BIODIVERSITY AND GLOBALIZATION

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Ours is very much a living planet populated by myriad life forms—as Darwin termed it: "endless forms, all beautiful"—and since no organism can exist without affecting its environment, globalization has significant implications for biological diversity. The converse is equally true.

Biological diversity is a relatively recent term meant to encompass the variety of life on Earth at all levels of organization from the genetic to the diversity of biomes (major biological formations, e.g., tropical rain forest). It is the subject of one of the major environment treaties that came out of the Earth Summit in Rio de Janeiro in 1992, but has been the subject of research and environmental management far longer than that.

THE LINNAEAN DREAM: EXPLORING LIFE ON EARTH

An important area of research that can be aided by globalization and modern information technology is the exploration of life on Earth. Begun formally in the eighteenth century by Linnaeus and his 17 disciples (who went out into the world to collect and describe plants and animals) using the Latin binomial system of species names, this is still an active field. Indeed the estimates vary but all concur that only a small fraction of species—ten per cent?—have actually been described by science. The reality is we cannot even say within an order of magnitude with how many species we share the planet.

The classification of organisms has always been a global exercise even in its earliest days. It requires travel and collection of specimens in distant places. It is based on comparison to specimens of known plant and animal species residing in reference collections in different places. No single country has enough taxonomic experts to identify specimens from all groups of organisms.

There is a grand opportunity, yet to be sufficiently recognized or addressed, to complete that exploration. A Frontier of Knowledge indeed. In recent decades we have learned of communities that depend on the primary energy of the Earth (around deep sea vents), of a vast array of microorganisms in seawater, organisms living two miles below the surface of the Earth, and more. The Tree of Life of my school days—with two mighty trunks, one plants and the other animals (with other forms of life at the base)—has been transformed. Today it is rather like a low spreading bush; plants and animals are but two terminal twigs. All the rest consists of microorganisms of various sorts with strange appetites and metabolisms many dating from the earliest days of life on Earth.

All of those discoveries have been made without the great concerted effort this deserves. This is in so many ways more important than space exploration. This is after all the grand living library not only for the life sciences of how biological systems work, but also with immeasurable benefit for humanity. Single species can morph from the esoteric to the valuable. For example, a species of slime mold from the banks of the Zambesi River has compounds useful in the treatment of tumors resistant to taxol (which itself derives from yew tree genus Taxus).

The Encyclopedia of Life based at the National Museum of Natural History at the Smithsonian Institution is poised to capture information electronically as it is discovered—with a "page" for each species covering the essence of its biology. All that is needed for the *Encyclopedia* to fulfill that vision in a reasonable time is recognition of its fundamental importance, and a concerted effort to rein in runaway extinction rates.

BIODIVERSITY AS AN ENVIRONMENTAL INDICATOR

In the late 1940s a young freshwater ecologist, Ruth Patrick, began studying the number and kinds of organisms in streams and rivers in the Mid-Atlantic States. With her colleagues she demonstrated that the number and kinds of species in these ecosystems, in particular of diatoms (algae with distinctive silica boxes), was the consequence not only of the natural physics, chemistry, and biology of the watercourses but also of the stresses from human activity in the watershed.

Ruth Patrick demonstrated that biological diversity provides the best measure of human impact on ecosystems. Sometimes called the "Patrick Principle," it applies not just to freshwater but to all ecosystems including terrestrial and marine. It lies at the base of all environmental management and science.

Environmental problems are by definition ones that affect living systems. What this means is that in addition to biological diversity loss being considered as a problem in itself, all environmental problems affect biological diversity. As a consequence biological diversity integrates all environmental problems—from chemical pollution to climate change—which is what makes it so challenging to address.

THE CLASSIFICATION OF ORGANISMS HAS ALWAYS BEEN A GLOBAL EXERCISE EVEN IN ITS EARLIEST DAYS. IT REQUIRES TRAVEL AND COLLECTION OF SPECIMENS IN DISTANT PLACES. IT IS BASED ON COMPARISON TO SPECIMENS OF KNOWN PLANT AND ANIMAL SPECIES RESIDING IN REFERENCE COLLECTIONS IN DIFFERENT PLACES.

