vegetation types: tropical moist broadleaf forest, dry forests, montane grasslands  
 Endemic plant species: 20,000  
 Hotspot area: 1,415,000 sq. km.  
 Population: 57,920,000  
 Population density: 40 persons per sq. km.  
 Population growth rate: 2.8% per year

Endemics include 320 bird, 558 reptile and amphibian species. Origin of several important crops and genetic relatives. Two-thirds of original natural vegetation cover already lost. Habitat for Peruvian yellow-tailed woolly monkey, mountain tapir, spectacled bear, marble spatula-tailed hummingbird.

### 2. Mesoamerica

Original extent remaining intact: 20%  
 Original extent protected: 12.0%  
 Location: Central America, from Panama north to central west coast of Mexico  
 Vegetation types: tropical moist broadleaf forest, tropical dry forest, mangroves  
 Endemic plant species: 5,000  
 Hotspot area: 1,099,000 sq. km.  
 Population: 61,060,000  
 Population density: 56 persons per sq. km.  
 Population growth rate: 2.2% per year

Distinctive continental species. Winter range for many North American song birds. Ranching, coastal development and agriculture pose serious threats. Species include the resplendent quetzal, ocelot, mountain squirrel.

### 3. Caribbean

Original extent remaining intact: 11%  
 Original extent protected: 15.6%  
 Location: the Florida Everglades and the Caribbean Islands  
 Vegetation types: tropical moist broadleaf forest, pine forests, wetlands, mangroves  
 Endemic plant species: 7,000  
 Hotspot area: 264,000 sq. km.  
 Population: 38,780,000  
 Population density: 136 persons per sq. km.  
 Population growth rate: 1.2% per year

Ancient flora and fauna, distinct from mainland. Everglades contain some 11,000 species of seed-bearing plants, 25 orchid varieties, 323 bird species. Islands are regional centers for marine endemism. Species include the solenodon (small insectivores), Caribbean manatee, many endemic frogs, marine turtles.

### 4. Atlantic Forest Region

Original extent remaining intact: 8%  
 Original extent protected: 2.7%  
 Location: eastern coast of Brazil, eastern Paraguay, small area in northern Argentina  
 Vegetation types: tropical moist broadleaf forest  
 Endemic plant species: 6,000  
 Hotspot area: 824,000 sq. km.  
 Population: 65,050,000  
 Population density: 79 persons per sq. km.  
 Population growth rate: 1.7% per year

Known in Brazil as *Mata Atlantica*, in Argentina as *Selva Misionera o Paranaense*. 54 percent of region's trees, 80 percent of primates are endemic. Less than 5 percent of once vast forest still intact. Coastal development and urban sprawl threaten remainder. Primates such as golden lion tamarin and black-faced lion tamarin endemic to region, as are maned sloth, red-billed currawow.

### 5. Chocó-Darién-Western Ecuador

Original extent remaining intact: 24%  
 Original extent protected: 6.3%  
 Location: coastal plains of Colombia, Ecuador, eastern Panama  
 Vegetation types: tropical moist broadleaf forests  
 Endemic plant species: 2,250  
 Hotspot area: 134,000 sq. km.  
 Population: 5,930,000  
 Population density: 44 persons per sq. km.  
 Population growth rate: 3.2% per year

World's richest assemblages of lowland plants and animals. High rates of deforestation during past half-century. Ecuador's lowland wet forest now below 10 percent of original cover. Species include cycad palms, jaguar, cotton-top tamarin, harpy eagle.

### 6. Brazilian Cerrado

Original extent remaining intact: 20%  
 Original extent protected: 1.2%  
 Location: central Brazil  
 Vegetation types: tropical woodlands and savannas  
 Endemic plant species: 4,400  
 Hotspot area: 2,160,000 sq. km.  
 Population: 14,370,000  
 Population density: 7 persons per sq. km.  
 Population growth rate: 2.4% per year

One of largest savanna-woodland complexes. Site of commercial agricultural expansion. Agriculture, charcoal production and water projects are main threats. Species include maned wolf, giant anteater, Spix's macaw.



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## 7. Central Chile

Original extent remaining intact: 30%

Original extent protected: 3.1%

Location: Chile

Vegetation types: mediterranean shrublands, temperate rainforest.

Endemic plant species: 1,605

Hotspot area: 320,000 sq. km.

Population: 9,710,000

Population density: 29 persons per sq. km.

Population growth rate: 1.4% per year

Chilean *matorral* shrublands highly diverse. Region includes only temperate rainforest in South America, which is home to over 3,000 plant species. Natural vegetation reduced to less than one-third of original. Most densely populated part of Chile.

## 8. California Floristic Province

Original extent remaining intact: 25%

Original extent protected: 9.7%

Location: the northern portion of the Mexican state of Baja California, to just north of the border of the U.S. state of California

Vegetation types: mediterranean shrublands, coniferous forest

Endemic plant species: 2,125

Hotspot area: 236,000 sq. km.

Population: 25,360,000

Population density: 108 persons per sq. km.

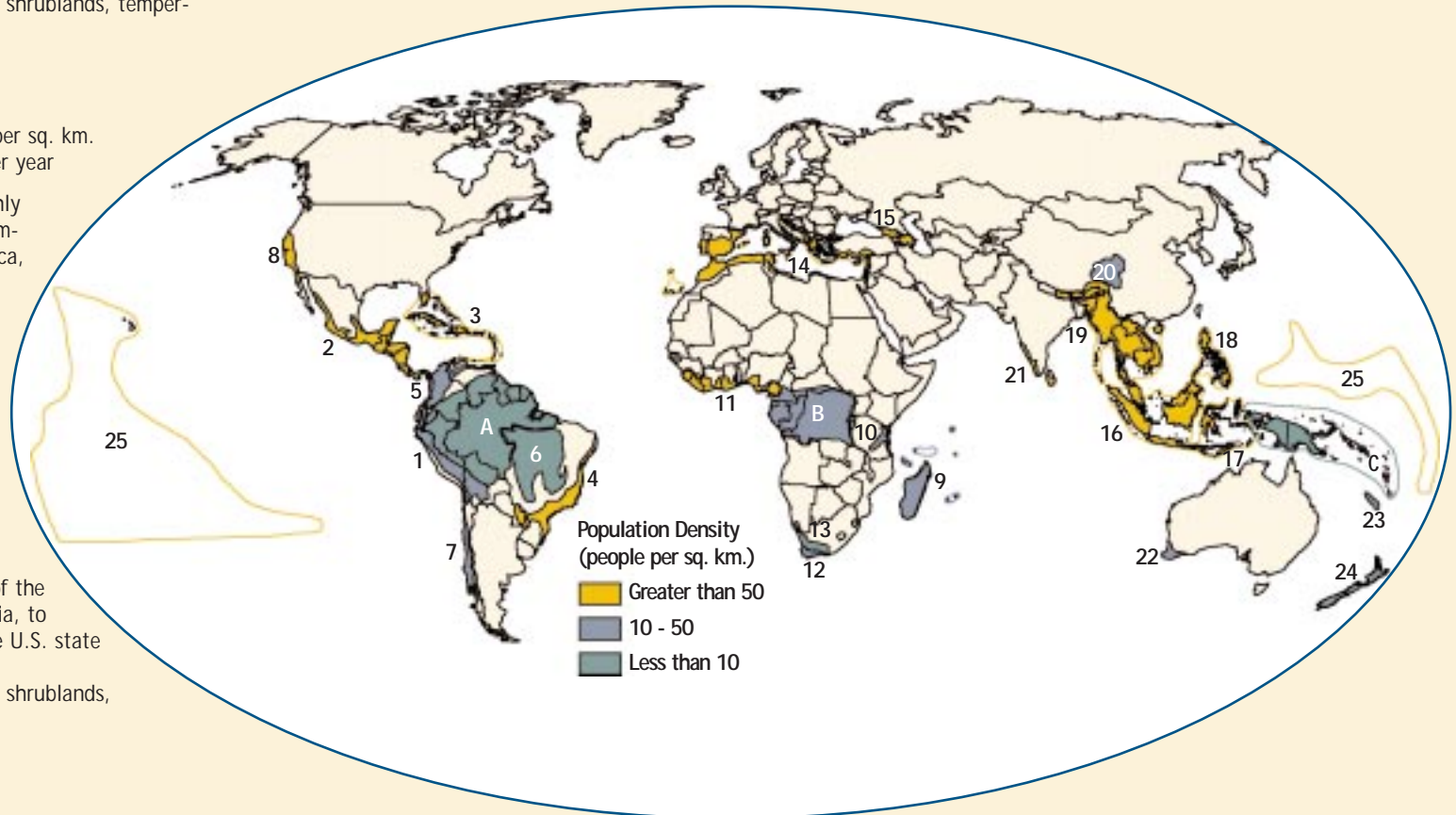
Population growth rate: 1.2% per year

*Chaparral* shrublands along coast are heavily threatened. Mountain ranges home to ancient forest remnants including redwoods and giant sequoias.

Region contains one-fourth of all plant species in the continental United States and Canada, half of which are endemic.

FIGURE 22

Population Density in the 25 Global Biodiversity Hotspots and Major Tropical Wilderness Areas, 1995



By 1995, population density (people per square kilometer) in the global biodiversity hotspots was, on average, almost twice that of the world as a whole. Out of the 25 hotspots (numbered 1 to 25 on the map), 15 had attained densities higher than the world population density of 42 people per square kilometer. For the time being, the three major tropical wilderness areas (A, B, C) remain populated at relatively low densities. Source: Population Action International; data from NCGIA/CIESIN, 1998.







