# the garden of eden endangered: the ecology and biology of conservation

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The United Nations has declared 2009 the International Year of Biodiversity, in homage to the bicentennial of the birth of Charles Darwin (1809–1882), whose book, *On the Origin of the Species by Natural Selection* (1859) marks the beginning of the science of biodiversity. At last, everything seemed to make sense: the subtle differences among similar species, the colorful plumage of birds and flowers, the numerous adaptations of animals to their surroundings, and the failures, reflected in fossils of fabulous animals that the Church—strapped for a better explanation—condemned as a clever trick by the devil to confuse the faithful. Science had formulated a rational explanation for what had only been explicable until then as the result of supernatural acts. Needless to say, Darwin's revolutionary theses were energetically combated for years. In Spain, the Cantabrian biologist, Augusto G. de L. (1845–1904), lost his post as Senior Professor of Natural History at the University of Santiago de Compostela for teaching Darwin's theories.

Darwin's work, combined with Mendel's Laws—the monk, Gregor J. Mendel (1822–1884), described the basic laws of genetic inheritance—is the seed from which modern biology has grown, triggering an unstoppable and logical sequence of fundamental discoveries such as DNA and the modern genome. The 150 years since the *Origin of the Species* was published are studded with achievements that have shaped a new science, Ecology, which seeks to decipher the keys to the functioning of the biosphere and the role of biodiversity in the balance of nature, expanding the frontiers of knowledge in order, in a moment of severe crisis, to delve deeper into the foundations of the present and future wellbeing of humanity.

In this chapter, I will offer a summary of the achievements and developments that mark the path leading to our understanding of how nature works, and I will point out the challenges we face in the twenty-first century. Rather than following a chronological order, which would offer a disorderly view of progress in this field, I have opted for a thematic organization in which I emphasize the most important achievements and challenges.

### The origin and diversification of life

The ocean is the cradle of life on earth. The oldest existing fossils were found in Australia and date from around 3,500 million years ago. They are of groupings of microorganisms with photosynthetic archaea and cyanobacteria that formed carbonate structures similar to the stromatolytes that still survive in different parts of the planet, including Australia (illustration 1).

The oldest existing organisms are microorganisms belonging to the domain of Archaea, which still constitute an important part of the biological communities in the deep oceans. This discovery of Archaea is a recent achievement that has revolutionized our conception of the organization of biological diversity. In 1977, the US microbiologist, Carl R. Woose was the first to use ribosomic RNA to establish relations among microorganisms. He discovered that communities of bottom-dwelling microorganisms included some that represented a new domain, different than both bacteria and eukaryotes. The development of molecular probes capable of distinguishing between bacteria and Archaea, which cannot be told apart under a microscope, has revealed that this group is present all over the planet and that they are particularly prominent in deep parts of the ocean—where there are habitats with conditions similar to those that existed when Archaea first appeared—and also in polar lakes. The discovery of Archaea led to a revision of the domains of life, and the recognition of three: Bacteria, Archaea, and Eukarya, which completely transformed traditional concepts.

Earth's primitive atmosphere lacked oxygen. It was very reductive and lacking in ozone, so ultraviolet radiation penetrated it easily, reaching the Earth's surface with an intensity that is incompatible with life. Only in the ocean, where ultraviolet radiation is strongly attenuated by deep water, was it possible for life to prosper on such a highly irradiated planet. Marine biota deeply and irreversibly altered the Earth's atmosphere, thus altering conditions for life on the continents as well. Specifically, the apparition of oxygen-producing photosynthesis—which produces oxygen by photolysis of water (the photosynthetic process that is characteristic of plants)—in marine microorganisms called cyanobacteria produced a fundamental change in the composition of the Earth's atmosphere: the apparition of oxygen. It now counts for 21% of the atmosphere and when it reacts to ultraviolet radiation in the Stratosphere (around 12,000 meters above the Earth's surface), it generates ozone that absorbs the most harmful ultraviolet radiation, allowing life on land. The concentration of $CO_2$ in the atmosphere also diminished, as the increase of $O_2$ is only possible when $CO_2$ is consumed at a proportional rate by photosynthesis and stored in organic form in seawater, soil, organisms, detritus, and petroleum and gas deposits. The change from a reductive atmosphere to an oxidizing atmosphere is a fundamental change that completely conditions all planetary chemistry including the functioning of the biosphere and the evolution of life.

According to fossil evidence, the origin of the cyanobacteria responsible for this change on Earth was relatively abrupt. It continues to be a mystery and we cannot rule out an extraterrestrial origin. In fact, the apparition of life in the ocean brought about a determinant transformation, not only of the atmosphere, but of the lithosphere as well, because the formation of carbonate and other minerals by marine organisms created the base for many sedimentary rock formations.