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INVASIVE SPECIES

In a sense first formally recognized as an environmental problem with Charles Elton's 1958 book *The Ecology of Invasions by Animals and Plants*, alien invasive species are particularly exacerbated by globalization. Increased trade and travel make it easier for plants, animals, and diseases to arrive in places where they are not native and are often less constrained by other organisms than are native species. Invasive species are today regarded as one of the major causes of extinction and as a major environmental problem.

The native earthworm fauna of the northeast United States has been pushed out by invasive worm species. The Philippine Brown Tree Snake has eliminated much of the native avifauna of Guam. Island species have been particularly vulnerable to invasive species including domestic animals—the Stephen Island Wren was exterminated by the lighthouse keeper's cat—and also deliberate introductions like mongooses or incidental ones like rats.

The Black Sea anchovy fishery has been undercut entirely by an introduced comb jellyfish (introduced with ballast water from the Atlantic waters of the western hemisphere), which basically short-circuited the food chain of the quarter-of-a-billion-dollar annual fishery. Ballast water is a frequent way in which aquatic organisms are transported around the world to locations where they can cause enormous problems, e.g., zebra mussels first in the Great Lakes and then later through much of North America.

Insect pests travel around the world and wreak havoc in new locations. The corn borer made it from the United States to Europe, probably as an unnoticed airfreight passenger. Tree pests like the Asian long-horned beetle and emerald ash borer are creating huge problems with native tree species in the United States, where they arrived as unintended passengers in the wood of shipping crates. Sometimes the introduction is deliberate, e.g. rabbits in Australia, or incidental to deliberate decisions as in the Burmese pythons liberated by pet owners to the point of being a major pest in the Everglades.

Disease organisms are part of the alien species picture also. Dutch elm disease and the American chestnut blight have made dramatic changes in eastern forests of the United States. The American elm was the desired shade tree in American cities; Hillhouse Avenue in New Haven Connecticut—itself termed the Elm City—was said by Charles Dickens to be the most beautiful street in America. The American chestnut was close to a keystone species in eastern US forests: not only with trees of enormous girth but its chestnuts a major food source for many species. West Nile virus took but five years to spread coast to coast once it appeared in the United States, aided by the spread of an invasive mosquito species, the Asian tiger mosquito (Aedes albopictus).

OVERHARVEST OF VALUED SPECIES

Historically the first impact of people on biological diversity has been with overharvest of a species valued as a resource. It clearly was happening before recorded history. As people spread through the islands of the South Pacific they had a major impact on the native avifauna; this was only recognized when ornithologists began studying middens and semi-fossil remains. The almost entire elimination of the great bison herds of North America is a classic example in historic time. The history of whaling is essentially fishing down one species and then moving on to repeat the same pattern with another, and yet another. The whaling history is an early form of globalization with stocks being fished out of one distant part of the world after another to feed markets in North America and Europe primarily. Whale oil was considered so valuable that ships would go to sea for years at a time pursing whales in waters many thousands of miles distant from home port.

The state of global fisheries is a dramatic example in which one fish stock after another has been fished down to low productivity with 70% of all ocean fisheries now depleted and large fishing fleets converging on the remaining ones at a rapid pace. Fortunately there is growing awareness of the importance of replacing that predatory approach with one which husbands and manages stocks in a sustainable fashion.

Overharvest continues to be a major problem, whether it be for global fish markets, including high value ones such as the Japanese one for blue fin tuna, for oriental medicine and food markets, for timber (e.g., mahogany), etc.

HABITAT DESTRUCTION AND MODIFICATION

Habitat destruction has long been considered as the single greatest impact on biological diversity. Half of all tropical forests are gone and the annual toll of tropical deforestation continues at a high rate. Much of Europe was deforested to create the landscape we know today. Most of the eastern United States was deforested by the end of nineteenth century but a lot is in the process of recovery as better farmland was encountered farther to the west and as the economy transitioned from a primarily agrarian state. Most of the great prairie grasslands of the United States have been converted to industrialized agriculture. Globally 38% of the land (not including Antarctica) has been converted to agriculture. About half of the world's wetlands have been drained or converted to other purposes since 1900.