## 9. Madagascar and Indian Ocean Islands

Original extent remaining intact: 10%  
Original extent protected: 1.9%  
Location: Madagascar and surrounding islands, including the Comoros, Mauritius, Mayotte, Reunion, Mascarene, Seychelles  
Vegetation types: moist tropical forest, dry forest, savannas, desert, mangroves  
Endemic plant species: 9,704  
Hotspot area: 587,000 sq. km.  
Population: 15,450,000  
Population density: 26 persons per sq. km.  
Population growth rate: 2.7% per year

About three-quarters of Madagascar's plants and animals are endemic. Lemurs, a threatened group of primitive primates, are best known mammals. Forests now at 20 percent of pre-human extent. Smaller ocean islands harbor distinctive fauna.

## 10. Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya

Original extent remaining intact: 7%  
Original extent protected: 16.9%  
Location: eastern Tanzania  
Vegetation types: tropical moist forests  
Endemic plant species: 1,400  
Hotspot area: 142,000 sq. km.  
Population: 7,070,000  
Population density: 50 persons per sq. km.  
Population growth rate: 2.2% per year

Once a site of profuse local evolution. Now just half of original cover remains. Usambara Mountains alone contain 50 endemic tree species. Threatened by firewood collection, agriculture. Home to 18 of 20 known species of African violets, 16 species of wild coffee, numerous birds including Hartlaub's turaco.

## 11. Guinean Forests of West Africa

Original extent remaining intact: 10%  
Original extent protected: 1.6%  
Location: from Nigeria along the southern portion of West Africa to Sierra Leone and Guinea  
Vegetation types: tropical moist broadleaf forest, mangroves  
Endemic plant species: 2,250  
Hotspot area: 660,000 sq. km.  
Population: 68,290,000  
Population density: 104 persons per sq. km.  
Population growth rate: 2.7% per year

Some of most species-rich habitats in Africa. Many plants and animals distinct from Congo Basin. Mammals threatened by poaching, including lowland gorillas and chimpanzees. Species include West African mahogany, zebra duiker (a tiny antelope), crowned eagle-hawk.

## 12. Cape Floristic Province

Original extent remaining intact: 24%  
Original extent protected: 19.0%  
Location: South Africa  
Vegetation types: mediterranean shrublands  
Endemic plant species: 5,682  
Hotspot area: 82,000 sq. km.  
Population: 3,480,000  
Population density: 42 persons per sq. km.  
Population growth rate: 2.0% per year

Coastal shrubland, known as *fynbos*, may have highest plant species density of any comparably-sized land ecosystem. 70 percent of plant species are endemic. One-third of original natural vegetation lost to agriculture and urban sprawl. Remainder degraded and highly fragmented.

## 13. Succulent Karoo

Original extent remaining intact: 27%  
Original extent protected: 2.1%  
Location: southwestern Namibia, South Africa  
Vegetation types: desert succulents  
Endemic plant species: 1,940  
Hotspot area: 193,000 sq. km.  
Population: 460,000  
Population density: 3 persons per sq. km.  
Population growth rate: 1.9% per year

Supports roughly 3,500 plant species, more than half endemic. Distinctive semi-desert communities, many over-grazed. Problems include over-pumping groundwater and illegal harvest of succulent plants. Species include centuries-old welwitschia, mountain zebra, black rhino.

## 14. Mediterranean Basin

Original extent remaining intact: 5%  
Original extent protected: 1.8%  
Location: coastal and near-coastal parts of southern Europe, the Middle East and North Africa  
Vegetation types: mediterranean shrublands, montane coniferous forests  
Endemic plant species: 13,000  
Hotspot area: 1,556,000 sq. km.  
Population: 174,460,000  
Population density: 111 persons per sq. km.  
Population growth rate: 1.3% per year

Home to more than 10 percent of all plant species, much of it in coastal shrublands known as *macchia*. Southern European mountains home to remnants of once diverse European fauna. Turkish Taurus Mountains particularly rich in plant species. Fauna include chamoix, brown bear, marbled polecat, Egyptian vulture. Until late Roman Era, North Africa supported fauna similar to present sub-Saharan plains, including elephants, rhino and lion.

## 15. Caucasus

Original extent remaining intact: 10%  
Original extent protected: 2.8%  
Location: Armenia, Azerbaijan, Georgia and small section of Iran  
Vegetation types: temperate montane forests  
Endemic plant species: 1,600  
Hotspot area: 184,000 sq. km.  
Population: 13,940,000  
Population density: 76 persons per sq. km.  
Population growth rate: - 0.3% per year

One of the most biodiverse temperate forests of Asia. High levels of plant and animal endemism. Remnants of European and Asian fauna, including Caucasian tur, chamoix, ibex, red deer, wolf, bear, lynx.

## 16. Sundaland

Original extent remaining intact: 8%  
Original extent protected: 5.6%  
Location: Indonesian islands of Sumatra, Java and Borneo, Brunei, peninsular and eastern Malaysia.  
Vegetation types: tropical moist forests, dry and monsoon forests, alpine meadows, mangroves  
Endemic plant species: 15,000  
Hotspot area: 1,500,000 sq. km.  
Population: 180,490,000  
Population density: 121 persons per sq. km.  
Population growth rate: 2.1% per year

Rainforest and mangroves highly biodiverse, but threatened by agriculture, logging, burning. Among richest flora in Asia. Includes relatives of crop and orchard species. Region's mangroves important marine nursing grounds. Species include Sumatran tigers, rhinos, gibbons, Sunda otter-civet, Bornean tarsier and orang-utans.

## 17. Wallacea

Original extent remaining intact: 15%  
Original extent protected: 5.9%  
Location: central islands of Indonesia, including Sulawesi and Moluccas  
Vegetation types: tropical moist forests, mangroves  
Endemic plant species: 1,500  
Hotspot area: 341,000 sq. km.  
Population: 18,260,000  
Population density: 54 persons per sq. km.  
Population growth rate: 1.9% per year

Extremely high levels of bird, mammal and plant endemism. Moluccan archipelago includes hundreds of heavily forested islands. Mix of Asian lineages, such as macaques and tarsiers, with Australian lineages such as eucalyptus trees and marsupials.

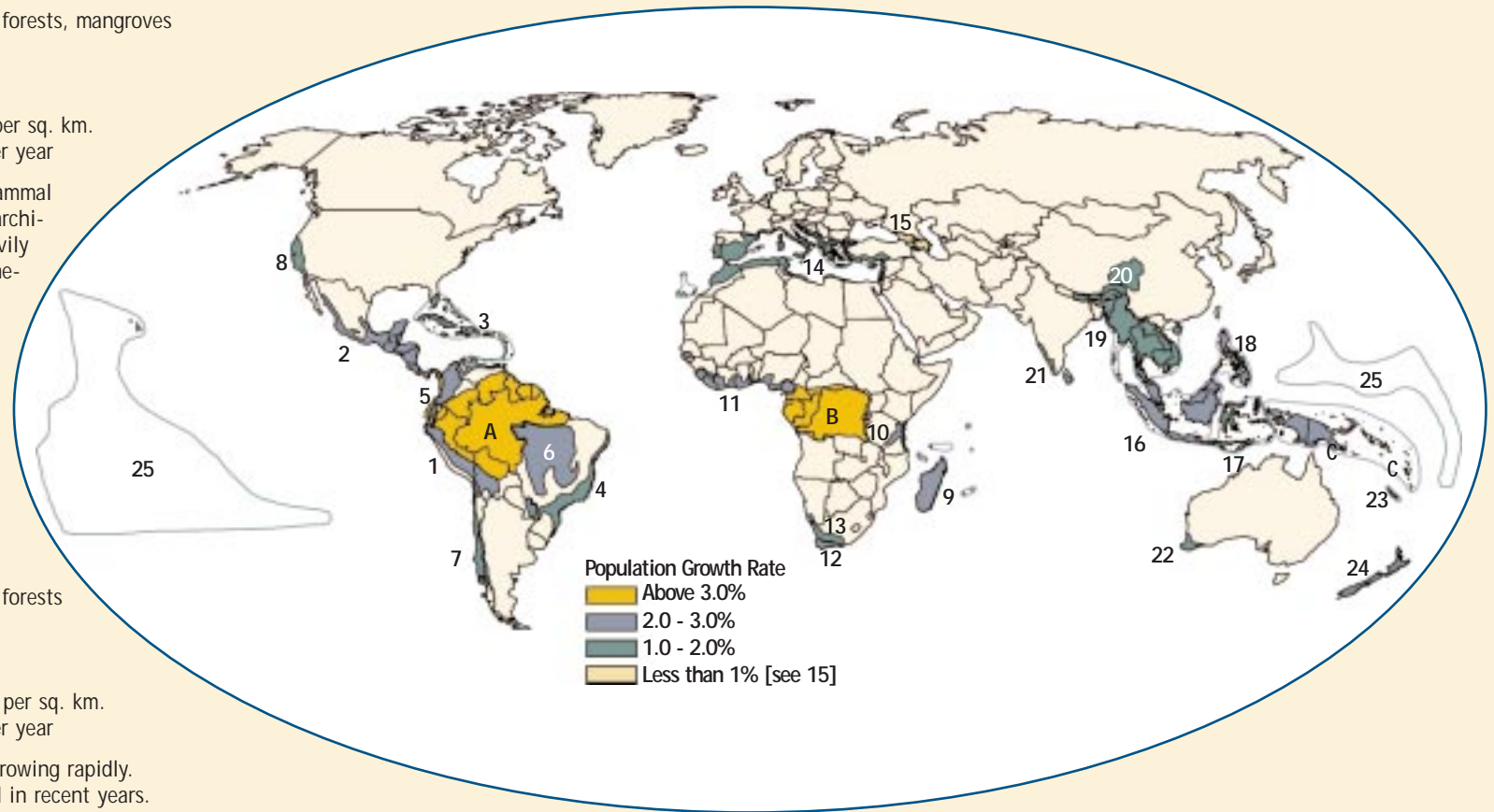
## 18. Philippines

Original extent remaining intact: 8%  
Original extent protected: 1.3%  
Location: 7,100 islands of the Philippines  
Vegetation types: tropical moist forests  
Endemic plant species: 5,832  
Hotspot area: 293,000 sq. km.  
Population: 61,790,000  
Population density: 198 persons per sq. km.  
Population growth rate: 2.1% per year

Densely populated, population growing rapidly. Numerous vertebrates discovered in recent years. About 8 percent of original forest remains. Over 460 endemic vertebrates. Species include Philippine tarsier, colugo (flying lemur), monkey-eating eagle.

FIGURE 23

## Population Growth in the 25 Global Biodiversity Hotspots and Major Tropical Wilderness Areas, 1995-2000



Despite significant declines in human fertility in several regions of the world, human population growth, which ranges from 1.0 to 3.2 percent annual growth in 24 of the 25 global biodiversity hotspots (numbered 1 to 25), remains an important factor in global biodiversity conservation. The three major tropical wilderness areas (A, B, C) are, on average, experiencing more rapid growth in population than the hotspots. Population growth in these heavily forested regions, as a whole, is 3.1 percent each year, a level over twice the global rate of population growth.  
Source: Population Action International, see Appendix 1h.





### 19. Indo-Burma

Original extent remaining intact: 5%  
 Original extent protected: 7.8%  
 Location: Eastern Nepal to Eastern India and Bangladesh, east to Vietnam and Hainan Island (China).  
 Vegetation types: tropical moist broadleaf forest, dry and monsoon forests, mangroves  
 Endemic plant species: 7,000  
 Hotspot area: 2,313,000 sq. km.  
 Population: 224,920,000  
 Population density: 97.8 persons per sq. km.  
 Population growth rate: 1.5% per year

Richest endemic bird area in Asia. In Indochina highlands biologists recently catalogued 2 mammals: Vu Quang ox and giant muntjac. Home to tiger, golden langur, lesser panda, clouded leopard, gaur and kouprey (wild cattle), Javan rhinos, several gibbons (apes), endemic pheasants, Asian elephants and many rare plants.

### 20. Mountains of South-Central China

Original extent remaining intact: 8%  
 Original extent protected: 2.1%  
 Location: parts of the Chinese provinces of Sichuan, Gansu, Qinghai, and Tibetan Autonomous Region  
 Vegetation types: temperate forests, grasslands, alpine meadows  
 Endemic plant species: 3,500  
 Hotspot area: 469,000 sq. km.  
 Population: 12,830,000  
 Population density: 25 persons per sq. km.  
 Population growth rate: 1.5% per year

One of richest assemblages of forest trees in the world. Many rare animals and plants endemic to this region, including numerous rhododendrons, the giant panda, golden pheasant, and copper pheasant.

### 21. Western Ghats and Sri Lanka

Original extent remaining intact: 7%  
 Original extent protected: 10.4%  
 Location: southwestern Indian states of Karnataka and Kerala, southwestern Sri Lanka  
 Vegetation types: tropical moist broadleaf forests  
 Endemic plant species: 2,180  
 Hotspot area: 136,000 sq. km.  
 Population: 46,810,000  
 Population density: 341 persons per sq. km.  
 Population growth rate: 1.4% per year

Among South Asia's last remaining tropical rainforests. Densely populated. Western Ghats home to 84 endemic amphibian species. Very high tree diversity including 13 species of commercially valuable dipterocarp. Uniquely high rainfall forest in Sri Lanka. Species include Asian leopard, Ceylon giant squirrel, Asian elephant, lion-tailed macaque, Malabar parakeet.

### 22. Southwest Australia

Original extent remaining intact: 11%  
 Original extent protected: 10.8%  
 Location: southwestern corner of coastal Australia  
 Vegetation types: mediterranean shrublands  
 Endemic plant species: 4,331  
 Hotspot area: 107,000 sq. km.  
 Population: 1,440,000  
 Population density: 13 persons per sq. km.  
 Population growth rate: 1.7% per year

Two-thirds of 5,500 resident plant species in coastal *kwongan* shrublands are endemic. Region well suited to agriculture, grazing and urbanization. Introduced plants pose major threat. Species include Albany pitcher plant, honey possum, and dragon orchid.

### 23. New Caledonia

Original extent remaining intact: 28%  
 Original extent protected: 2.8%  
 Location: island of New Caledonia  
 Vegetation types: tropical moist broadleaf and dry forests  
 Endemic plant species: 2,551  
 Hotspot area: 16,000 sq. km.  
 Population: 140,000  
 Population density: 8 persons per sq. km.  
 Population growth rate: 2.1% per year

Endemism due to long geographic isolation. 80 percent of plants endemic. Wildly colorful flowers. Extraordinary endemic reptiles and high degree of endemism among birds and invertebrates. Original forests down to less than 10 percent of island. Species include the kagu (a flightless bird), terrestrial crocodiles, giant gecko.

### 24. New Zealand

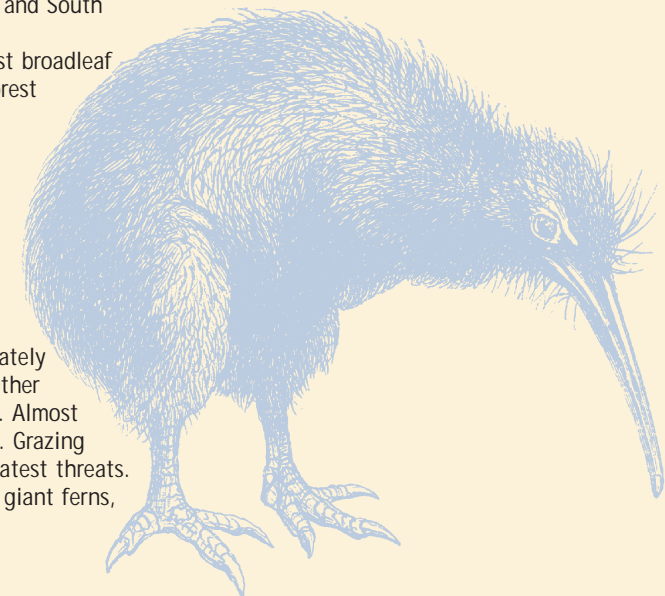
Original extent remaining intact: 22%  
 Original extent protected: 19.2%  
 Location: New Zealand's North and South Islands  
 Vegetation types: tropical moist broadleaf forests and temperate rainforest  
 Endemic plant species: 1,865  
 Hotspot area: 260,000 sq. km.  
 Population: 2,740,000  
 Population density: 11 persons per sq. km.  
 Population growth rate: 1.0% per year

Endemic species evolved separately from ancestors on mainland. Other than bats, no native mammals. Almost all flightless birds now extinct. Grazing and introduced species are greatest threats. Species include the kauri tree, giant ferns, kiwi, crested penguin.

### 25. Polynesia / Micronesia

Original extent remaining intact: 22%  
 Original extent protected: 10.7%  
 Location: Pacific Ocean islands, from the Samoan Islands and the Federated States of Micronesia, to Fiji, and east to Hawaii (U.S.).  
 Vegetation types: tropical moist broadleaf forests and dry forests  
 Endemic plant species: 3,334  
 Hotspot area: 46,000 sq. km.  
 Population: 2,900,000  
 Population density: 58.4 persons per sq. km.  
 Population growth rate: 1.3% per year

For some islands, over 95 percent of species are endemic. Majority of original land bird species extinct. Remaining native birds, plant species and invertebrates succumbing to biological invasion. Species include Hawaii's native hibiscus trees and flightless goose (nene), Fiji iguana, orange dove.





## Major Tropical Wilderness Areas

### A. Upper Amazonia and Guyana Shield

Area: 5,830,000 sq. km.

Location: east of the Andes Mountains in Colombia, Ecuador, Peru and Bolivia; the northern Brazilian Amazon Basin; the southern parts of French Guiana, Guyana, Suriname and Venezuela

Vegetation types: tropical moist and inundated broadleaf forests

Population: 14,750,000

Population density: 3 persons per sq. km.

Population growth rate: 3.9% per year

Largest remaining continuous tract of tropical rainforest. Share of global biodiversity between 15 and 20 percent. Survival of numerous indigenous Amerindian tribes tied to fate of forest region. Forests target for extraction of tropical timber, pulp, gold, rubber and wildlife for international pet trade.

### B. Congo Basin

Area: 2,886,000 sq. km.

Location: west central Africa, northern Angola to Cameroon and east to Rwanda, most of Democratic Republic of the Congo

Vegetation types: tropical moist and broadleaf forests, upland dry forest, mangroves

Population: 54,040,000

Population density: 18 persons per sq. km.