About 40 years ago attention began to be paid to an unremarked handmaiden of habitat destruction, namely habitat fragmentation. Fragmentation is a close to ubiquitous aspect of habitat conversion in any part of the world with fragments of forest (or other habitat) being left behind sometimes deliberately for conservation purposes but most often just incidentally.

What in many ways drew attention to it was the theory of island biogeography. Initially a paper and then a book by Robert MacArthur and Edward O. Wilson, the theory endeavored to understand the differing number of species on real islands. The essence of the theory was the number on any given island was set by the balance between the immigration rate and the extinction rate. What was particular intriguing was the rates were set in part by the size of an island and in part by the distance from a colonizing source. It was elegant in its simplicity.

Two aspects were of particular interest from a conservation perspective. Large islands held more species than small islands. And islands that had always been islands ("oceanic islands") generally held fewer species than similar size islands that had once been continuous with a mainland. An example would be Trinidad, which had been part of South America when sea levels were lower at the time of the last glaciation. Such islands were termed "continental islands."

The conclusion was drawn that a continental island, like Trinidad, had held as many species as an equivalent area of mainland South America, but had been losing species since isolation from sea level rise. The interpretation was that this loss would continue until it came to a dynamic equilibrium around the same number of species as an equivalent oceanic island.

It was not a great jump to think about habitat fragments (such as forest fragments) as the equivalent of islands in a sea of agriculture or other habitat. Obviously they are not isolated by water but certainly sit in a very different habitat so the island analogy wasn't too big a stretch. The questions arose quickly: do fragments lose species after isolation? Do bigger fragments hold more species than smaller? Does the species loss follow an order or pattern?

All this led to an enormous controversy in the scientific literature with one group asserting that it implied conservation areas had to be large, and another asserting that the theory of island biogeography was neutral. In a sense the latter were correct in that the theory treated all species as equal. But all species clearly are not and one could infer from species with large home ranges or low densities that large conservation areas would be important.

Basically the only "data available" were from Barro Colorado Island (BCI), a former Panamanian hilltop rendered an island by the rising waters of Lake Gatun (created for the Panama Canal). Originally known as the Canal Zone Biological Area it later came under the administration of the Smithsonian Institution. Regular bird studies over decades showed the loss of species. Other available data were some forest fragments in southern Brazil with the larger showing more species than the small fragment. It was not clear whether they were comparable or what had been the original state.

So the debate known formally as the Single Large or Several Small (SLOSS) raged mostly for lack of direct data (other than BCI). Nobody had actually seen species loss taking place so it was hard to derive suggestions for conservation design and management.

I continued to worry about the subject because it was so central to sound conservation practice. The Monday before Christmas 1976 I was in a meeting discussing it at the National Science Foundation with John L. Brooks, Frances C. James, and Daniel Simberloff, when I had the wild idea that the Brazilian law that then required 50% of any project in the Amazon remain in forest might be used to conduct a giant experiment in landscape ecology.

The idea would be to create a series of fragments of different size in the course of development for cattle pasture, where we could study them before isolation as fragments and also compare them with similar sized plots in intact forest. Such ideas rarely turn into reality but in this case it did with the input of many, including Brazilian colleagues and institutions. And so was born what is now known as the Biological Dynamics of Forest Fragments Project for which William Laurance and I were honored by the 2008 Frontiers of Knowledge Prize in Ecology and Conservation Biology.

Thirty years of research has yielded a lot. The size question is answered in favor of large: 100 hectare fragments lose half their forest interior bird species in less than 15 years, so for the moment a minimum size of 100,000 ha seems in order for Amazon forest conservation units. The changes turn out to be far more complex than envisioned: for example, isolated fragments tend to lose biomass because larger trees become vulnerable to windthrow when no longer protected by surrounding forest. The influence of the surrounding matrix (e.g., pasture, young secondary growth, or whatever) has a real influence on the fragments themselves.

The conclusion is that even though fragments have their own value and are certainly better from a biodiversity point of view than no forest, they cannot be considered as equal to forest in their contribution to biodiversity conservation.