Population growth rate: 3.0% per year

Some of richest and most intact forests in the world. Eastern Congo particularly rich in ancient species. Species threatened by hunting, logging. Home to bonobo (pygmy chimpanzee), pygmy hippo, okapi, crowned crane, forest elephant, recently described suntailed monkey, rare orchids and butterflies, weaver birds and sunbirds.

### C. New Guinea and Melanesian Islands

Area: 906,000 sq. km.

Location: Indonesian state of Irian Jaya on the island of New Guinea, Papua New Guinea, Solomon Islands, Vanuatu

Vegetation types: montane and lowland moist forests, mangroves

Population: 6,120,000

Population density: 6 persons per sq. km.

Population growth rate: 2.6% per year

Largest of all tropical islands, highest in altitude. Lowland forests harbor over 1200 trees species, 2000 ferns. Home to world's largest butterfly, Queen Alexandra's birdwing, bird-of-paradise species, echidna (an egg-laying mammal), marsupial mammals. Small islands contain diverse birds and plants, distinct from New Guinea.

#### Sources:

"Global Biodiversity Hotspots" (Washington, DC: Conservation International), <http://www.conservation.org/web/fieldact/hotspots/hotspots.htm>, (last accessed Jan. 8, 1999).

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source for this continued growth, specifically in the U.S. states of California (California Floristic Province), Florida (Caribbean) and Hawaii (Polynesia and Micronesia); and in Southwest Australia and New Zealand. That growth is mainly produced by domestic re-location—people moving from colder localities to warmer spots along coastlines, and from cities to more natural settings<sup>6</sup>—mixed with immigration from developing countries.

One hotspot, the Caucasus of Central Asia, is presently decreasing in population (-0.3 percent annually), though it remains among the ten most densely populated hotspots. And while densely populated southern Europe is close to stabilization, population is still growing at a net rate of 1.3 percent annually in the Mediterranean hotspot, bolstered by rapid growth among Middle Eastern and North African countries within the hotspot.

## Implications

Population trends in the biodiversity hotspots and major tropical wilderness areas suggest that the risks of continuing species loss are high in the most biologically diverse terrestrial regions of the world. Human population density is already a significant concern in about three-quarters of the hotspots, particularly the Western Ghats/Sri Lanka, the Philippines and the Caribbean. The hotspots are rapidly urbanizing. Currently there are 146 major cities presently located in or directly adjacent to a hotspot. Because of their mild climates and locations near coastlines, *mediterranean*







Whatever strategies ultimately emerge, geographical patterns of human population density, growth and migration will continue to influence decisions in global biodiversity conservation.



*shrublands* (regions with climates and vegetation similar to the Mediterranean Basin) are attractive to human settlement. Within the 25 hotspots lie 62 cities having over 1 million inhabitants each. Of these, 22 are within the 5 hotspots dominated by mediterranean shrublands.

Together, unsustainable natural resource extraction and the persistent spread of agriculture pose a dual threat to tropical forest habitat. Within the Southeast Asian hotspots alone—the Philippines, Wallacea, Sundaland and Indo-Burma—cropland grew by some 11 million hectares (roughly the size of Bulgaria) in the decade prior to forest surveys taken in 1992-94.<sup>7</sup> Nearly all of this new cropland was cleared from forest. More recently, rates of deforestation appear to have accelerated, assisted by burning in 1997 and 1998, and by commercial logging that was stepped up during the recent Asian economic crisis.

Although fertility rates in Brazil and Indonesia have fallen dramatically over the past decade, pro-migration policies undermine any likelihood that high rates of population increase in the three tropical wilderness areas will slow in the immediate future. A half-century ago these areas were almost exclusively the domains of indigenous hunter-gatherers. Today, only the Amazonian and Guyanan forests have densities of less than five people per square kilometer. And even here, low population density is likely to be short-lived. The area's population growth rate, at 3.9 percent per year, is the highest of the three tropical wilderness areas. If growth continues at this rate, the area's mostly immigrant population would double in under 19 years. Already, life expectancy at birth for

dwindling indigenous Amazonian populations is roughly 20 years below the Brazilian average of 66—and it is falling.<sup>8</sup>

Tropical wilderness areas are at a crossroads. Policies applied to these forests have, in the past, resembled those in western North America in the late 19<sup>th</sup> century that granted land to migrants, and concessions for logging, mining and grazing. In general, the results have been the same: rapid deforestation, loss of natural ecosystems, and depopulation of native peoples. Yet, there is still time in the tropics to change the outcome. Recently the government of Suriname, with assistance from the Global Environmental Facility and Conservation International, created the Central Suriname Nature Reserve by putting aside some 16,000 square kilometers of rainforest (roughly equivalent to the area deforested annually in the Brazilian Amazon).<sup>10</sup> More large tracts could be reserved for future needs, some as managed natural resource areas and indigenous reserves, others as national parks, recreation sites and research stations.

## Population and Global Biodiversity Strategies

One of the most important tasks for conservationists in the 21<sup>st</sup> century will be to determine where to salvage the scant remains of evolution's legacy. To that end, the hotspots and other global biodiversity prioritization systems are essential tools. Yet, knowledge of the global biodiversity hotspots does not eliminate a fundamental dilemma for international donor and lend-

ing agencies, many of which have increased funding to biodiversity programs over the past decade. Each agency must decide how to invest: whether to concentrate efforts in the hotspots where the threats are most immediate, and the remainder of unprotected biodiversity-rich habitat is relatively small; or to dedicate the lion's share of its funds to establish reserves enclosing much larger tracts of rainforest in the tropical wilderness areas.<sup>11</sup>

Whatever strategies ultimately emerge, geographical patterns of human population density, growth and migration will continue to influence decisions in global biodiversity conservation.<sup>12</sup> Future demographic patterns, however, are themselves uncertain. To some extent local population density and migration, particularly as they operate by the middle of the 21<sup>st</sup> century, will be influenced by how quickly the ongoing global revolution in reproductive self-determination is extended to couples in the biodiversity-rich tropics.

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## Hotspot Population Profile: Madagascar

It is on tropical oceanic islands that evolution seems most wondrously productive. Left in isolation from mainland predators and competitors, given tens of millions of years and just a modest few forms to start with, its processes have produced entirely new and unusual repertoires of species. Madagascar, the islands of the Caribbean Sea, Polynesia and the Philippines are among the best examples. Nowhere does organic evolution seem more wildly creative—almost experimental—as on these islands. And nowhere today are evolution's creations more threatened.

Two major events shaped Madagascar's biodiversity. The first was its separation from Africa around 180 million years ago, setting off a burst of isolated evolution among plant and animal life. The second was the arrival of *Homo sapiens* less than 2,000 years ago from somewhere in the Indonesian islands. Not long afterwards, much of what evolution had fashioned forever disappeared.

Among the animals that thrived until our own species set foot on Madagascar was the flightless elephant bird, one of the largest birds that ever lived. A pygmy hippopotamus also went extinct, along with a giant tortoise and an armadillo. Two giant lemurs—*Archaeonindris*, which was larger than a male gorilla, and *Megaladapis*, as big as a female gorilla—disappeared after human arrival, as did a large tree sloth-like lemur called *Babakotia*.<sup>1</sup> Today humans and their livestock are the only animals on Madagascar weighing over 12 kilograms.<sup>2</sup>

Despite the losses, Madagascar remains biologically unique. Roughly 80 percent of Madagascar's plants are endemic. And though the island, which is considered part of Africa, represents less than 2 percent of that continent's land, it is home to fully a quarter of all African plant species. More species of orchids are native to Madagascar than to the rest of Africa. Thirty species of reptiles and 178 species of frogs—staggering



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numbers for one island—have been recorded there to date, and more are discovered each year.

All the world's 32 species of lemurs live on Madagascar and nearby islands, and nowhere else. Twenty lemur species are threatened with extinction, four with only slim chances for survival. Less recognized is a second completely endemic family of small, primitive insect-eating mammals, the

Malagasy tenrecs, comprising 30 species. IUCN-World Conservation Union classifies 10 of these as threatened.<sup>3</sup>

### Our Own Species

During the latter half of the 20<sup>th</sup> century, dramatic demographic changes occurred in Madagascar. Responding to modest improvements in public health conditions, mortality rates declined in the mid-1950s, while fertility rates remained high. As a result, the rate of annual population growth climbed to 3.4 percent by 1985. The valleys of Madagascar's central plateau filled with farms

and began to urbanize. In less than 50 years, the island's population more than tripled, growing from 4.2 million in 1950 to about

15.4 million by 1998.

Four out of five of the country's workers are farmers. And three out of four earn less than \$1 a day.<sup>4</sup> Less than one-fifth of a hectare of cropland is available per capita, one of the lowest such figures in the world. To feed their families, new generations of Malagasy farmers have moved further upslope, burning the island's remaining tropical forests from the hillsides of its eastern region, and planting its thin soils with upland rice. Madagascar's remaining woodlands cover less than 20 percent of that which Malay mariners encountered some 15 centuries ago. Then, perhaps, the island held opportunities for the new migrants. Today, Madagascar's farming families are typically poor, conservatively traditional, and situated far from the meager rural services that their government provides.

Recent surveys show that Malagasy women express the desire for somewhat smaller families—on average, one child less than the present six children per woman recorded. About 19 percent of women who lack access to family planning services would like to use contraception to limit childbirth. Another 16 percent want to lengthen the period between births. Studies suggest that delayed child-bearing could substantially reduce infant mortality.<sup>5</sup> It could also slow the growth of population by spreading out the time between generations.

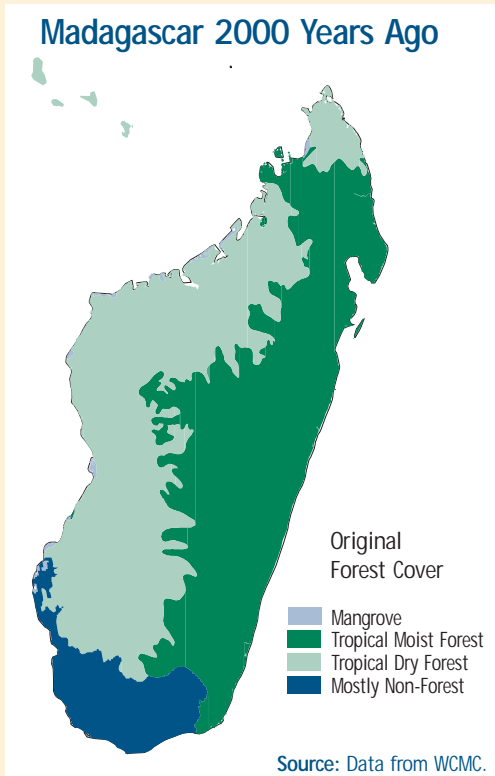
Despite the gravity of reproductive health needs, Madagascar's budget for family planning services is only one-fifth the amount spent on conservation efforts. A spokesperson

from the UN Population Fund (UNFPA) estimates that Madagascar falls short of meeting the present demand for contraception among low-income couples by \$650,000 a year.<sup>6</sup>

### Community-Based Population and Environment

The need for family planning and maternal health services appears greatest in Madagascar's countryside, where infant and child mortality is nearly one-third higher than in urban areas. However, Madagascar's Health Ministry is understandably hesitant about trying to move reproductive health services into the countryside when demand for family planning goes unfulfilled in the island's rapidly growing cities. Most of the few efforts to provide such services are run by non-governmental organizations—including several managed by environmental organizations focused on saving Madagascar's remaining biodiversity. Since 1995, APPROPOP, a program sponsored by the U.S. Agency for International Development, has linked local health providers to environmental field projects, each at the edge of a protected area, where community-based natural resource projects are already active. One is located near the Zahamena Integral Reserve, one near Ranomafana and another near Andohahela National Parks.<sup>7</sup>

These projects have tried to minimize habitat loss in and around the parks while developing and encouraging sustainable income-generating practices in the same gen-





eral areas. In Ranomafana local villagers manage tourist campsites, returning proceeds to committees of village elders. Half of park admittance fees return to village communities for use in conservation projects.<sup>8</sup>

These community-based initiatives provide materials and train community members in a variety of environmentally sound livelihoods, from community gardening and small-scale aquaculture to beekeeping and ecotourism. For their part, health providers on the projects operate mobile health units offering basic health care as well as family planning information.

Concern about demographic pressures on wildlife is no doubt among the concerns that motivate these partnerships, which combine local and foreign development workers. But an equally important motivation is simply to respond to pressing health needs—needs often articulated clearly by women and other community members themselves.

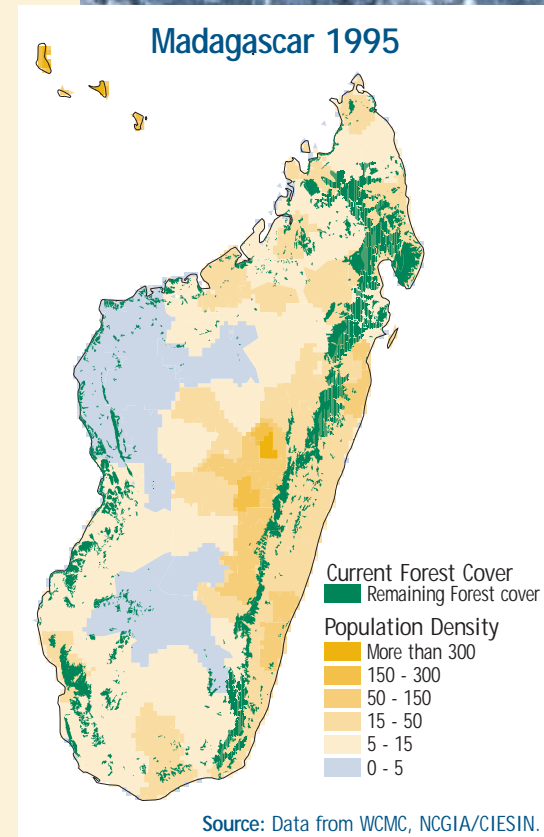
Projects that link natural resource conservation with family planning and reproductive health services tend to view economic development, education and people's control over their own fertility as interrelated and vital to both community well-being and environmental sustainability. The demographic bonus, if one develops, is merely one among several important benefits that result from this approach.

Some conservationists warn that improved services and training programs

could attract more settlers to project sites. In Madagascar, however, population is projected to triple or quadruple by 2050. There can be no illusion that failing to provide services for populations in wildlife-rich areas will dissuade people from living there. On Madagascar, biodiversity's last hope lies in a partnership with its people. And that partnership requires not only effective natural resource management but quality health care—including family planning services for those who seek them.

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The valleys of  
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## Hotspot Population Profile: Urbanization in the California Floristic Province

Not all of the global biodiversity hotspots are situated in the tropics. Endemic plant species—the biological criteria for hotspots—are found in great diversity in mid-latitude coastal shrublands that are graced with mild and stable mediterranean-like climates. Five such hotspots have been identified: the California

Floristic Province in the United States, Southwest Australia, the Cape Floristic Province of South Africa, Central Chile and the Mediterranean Basin itself.

These five hotspots are also preferred human habitat. Within their boundaries lie nearly 40 percent of all the urban areas that have reached 1 million inhabitants within the 25 hotspots.

Among the most notable clashes between biodiversity and human population growth is one at the western edge of the continental United States, extending southward onto the Baja California Peninsula of Mexico. This hotspot, the California Floristic Province, is witnessing some of the most rapid population growth in the industrialized world, with few signs of the slowdown that characterizes population growth in much of the rest of the world.

Nearly half the plant species that are unique to the United States are found in this modest-sized hotspot, along with an estimated 30,000 species of insects, 341 birds, 145 mammals, 61 reptiles and 37 amphibians. Outside of Australia and New Zealand, no other similar-sized area of a developed country can compare.<sup>1</sup>

Yet consider what California has lost as its population has grown from fewer than 1 million people in 1850 to more than 34 million at the end of the 20<sup>th</sup> century.<sup>2</sup> Only 1 percent of the state's original grassland remains, as does just 5 percent of its once-pervasive redwood forests and 6 percent of its interior wetlands.<sup>3</sup>

As with all such correlations between human population growth and biodiversity, no method for quantifying the causal relationship is readily apparent. But a quick glance at the Los Angeles metropolitan area, home to nearly 14.5 million Californians (1997 estimate), makes clear how inhospitable dense human settlement can be for wild species. After decades of population growth and suburban development, the Los Angeles-Anaheim-Riverside urban conglomerate covers about 88,000 square kilometers, an area a little larger than the state of Maine.<sup>2</sup> The area's crowded highways carry more than 7 cars for each 10 of the area's human beings.<sup>4</sup> And its sanitation systems release around 800 million gallons (3 million metric tons) of minimally treated sewage directly into the Pacific Ocean every day, placing nearby marine life at risk.<sup>5</sup>

California's growing economy has offered mobility to millions who have migrated from other parts of the United States, from Latin America and from Asia. The scale of growth and many of its impacts, on humans as well as on biological diversity, are nonetheless clear. California can claim more threatened species than any other U.S. state except Hawaii. In 1997, 200 of its species were listed by the U.S. Fish and Wildlife Service as endangered, including the famed northern spotted owl. Even the official "state mammal," the grizzly bear, survives only on the state flag. It disappeared from California's forests in 1922.<sup>5</sup>

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Sally Ethelston

# VI. Strategies

*The protection of ... major parks and reserves is conceivable, if there is a willingness to share resources on a global level – to provide major support from industrialized countries not merely for the protection of parks and reserves but for the creation of conditions in which all people can live with a measure of human dignity. The decisive factors will be social, political, and economic; they will not be limited simply to [society's] willingness to conserve.<sup>1</sup>*

*Peter H. Raven,  
1986*

*Evolutionary*

*Botanist*

*Director, Missouri*

*Botanical Garden*



*Rio de Janeiro, Vicky Hancock*

**T**he current rapid rate of species extinction, out of all proportion with background rates and thus clearly related to human activities, should warn us that society is approaching a classic double bind. Continued population growth and steady increases in per capita consumption mean that we are accumulating more needs and more wants, much of which can only be satisfied by the biological world around us. Yet, in failing to conserve biodiversity, humanity is simultaneously eliminating those naturally endowed options that may be key to improving our own lives, and the lives of our descendants.

It will take decades, even centuries, to secure the long-term survival of the richest possible diversity of non-human life. This is one reason the future growth of human population is so critical an issue—and so important to address in this context. Policies that lead to a stabilized human population, though often missing in recommendations for conserving biodiversity, may be among the most important in the long run. And they must work in tandem with strategies that act more directly to limit further losses of species and maintain functioning ecosystems.