CHEMICAL POLLUTION

Biological systems are potentially affected by manmade chemicals with which there has been no evolutionary experience, and all are exacerbated by globalization and markets that move things and affect places far distant. Chlorinated hydrocarbons such as DDT had major effects on species like Peregrine Falcons, Bald Eagles, and Ospreys at the end of long food chains, primarily through affecting calcium metabolism and hence the ability to lay healthy hatchable eggs. Those and other compounds show up in places far distant from original use, carried by air and water currents and working their way through food chains, and appearing in Antarctic penguins and in the Arctic in marine mammals and Inuit people.

There are currently about 70,000 different human-made chemicals with another 1,500 being created every year. The persistent organic pollutants are the subject of a special treaty but only 12 are listed, far fewer than should be. The chlorinated fluorocarbons, which affect the ozone layer, are managed separately under the Montreal Protocol. In addition there are heavy metal problems such as mercury, probably the subject of a new international agreement. There is growing concern about a class of chemicals that act as endocrine disrupters. What is clear is the effect of most of this vast array of artificial molecules is unknown, let alone the potential for negative synergistic interactions.

DISTORTION OF GLOBAL CYCLES

On top of this is human activity at a scale that is distorting major global cycles. Problems with sulfur on a regional basis, primarily through the combustion of sulfur laden coal and the creation of acid rain are in a sense but an overture—although one repeated in most continents of the world. At the Hubbard Brook experimental forest in New England it appears that the acid rain has leached the soil sufficiently that forest growth has been seriously affected. Very frequently the movement of pollutants in air and water crosses boundaries in another form of globalization.

One of the earliest problems to be noted with a global cycle is that of nitrogen. Today there is about twice as much biologically active nitrogen available as occurs naturally. The most prominent effect is the proliferation of dead zones in coastal waters, where the chemical imbalance caused by continental runoff essentially leads to oxygen depleted waters in which few organisms can grow. The first major dead zone was in the Gulf of Mexico primarily from runoff from the Mississippi watershed. There are now more than 100 around the world and the number is growing.

The ultimate form of globalization and environmental challenge is the distortion of the carbon cycle, namely climate change.

CLIMATE CHANGE

In 1896, Swedish scientist Svante Arrhenius asked the important question: why is the Earth a habitable temperature for humans and other forms of life? His answer was greenhouse gases and the greenhouse effect. He even made a projection of what doubling the natural level of greenhouse gases would do to the Earth's temperature.

What Arrhenius could not have been aware of is that the average temperature of the planet over the last 100,000 years shows a lot of abrupt natural climate change. For the last 10,000 years it also shows a period of remarkable stability. That implies two important things. Firstly, the entire human enterprise for 10,000 years has operated on the assumption of a stable climate—even when we find reason to talk about its much finer variability, namely the weather. Secondly, all ecosystems have been adjusting to a stable climate.

That is changing through the addition of greenhouse gases to the atmosphere from two sources: the burning of fossil fuels (coal, oil, and gas), which is essentially the consequence of ancient plant productivity, plus current deforestation/biomass loss, which releases the energy trapped from the Sun by modern photosynthesis. Life is built on molecules of carbon and when combusted releases large amounts of carbon dioxide.

Carbon dioxide concentrations in the atmosphere have climbed to just shy of 390 parts per million (ppm) having started at pre-industrial levels of 280 ppm. The global climate system has begun to respond. The Earth is currently about 0.8 degrees warmer than in pre-industrial times and an additional 0.5 degrees is essentially in the works, which would bring the average temperature rise to 1.25 to 1.3 degrees.

The physical environment is changing primarily between the solid and liquid phases of water. Northern hemisphere lakes are freezing later and the ice breaking up earlier every year. Glaciers are in retreat in most parts of the world, including those in the Andes that are the water supply for cities like La Paz, and in the Himalayas where they feed the major rivers of China and India. Most tropical glaciers (on top of high peaks like Kilimanjaro) are retreating at a rate such that they will all be gone by 2015.

The most extreme of these kinds of change involve the Arctic Ocean sea-ice. The first summer during which an ice-free Arctic Ocean is projected has been changed from 2100, to 2050, to 2015, and maybe even sooner. In addition Greenland glaciers are melting faster than projected adding glacier melt to the sea-level rise occurring simply because of the expansion of water at warmer temperatures.