## A Plan of Action

Each of us can take action to preserve the planet's wealth of living species. This report's recommendations are addressed to policymakers, to scientists and conservationists, and to the general public:

- **The conservation of biological diversity should be elevated to a high priority in donor agencies, nations and communities. While innovative conservation programs deserve support and funds, there is a pressing need to encourage broader understanding of biodiversity and its value to society. To further this objective, governments and donors should work to expand the ranks of biodiversity scientists and environmental educators in the species-rich tropical countries.**

Work should continue on innovative approaches to biodiversity conservation, especially financial mechanisms that spread the cost of such strategies among all who can afford them. The biodiversity that finds its home in poor countries matters to the survival and quality of life of all humanity. Mechanisms need to be developed that encourage all nations to shoulder the costs of species preservation, wherever it occurs, according to their capacity to pay and the benefits they and their descendants will derive.



... legislation that specifically protects species—such as the Endangered Species Act in the United States—deserves support in all countries, as do measures designed to keep intact natural terrestrial, aquatic and marine ecosystems.



Subsidies that lead to biodiversity loss should be ended, and biodiversity management plans should become key elements in national and community planning. Efforts are needed to more accurately assess and publicize the long-term value of functioning ecosystems and the species they shelter. And legislation that specifically protects species—such as the Endangered Species Act in the United States—deserves support in all countries, as do measures designed to keep intact natural terrestrial, aquatic and marine ecosystems. National and community planning should require that economic development not put at risk critical biological resources that can never be replaced.

Education on the value of biodiversity is vitally needed now. Most policymakers and much of the general public cannot define the term *biodiversity* and have little idea why scientists and conservationists find its accelerating loss alarming. That loss is unlikely to be reversed until those who care about it find effective ways to communicate biodiversity's importance and beauty to the news media and the general public.

International donors can do more to increase the number of professionals specializing in biodiversity. Developing countries, where the vast majority of biological diversity resides, face extreme shortages of biodiversity scientists and technicians with biodiversity-relevant skills. Developing countries also need more and better equipped environmental watchdogs and advocates, and programs that promote an environmentally-aware and educated public.

To succeed in the long term, conservationists will need to influence the underlying conditions that drive biodiversity loss. Many scientists no doubt consider a broader role in development to be outside their expertise. Yet, most of the larger conservation organizations—IUCN-World Conservation Union, the World Wildlife Fund and Conservation International among them—have integrated social scientists into their professional (and mostly biologically-trained) staff. These organizations see the need to influence social and economic conditions, including those that affect population growth, so that their biological programs can succeed.

- **The Convention on Biological Diversity, an international agreement aimed at maintaining the planet's biodiversity and equitably sharing its benefits, deserves the support of all nations and peoples. Negotiators seeking to improve it and further its progress should consider the interactions between species survival and human population dynamics. By slowing the growth of population while improving the capacity of all people, especially women, to manage their own lives, the social investment strategies called for at the 1994 International Conference on Population and Development support and amplify other measures to conserve Earth's complex web of life.**

At the 1992 Earth Summit (the UN Conference on Environment and Development) in Rio de Janeiro, the world's nations agreed to the text of the

Convention on Biological Diversity. This international treaty is designed to establish rights to original genetic materials and promote commercial incentives that encourage nations to identify, conserve and thoughtfully manage those species and ecosystems within their national boundaries. So far, 175 countries have ratified the Convention on Biological Diversity.<sup>2</sup> Despite the importance of this treaty to global conservation, the United States is not one of them. Clearly, it should be.

Human population and its dynamics go unmentioned in the Convention on Biological Diversity, despite language calling for minimizing adverse impacts on biodiversity. Clearly, biodiversity will fare worse if population size and density follow high-growth scenarios rather than low-growth ones. Just as clearly, a range of social policies and programs will ultimately influence the future of biodiversity. Among them are population programs consistent with the Programme of Action agreed to by 179 countries (including the United States) at the 1994 International Conference on Population and Development (ICPD) in Cairo.

The ICPD Programme of Action affirmed the principle that population policy must be based in social investments aimed at human development and in the rights of women and men to determine for themselves the timing of childbirth and the size of their families. Among the most important of these social investments is the provision of family planning services for all who seek to use them, and that





includes the vast majority of the world's approximately 1.5 billion women of reproductive age. A recent study concluded that nearly 40 percent of all pregnancies worldwide are either mistimed or not intended at all, suggesting that the world's nations still fall far short of offering sufficient services, information and personal freedoms for couples to successfully manage their own reproductive lives.<sup>3</sup> Governments should support the policies agreed to at the ICPD in 1994. These policies would facilitate an early peak in the size of human population while immediately improving the well-being of women and their families.

Efforts to address human population growth and biodiversity loss go hand in hand. And the survival of anything like the present panoply of plant and animal species will depend on investments made today, both directly in biodiversity conservation and in human development efforts that end up, as a side benefit to their main purposes, slowing the growth of human population.

- **The public and private sectors should cooperate to diminish the environmental impacts of the expansion of agriculture and housing. Significant investments in research and improved standards in engineering and zoning for these sectors could help minimize the conflict between efforts to conserve biodiversity and efforts to alleviate poverty and accommodate the population growth that occurs during the next several decades.**

On the following point few experts would disagree: for worldwide biological conservation efforts to be successful, agriculture and human settlement (housing and basic services, such as power, water and waste disposal) will have to become several times more land- and water-efficient and far less polluting than they are today. In poor agricultural economies, development that includes massive job creation in urban areas, land equity in rural areas, and serious protection and management of forests will likely be needed to halt tropical deforestation.

Put simply, society should invest in conserving biodiversity just as it invests in harvesting it. If humanity would apply to conservation a mere fraction of the financial resources and technological genius that it has applied to increasing grain and fish yields and modifying the landscape, biodiversity's future might look considerably less bleak than it does today. Eliminating subsidies that induce unsustainable natural resource use would serve the same purpose.

Scientists can do more to help policy-makers understand the implications of population growth on biodiversity. Much more research is needed, particularly related to how changes in population density, lifestyles and land-use practices influence long-term processes associated with biodiversity decline. When long-term data is unavailable, studies that sample along a path of increasing human density, from near-pristine ecosystems to urban ecosystems, can be a revealing analytic tool. Besides documenting the influence of

demographic change on ecosystems and wildlife populations, more research may help scientists learn how to retain critical aspects of biodiversity in certain human-dominated ecosystems.

- **Where organizations work in remote rural areas to promote biodiversity conservation, conservationists should consider cooperating with qualified providers of reproductive health services. They can do so without jeopardizing their mission in conservation by working as part of broad-based efforts to promote community development, address basic human needs, and improve the management of natural resources that sustain human and non-human life.**

As women have increasingly stepped forward to ask for access to family planning services, some conservation and community-development organizations working in the field have begun responding by entering into partnerships with reproductive health service organizations. These partnerships respond to explicit requests for services emanating from communities themselves. The most direct benefit is that such communities are better able as a result to manage their natural resources and thus their stewardship of biological assets that surround them.

An added benefit of including family planning services in such integrated or linked-service efforts is that population growth is likely to slow as a result of later childbirths and smaller families. At least 48 community-based projects or

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At least 48 community-based projects or groups of projects worldwide now link conservation and natural-resource management efforts with the provision of reproductive health services to those who request them.



groups of projects worldwide now link conservation and natural-resource management efforts with the provision of reproductive health services to those who request them. In some cases such projects are able to supply remote populations with contraceptive options that were otherwise unavailable. The single most important component in successful community-based projects appears to be the active engagement of women. But it also requires that conservationists and others helping to sponsor such linked-service projects be adaptable and willing to learn about human needs outside their area of expertise.<sup>4</sup>

- **In research publications and other communications, scientists and educators should use the range of future population possibilities—the high and low scenarios projected by the United Nations—rather than the medium scenario alone. There are immeasurable possibilities for unexpected demographic changes, even in the regions where up to now there has been little improvement in women’s status and little decline in fertility rates.**

Conservationists can learn more about human population and fertility dynamics and promote that understanding in their publications. When using the United Nations population projections, scientists and educators should employ the range of future population possibilities—the UN high and low scenarios—rather than the medium scenario. This approach communicates the uncertainties and possibilities

that are associated with the demographic future.

Rates of population growth tend to change slowly in the short term, but aspects of society that bear upon fertility can change rapidly. Among the most important of these aspects is improved access to a range of choices in modern contraception and other reproductive health services. Similarly, delays in the age of marriage for women, increases in the time interval between births, improvements in girls’ enrollment and educational achievement, and increased female employment and better job mobility all could result in slower population growth and lower peaks in future population size.

- **Consumers should learn about and consider the role of their purchases, their pets, and their daily activities in putting biodiversity at risk. They should inform themselves about and consider how their lifestyles and their political choices influence native species and ecosystems.**

Personal lifestyles and everyday choices affect biological diversity in an increasingly populous world. Both are important forms of expression in democratic societies and in market economies.

These choices are most effective when they transmit strong *signals*—messages about preferences, acceptable standards and willingness to pay—to those controlling the distribution of goods and services. For example, paying a little more for products like habitat-friendly shade-grown coffee, paper produced through

sustainable forestry, or tuna caught using methods that spare porpoises, obliges the private sector to recognize biological diversity’s value on its own terms. Supporting conservation organizations, contributing to their purchase of critical habitat, their activism on endangered species and on reducing greenhouse gas emissions, helps policymakers and business leaders take measure of the public’s concern about biodiversity loss. And the way we vote, our presence at public meetings and interchange with the media, can eventually transform land use and water policies into those that maintain natural ecosystems and native species over the long term. Consumers today remain largely unaware of their own potential to help sustain biodiversity.

- **Couples and individuals should consider the impact of their reproductive decision-making on the well-being of their communities and of the world as a whole.**

Only couples and individuals can decide when and how often to have children. And in general, the social and economic realities of personal and family life tend to play the strongest roles in most couples’ reproductive decision-making. But collectively such decisions will affect the future of biodiversity and the quality of life of all future human beings. Governments, for their part, should encourage environmental and population education, and promote the diffusion of information that leads to responsible reproductive decision-making.



## No Biosphere Like Home

When human population growth induces scarcity, according to one line of economic reasoning, the price of the scarce resource rises. That, it can be argued, spurs innovation and invention, which stimulates production and provides reasonably-priced substitutes. Thus, scarcity-induced problems are eliminated, making resources once again affordable. This reasoning may well apply to certain non-renewable resources like metals or energy sources. It is foolhardy thinking, however, when assumed to predict the response of non-human life and complex ecosystem relationships. If proof is needed, there is Biosphere 2.

A fully enclosed, live-in ecosystem located in Arizona, Biosphere 2 occupies 1.3 hectares and has its own atmosphere, ponds, plants and animal life. The project was engineered to provide data that could someday make it possible to operate the life support systems needed for long-term space travel. A further point was to help scientists learn more about life-sustaining processes on what was dubbed “Biosphere 1”—the living Earth—and to provide insight into ecologically sound agriculture and technology.<sup>1</sup> The enclosure cost an estimated \$200 million to design and construct.

From 1991 to 1993, eight “biospherians” lived and worked within the arti-

ficial ecosystem, demonstrating its potential, dealing with its challenges and documenting changes in its environment. From its early stages the project drew frequent coverage from the science news media. As time wore on it became apparent that even with considerable financial resources at their disposal, scientists and engineers are still a long way from replicating systems that successfully deliver the services that Earth’s ecosystems offer free of charge.

Trying to maintain Biosphere 2’s biodiversity may have been the project’s biggest challenge. Although the enclosure was over-stocked with species to see which could survive the competition, more extinctions occurred than scientists had anticipated. Of the system’s 25 species of vertebrates, 19 went extinct, as did most of its insect species. With most competitors and predators gone, ants seemed to thrive, along with cockroaches and katydid. All of the enclosure’s pollinators became extinct, leaving many of the plant species without a means to successfully reproduce. Biosphere 2’s aquatic and marine communities underwent comparable changes.<sup>2</sup>

The most immediately hazardous problem involved the ecosystem’s carbon cycle, which came close to threatening the human lives that breathed its air.

Carbon dioxide (CO<sub>2</sub>) levels shot up dramatically as microbes in Biosphere 2’s rich garden soils quickly consumed the system’s oxygen and released above-normal quantities of CO<sub>2</sub>. Less than 18 months after the biospherians sealed themselves into the enclosure, the system’s atmospheric oxygen concentration dropped by nearly one-half.

Air temperatures, however, climbed. Vines introduced to absorb CO<sub>2</sub> grew explosively, blocking light and threatening Biosphere 2’s crops and other plants. Trees stressed by high CO<sub>2</sub> concentrations dropped branches too brittle to hold their own weight. With natural processes spiraling out of control, the researchers abandoned the illusion that Biosphere 2 was truly isolated from Biosphere 1—and pumped in outside oxygen to sustain the human occupants within.

In summing up the lessons learned from the project, ecologists Joel Cohen and David Tilman concluded that “there is still no demonstrated alternative to maintaining the viability of Earth.”<sup>2</sup>

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“... there is still  
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maintaining the  
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The future could see a continuation of today's impressive decline in fertility—if citizens and the governments that represent them support and fund the policies and programs that make such change possible.



## Demographic Hope for Biodiversity

At the dawn of the 21<sup>st</sup> century, we find—and who would have predicted it?—that human population growth is among the most resolvable of all of the major global trends that now threaten biodiversity. A recent study estimated that, today, the population of the developing world is around 700 million smaller than it would have been without organized family planning programs. That figure, representing unintended pregnancies that otherwise would have contributed to population growth were it not for the availability of effective contraception, is projected to reach 3.1 billion by 2050—assuming continued investments in these programs.<sup>5</sup>

The past 30 years have seen enormous progress toward providing universal access to family planning services, as called for in the Cairo Programme of Action. There is still a long distance to go. More than 100 million married women would like to space and limit childbirth but lack access to the means to accomplish these goals.<sup>3</sup>

Fertility rates are not descending “on their own,” in apparently spontaneous response to economic change. The investment and hard work of governments—those of developing countries as well as industrialized donor nations—and non-governmental organizations have made a difference. Studies of Southeast Asian nations suggest that today’s population growth rates resulted

in large part from policies and programs supported decades earlier. Voluntary family planning programs were key. But so were other policies that increased the demand for these programs—especially policies that put more girls into classrooms, and opened employment opportunities for women.<sup>6</sup>

The future could see a continuation of today’s impressive decline in fertility—if citizens and the governments that represent them support and fund the policies and programs that make such change possible. Decisions made today will have an enormous influence on the future size of world population. No prognosticator can predict how much of a difference a stabilized or even temporarily declining world population will make to the survival of the uncountable trillions of beings that accompany us on this living planet. But the difference could hardly be small. And we humans ourselves—simultaneously the threat to, and the caretakers of, earthly life—will be among the greatest beneficiaries.

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# Appendices

## Appendix 1: Data Sources and Methodology

### a) Demographic estimates and projections

For past estimates and future population projections, this publication uses data from the United Nations 1998 medium-range projections, which estimate past populations at 5-year intervals from 1950 to 1995, and project from 2000 to 2050.<sup>1</sup> The UN long-range projections, which project population for India, China, and the world's regions are used for scenarios out to 2150.<sup>2</sup> Sub-national estimates of population density, used in the global biodiversity hotspot analysis, were obtained using geographic information systems data. Methods employed in this analysis are outlined in section h of this appendix.

### b) Threatened species (conservation status)

Population Action International and most environmental organizations recognize the *IUCN Red List* as the principal authority on the *conservation status* of known species. Featured on the *Red List* are species that biologists, working in conjunction with the IUCN–World Conservation Union, have determined to be *threatened* with extinction. These are species believed to be nearing extinction or declining rapidly. There are three degrees of threatened status in IUCN's system (listed from least to most threatened): *vulnerable* to extinc-

tion, *endangered*, and *critically endangered*. In the early 1990s, IUCN's Species Survival Commission standardized a series of methods that scientists now use to determine the category into which a species under study is appropriately fit.<sup>3</sup>

Readers in the United States should be careful not to confuse IUCN's conservation status categories with those established in the Endangered Species Act and used by the U.S. Fish and Wildlife Service. In the United States, unlike in the IUCN system, threatened and endangered remain separate categories.

IUCN (which retains the acronym from its former name, the International Union for the Conservation of Nature) is an international body headquartered in Gland, Switzerland, that brings together over 900 governmental and non-governmental organizations. These embrace more than 12,000 scientists from 139 countries concerned with environmental conservation, management, regulation and protection. This report uses IUCN as its principal source for conservation status, scientific names, and for the spelling of common names of species.

### c) The species-area relationship

Over time, the number of original species tends to decrease with the loss of habitat area. This

trend is described by a curve generated by the *modified exponential function*

$$S = cA^z$$

where **S** is the number of original species remaining, **c** is a constant and **z** controls the shape of the curve. The z-value ranges between 0.15 and 0.35 over most of the research that has been conducted on this topic. There is a growing consensus that 0.25 is a good approximation for the value of the exponent **z** in most cases.<sup>4</sup>

### d) Estimating body weights of human and livestock populations

To estimate the total mass of humans, we began with age-specific expected body weights described by the National Research Council,<sup>5</sup> averaged for males and females, and fit a polynomial curve to this curve ( $r^2 = 0.99$ ). We reduced the age-related weights by 20 percent to account for lower average weights in developing countries. Then, average body weight in kilograms (BW) for each age group is:

$$BW = 0.8(0.0006[AGE]^3 - 0.0949[AGE]^2 + 4.6361[AGE] + 1.9325),$$

where AGE is the median age for each 5-year age category. For age category 80+ , AGE was set to 80. To estimate global human body weight we estimated the average for each 5-year category,





multiplied by the number in that age category, and then summed for all age categories in the world population.

For domestic animal species, we used adult weights from various sources, and used the median weight from the range listed.<sup>6</sup> We assumed that in species living more than two years, one-year-olds attain one-third of adult weight, two-year-olds two-thirds of adult weight, and from three years onward they attained adult body weight. For species living two years, we assumed two-thirds weight for one-year-olds, and full weight thereafter.

### Ⓔ Estimating population densities of mammals

Robert Henry Peters used numerous studies of mammals to derive statistical models that relate adult body weight to the observed abundance of these animals in the wild. Peters' work predicts that the density of mammalian species' within their home ranges, if living in an undisturbed condition, should vary according to the following relationships:<sup>7</sup>

$$\text{Population Density of Carnivores} = 15 \times [\text{Average Body Weight}]^{-1.16}$$

$$\text{Population Density of Herbivores} = 103 \times [\text{Average Body Weight}]^{-0.93}$$

### Ⓕ Species in human-dominated ecosystems

To produce rough estimates of the number of species that presently show signs of co-existing with humans in human-dominated ecosystems, we surveyed several guides to well-studied

plants and animals. A species was counted as being likely not to incur elevated risks of extinction due to the continued proliferation of human-dominated ecosystems if the species was identified with a human-made structure, a land-use type, or a domestic species. Key words included: city, suburb, roadside, mine, waste place, garbage dump, building, farm, livestock, crop or garden. Because large predators are effectively eradicated to reduce losses to livestock, the method likely overestimates the number of large predators that will survive in human-dominated ecosystems.