In addition there is a statistically significant increase in wildfires in the American West, and perhaps elsewhere, as a result of longer dryer summers and earlier snow melt. There is also the distinct possibility of increased frequency of more intense tropical cyclones as well as severe weather events in general.

Not surprisingly living nature is showing lots of change as well. Many plant species are flowering earlier every year. Animal species are also changing their timing with some birds migrating, nesting and laying eggs earlier. In addition, species are beginning to change where they occur, moving both poleward (i.e., northward in the northern hemisphere) and upward in altitude. The American Arbor Day Foundation found it necessary to publish a new hardiness zone map, which guides tree lovers as to which species they can expect success with where they happen to live. All of these changes taking together are statistically robust. There can be no question: nature is on the move almost anywhere anybody has looked in the world.

These changes are occurring in aquatic systems as well, with changes in plankton and fish distribution in the oceans. The highly productive sea-grass communities of the great Chesapeake Bay estuary are moving steadily northward because sea grass has a strict upper temperature under which it thrives.

Changes are occurring in the tropics as well. The legendary cloud forest of Monteverde in Costa Rica is experiencing increasingly frequent dry days because clouds are forming at a higher altitude. This has serious consequences for a forest type that depends on condensation from clouds for almost all its moisture. It is believed the first species recorded as driven to extinction by climate change is the Golden Toad of Monteverde. Climate change is implicated as one of the factors involved in the spreading amphibian extinction crisis.

Tropical coral reefs are suffering serious negative effects. Just a slight increase in water temperature causes the fundamental partnership at the basis of the coral reef ecosystem to fail: the coral animal ejects the alga partner creating what is termed a bleaching event. This occurred for the very first time in 1983 and will happen with ever greater frequency as warming increases.

Of course the most dramatic effects are being seen on wildlife with ice related natural history. The polar bear is the iconic species in that context, but others are also showing what is known as a decoupling event, when two species closely coordinated in their biology decouple because one relates to temperature change and the other to another factor. The Black Guillemot nests on land at the edge of the Arctic Ocean and flies to the edge of the sea ice to feed on the Arctic Cod that is found close to or immediately under the edge of the ice. As that edge retreats from the shore the journey eventually becomes too great a distance and the nest and the colony fail. Decoupling events are being recorded all over the world, not just in Arctic regions.

Looking ahead (but not very far), clearly species at high altitudes will be in trouble as a class simply because at some point there will be no farther up to go. The American Pika, which occurs in several spots at high altitude in the Rocky Mountains, is currently being studied as a candidate for the Endangered Species list as a consequence. In addition, island species will be in jeopardy because their required conditions will move beyond the limits of the island itself.

THERE ARE CURRENTLY ABOUT 70,000 DIFFERENT HUMAN-MADE CHEMICALS WITH ANOTHER 1,500 BEING CREATED EVERY YEAR.

Moreover, species on low lying islands like the Key Deer will be in jeopardy from sea level rise.

Looking ahead the picture is even more challenging. In the past, as climate changed species moved in response, but today much of the landscape has been converted to non-natural state essentially creating an obstacle course to dispersal. The probability of successful dispersal will be lowered as a consequence.

In addition, it is known that in the past as species responded to climate change they did so as individual species not as biological communities. Each species will disperse in its own direction and at its own rate. What this means is that ecosystems will disassemble and the surviving species will assemble into a novel ecosystem configuration rather hard to envision.

Ecosystem failure is already beginning to happen. Coral bleaching is a clear example in the oceans. The first example in terrestrial systems involves the massive mortality of trees in boreal forests because milder winters and longer summers confer an advantage on the native pine park beetle It is estimated 22-million acres will be affected in North America and the phenomenon appears to be occurring in Europe as well.

Beyond that is the prospect of system change. The hydrological cycle that provides half the rainfall to the Amazon forest, as well as rainfall to southwestern Brazil and northern Argentina, has been projected by the Hadley Center to degrade and cause “Amazon dieback” at 2.0 degrees increase. The greatest recorded drought in Amazon history in 2005 may in fact have been a preview of that scenario. More important when coupled with current deforestation and fire, the tipping point for Amazon dieback appears to be much, much closer.