For example, in three guides to North American birds, descriptions of about 25 to 35 species (roughly 5 percent of the 650 birds) mention cities, lawns, and buildings or farm fields, crops and livestock. Using the same method, about 15 percent of listed European birds fall in this category. For flowering plants, around 10 percent mention human-dominated ecosystems. Some 70 percent of these are weedy exotic species. In guides of North American plants (around 380 species) some 15 percent show similar references. For mammals, however, more than half of these references are for bats, most of which roost in buildings and are being exterminated because of this habit. Also in that number are predators that occasionally kill livestock, some of which have been actively hunted with some success. Omitting these groups provides a more realistic estimate of around 5 percent.<sup>8</sup>

### Ⓖ Geographic information systems (GIS) data layers

*Spatial population density* data are obtained from the *Gridded Population of the World, 1995*, published by the National Center for Global Geographic Analysis (NCGIA), University of California, Santa Barbara, USA. These data can be downloaded from Columbia University's Center for International Earth Science Information Network (CIESIN) Website, at the following address: <http://www.ciesin.org/datasets/gpw/globldem.doc.html>.<sup>9</sup> The year 1995 is the basis for all population density mapping in this publication.

*Hotspots and major tropical wilderness boundaries* were created and digitized by Conservation International (CI). CI continues to identify hotspots from among the most biodiverse regions of the world, and to modify boundaries of the hotspots that it presently recognizes.

*Current forest cover* and *original forest cover*, used in the Madagascar case study, were mapped from various country sources by the World Conservation Monitoring Centre.<sup>10</sup>

### Ⓗ Biodiversity hotspots and human population analysis

Geographical information systems mapping and analysis was conducted using ArcView software, a product of Earth System Resources, Inc. (ESRI). Population densities of hotspots and major tropical wilderness areas were determined using *Spatial Analyst*, an application developed for ArcView workstations by ESRI.

*Hotspot land area* was calculated using Spatial Analyst and CI's hotspot layer. Spatial Analyst provided the percentage of each country occupied by the hotspot. Data from the UN Food and Agricultural Organization (in *World Resources*, World Resources Institute, 1997) were used as the source for most country areas. Total land areas for Anguilla, Federated States of Micronesia, Marshall Islands, Mayotte, Monaco, Montenegro, Northern Mariana Islands, Palau, Pitcairn Islands, and the West Bank were taken from data provided by *The CIA World Factbook, 1997*.

*Average hotspot population density* was calculated using Spatial Analyst applied to NCGIA's Gridded Population of the World, 1995. As a preliminary step to calculating average hotspot growth rates, population density was calculated for the total hotspot, the portion of each country within the hotspot. In cases where sub-national population growth rate data were available, population density was determined for sub-national units (provinces, states).

*Hotspot population growth rates* were estimated by partitioning hotspots into their respective countries and provinces within countries, and calculating a population-weighted average of growth rates for all of the portions. Where hotspots covered only portions of countries, sub-national data (provincial or state data) were used when available to weight the portions within those sub-national units. In this publication sub-national population growth rates were applied to parts of Argentina, Australia, Brazil, Bolivia, Colombia,



China, Ecuador, France, India, Indonesia, Mexico, Panama, Peru, South Africa, Spain, Turkey, the United States, and Venezuela in order to determine average population growth rates for biodiversity hotspots or major tropical wilderness areas.

### **i** Human population between the tropics

There were several methodological steps used in estimating population within the *tropics*, the land situated between the Tropics of Cancer and Capricorn. First, an estimate was made of the 1995 tropical population. Where countries were wholly within the tropics, national populations were obtained from the UN Population Division, and summed. To estimate contributions to this sum from countries straddling the tropics, sub-national tropical populations were estimated using the 1995 World Population Density GIS layer.

A somewhat different method was used to estimate for past years (1950 to 1990, at 5 year intervals). For countries wholly within the tropics, again the UN Population Division's estimates were used and summed. Because GIS sub-national population density data does not exist prior to 1995, it was assumed that the percentage of the population in those sub-national areas within each country that straddles a tropic (such as Australia, China, India, Mexico and others) was identical to the 1995 percentage. This source of inaccuracy makes this a rough estimate, but one that should be accurate to within a hundred million people.

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## Appendix 2: Figures and Their Sources

### Figure 1: Possibilities in the Demographic Future

Source: data from UN Population Division, *World Population Projections to 2150*, (New York: United Nations, 1998).

### Figure 2: Population and Status of the Great Apes

Sources: see reference following text

### Figure 3: Counting Earth's Species

Source: adapted from N.E. Stork, "Measuring Global Biodiversity and Its Decline," in *Biodiversity II: Understanding and Protecting Our Biological Resources*, ed. M.L. Reaka-Kudla, D.E. Wilson, and E.O. Wilson (Washington, DC: Joseph Henry Press, 1997), 41-68.

### Figure 4: Species Numbers and Habitat Area

Source: adapted from A. Dobson, *Conservation and Biodiversity* (New York: Scientific American Library, 1996), p. 66.

### Figure 5: Centers of Crop and Livestock Origin

Source: N.I. Vavilov, "The Origin, Variation, Immunity and Breeding of Cultivated Plants," transl. K.S. Chester, *Chronica Botanica*, 13, 1-6 (1949-50); N.W. Simmonds, *Principles of Crop Improvement* (New York: Longman, 1979); N. Myers, *The Wild Supermarket: the Importance of Biological Diversity to Food Security* (Gland: World-Wide Fund for Nature, 1990).

### Figure 6: Human Colonization and Associated Species Loss

Source: adapted from J. Diamond, *The Third Chimpanzee: The Evolution and Future of the Human Animal* (New York: Harper Collins, 1992).

### Figure 7: Islands of Nature: Population Growth and the Isolation of Protected Areas

Source: R.S. Reid, L. Kruska, U. Deichmann, P.K. Thornton, and S.G.A. Leak, "Human Population Growth and the Extinction of the Tsetse Fly," (unpublished manuscript, 1999).

### Figure 8: Domesticated Demographics: the Growth of Domesticated Animals

Source: data from FAO STAT, CD-ROM (Rome: Food and Agriculture Organization, 1998).

### Figure 9: Newly Emerging Diseases

Source: D. Pimentel and others, "Ecology of Increasing Disease," *Bioscience* 48, 10 (1998): 817-826.

### Figure 10: Population in the Tropics

Source: estimates by Population Action International; data from GIS analysis of *World Population Density, 1995*, GIS Data Layer (CIESIN/UNEP, New York/Sioux Falls, SD, 1997).

### Figure 11: Expected Population Densities of Mammals

Source: adapted from equations published in R.M. Peters, *The Ecological Implications of Body Size* (New York: Cambridge Univ. Press, 1983).

### Figure 12: Human Fertility Change in Highly Biodiverse Countries

Source: UN Population Division, *World Population Prospects: The 1998 Revision* (New York: United Nations, 1998); list of biodiversity countries from R.A. Mittermeier, P. Robles Gil, and C. Goettsch Mittermeier, *Megadiversity: Earth's Biologically Wealthiest Nations* (Mexico, C.F.: Cemex, 1997).

### Figure 13: World Population: Past and Projected

Source: UN Population Division, *World Population Projections to 2150*, (New York: United Nations, 1998).

### Figure 14: Population in the Industrialized Countries

Source: UN Population Division, *World Population Prospects: The 1998 Revision* (New York: United Nations, 1998).

### Figure 15: Understanding Momentum

Source: UN Population Division, *World Population Prospects: The 1998 Revision* (New York: United Nations, 1998).

### Figure 16: Trends in Extinction

Source: data from World Conservation Monitoring Centre, *Global Biodiversity: Status of the Earth's Living Resources* (London: Chapman & Hall, 1992).

### Figure 17: Threats to Species

Source: (A.) Population Action International; (B.) D.S. Wilcove and others, "Quantifying Threats to Imperiled Species in the United States," *Bioscience* 48, 8 (1998): 607-615.

### Figure 18: Limited Alternatives: Population Growth and Responses in Agriculture and Housing

Source: Population Action International

### Figure 19: More People, More Non-Native Species

Source: adapted from E.H. Rapoport, "The Process of Plant Colonization in Small Settlements and Large Cities," in *Humans as Components of Ecosystems*, ed. M.J. McDonnell and S.T. A. Pickett (New York: Springer-Verlag, 1993), 190-207.

### Figure 20: Nitrogen Pollution and Population Density

Source: J.J. Cole and others, "Nitrogen Loading of Rivers as a Human-Driven Process," in *Humans as Components of Ecosystems*, ed. M.J. McDonnell and S.T.A. Pickett (New York: Springer-Verlag, 1993), 141-162.

### Figure 21: People and Property Values

Source: data from U.S. Census Bureau, "Taxable Property Values: Assessed Valuations for Local General Property Taxation," GC92, Vol. 2 (Washington, DC: U.S. Dept. of Commerce, 1996).

### Figure 22: Population Density in the Biodiversity Hotspots

Source: Population Action International, data from GIS analysis of *World Population Density, 1995*, GIS Data Layer (NCGIA, University of California, Santa Barbara, 1994).

### Figure 23: Population Growth in the Biodiversity Hotspots

Source: Population Action International, synthesized from various sources, see Appendix 1h.





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