Major system change is already occurring in the oceans. Increased CO_2 in the atmosphere has increased acidity because some of the CO_2 is converted to carbonic acid. The oceans are already 0.1 pH units more acid than in pre-industrial times; in relative terms that is 30% more acid. Acidity is a major problem for the tens of thousands of species in the oceans that build skeletons and shells from calcium carbonate, including zooplankton important to food chains. Coral reefs are especially vulnerable because their form of calcium carbonate, aragonite, begins to corrode and dissolve at lesser acidity than the other form calcite. It is hard to be sanguine about the future of coral reefs, and effects have already been seen at the base of food chains in the North Atlantic and off Alaska.

HOW GLOBALIZATION COULD WORK FOR BIOLOGICAL DIVERSITY AND SUSTAINABILITY

So biological diversity and ecosystems clearly are highly sensitive to climate change. With ecosystem failure and system change happening in the oceans and in the offing in the Amazon, it becomes clear that greenhouse gas concentrations are already higher than they should be. Two degrees temperature increase over pre-industrial levels will be disastrous for ecosystems. Rather we should be thinking about no more than 1.5 degrees and the 350 ppm limit suggested by climate scientist Jim Hansen. The problem of course is that concentrations are already close to 390 and climbing rapidly—beyond the worst-case scenario of the most recent report from the Intergovernmental Panel on Climate Change (IPCC).

This only makes the need for an energy transformation to a low carbon base yet more urgent. Of course it also means that a lot of work needs to be done to make ecosystems more resilient in the face of the climate change they will experience. This latter is a relatively new field, but certain things are obvious: the more natural connections are restored in landscape the more easily species will be able to move in response to the changing climate. Places facing dryer conditions or the loss of glacial melt will require very thoughtful resolution between demands for water for direct human uses and the water ecosystems will need.

Ecosystems can make an important contribution to reducing atmospheric concentrations of CO_2. In fact a significant amount of CO_2 has been lost to the atmosphere from ecosystems over the last three centuries—perhaps on the order of 200 billion tons. It continues to be emitted at the average rate of 1.5 billion tons a year principally from tropical deforestation and biomass burning. So one of the first priorities is to prevent further emissions from deforestation—a major topic in the upcoming climate negotiations.

Beyond that, however, there is a potential for a positive contribution of removing CO_2 from the atmosphere by restoring terrestrial ecosystems on a planetary scale. This would involve reforestation, restoration of grasslands and degraded grazing land, and management of agriculture in ways that build up carbon in soils. It is not easy to put a precise number on the potential sequestration (the technical term) from terrestrial ecosystem restoration but I believe if thoughtfully pursued it could be in the order of 150 billion tons (3 billion tons/year for 50 years). That is roughly equivalent to pulling down atmospheric levels down by 40 parts per million (the difference between current levels and the imagined limit of relative safety for ecosystems). There is almost certainly an additional amount that could be sequestered by management and restoration of marine (including coastal) ecosystems.

The challenge to producing a precise number for this potential sequestration is that of competing land uses (as well as a changing climate affecting ecosystems and their potential). Out of the single land base of the planet must come food for the present and growing human population, biofuels (as part of the substitution for fossil fuels), biological diversity conservation, and carbon sequestration. This is going to require wisdom and coordination at a level yet to be seen except in local instances.

What is abundantly clear is that the time is past when we can afford an ad hoc approach to the environment and contenting ourselves with the consequences. We must finally recognize the planet works as a biophysical system, and that it has to be consciously managed as such. Edward O. Wilson refers to this as Wilson's Law: if the planet is managed only as a physical system, the living systems will be seriously damaged. Conversely, if the planet is managed for its biological systems, the physical aspects will be taken care of adequately.

If ever there was a challenge and an opportunity for globalization, it is caring for the magnificent living planet of which we are fortunate to be a part.

ANTONIO BUENO ▸
LANDSCAPES UNDER SURVEILLANCE, 2007