There are animal fossils dating back 800 million years, although the first complex animals appeared around 640 million years ago, again in Australia. The first animal occupation of the continents dates from a little over 400 million years ago, and we have found centipede and spider fossils from that time. In fact, the occupation of the continents by life would not have been possible without the alteration of the conditions on planet Earth brought about by primitive marine organisms.

So the evolutionary history of life is much longer in the ocean than on dry land, and this is reflected by the greater diversity of life forms in the ocean. While the ocean contains a modest proportion of the species that inhabit the Earth, it contains an almost complete repertory of all the genomic diversity generated by evolution. Genomic diversity refers to the diversity of genetic machinery made up of genes that codify the proteins that determine different functions. For example, it is sufficient to consider that the genomes of a worm or a fruit fly differ from the human genome in less than half their sequences, so the path of genomic diversity among land animals is relatively short.

The tree of life that reflects the diversification of life forms on Earth has its roots in the ocean. There are 30 phyla—the large branches of that tree—in the ocean, thirteen of which are only found there. In comparison, only 15 phyla have been found on dry land, and only one of them is exclusive to it. In fact, the diversity of life forms in the ocean is often perplexing. For example, many sessile and colored organisms, similar to the flowers that adorn our landscapes, are actually animals—like anemones—or a mixture of animal and plant, like colored tropical coral, whose color is due to the pigments of photosynthetic algae that live among the colonies of polyps that form the coral. In fact, the simple division between animal and plant that is useful on land is frequently misleading in the ocean, as many animals are actually consortiums of photosynthetic species and animals, and many unicellular organisms have capacities belonging to both.

**How many species are on this planet?**

Ever since the Swedish scientist, Carl Linnaeus established the basis of taxonomy with a system of nomenclature for classifying living beings—in his *Systema Naturae,* published in 1735—the number of described species has never ceased to grow. There are now around 2 million described species. The inventory of species in the biosphere seems endless, although clearly the number of existing species must necessarily be finite. In recent years, there have been significant efforts to arrive at a trustworthy estimate of the number of species the biosphere may contain.

Despite the long evolutionary history of life in the oceans, only about 230,000 known species live there now. That is fifty times less than on land, where some 1.8 million known species currently live (Jauma and Duarte 2006; Bouchet 2006). This has intrigued scientists for many years, leading to diverse hypotheses that attempt to explain such a paradox. There has been talk of the enormous potential for dispersion by marine animals' propagules (eggs and larvae), which would avoid genetic segregation caused by the separation of populations. For example, there are only 58 species of superior marine plants, with seeds and fruit (angiosperms), as opposed to 300,000 on the continents. And there are practically no insects in the ocean, even though arthropods—including insects, crustaceans, arachnids, mites, and other lesser groups—constitute 91% of the inventory of land-based species. A variety of approaches have been taken to estimating what the total number of species might be. There have been extrapolations from the best-known to least-known taxa, assuming a proportionality of species; extrapolations based on the number of new species appearing per unit of examined area, times the total surface area occupied by different habitats; and statistical estimates based on the progression of the rate of discovery of new species. These estimates indicate that the total number of species could be around 12 million. Of these, the largest group would be insects, with almost 10 million species, and nematodes, with around 1 million species. The number of marine species could be slightly over 1 million, making it a little more than 10% of the total number of species (Bouchet 2006).

**Illustration 1.** Stromalytes at Shark Bay, Western Australia, where living stromalytes were discovered for the first time (photo: Carlos M. Duarte).

**Discoveries in the exploration of biodiversity**

Each year, around 16,000 new species are described, of which around 1,600 are oceanic (Bouchet 2006). The annual growth of the biodiversity inventory is close to 1%. Given that the current number of described species is thought to be about 10% of the total, at the present rate of discovery, it will take over 200 years to complete the inventory, and possibly longer in the case of marine species, whose inventory progresses more slowly than that of land animals. The Census of Marine Life (www.coml.org) is an international project that coordinates the efforts of thousands of researchers around the world in order to arrive at an inventory of all the existing species in the ocean. Each year, 1,635 new marine species are described—the great majority are crustaceans or mollusks—by close to 2,000 active marine taxonomists (Bouchet 2006). And yet it has been estimated that, at that rate of discovery, we will need from 250 to 1,000 years to complete the inventory of marine biodiversity, which could well have a total number of around a million and a half species—six times that which has been described up to now (Bouchet 2006).

This inventory work involves significant surprises involving not only microscopic organisms, but also relatively large vertebrates such as monkeys (for example, the mangabey monkey, *Lophocebus kipunji,* discovered in Tanzania in 2005) and fish. Although the number of species discovered each year on land is far greater than the number of marine species; discoveries on land are limited to new species from known genera or families, while the taxonomic range of innovations in the ocean is far wider. Our knowledge of the diversity of life in the oceans is still very limited, and the rate of discovery is still surprisingly high.

In the area of microscopic organisms, some of these discoveries also mark significant milestones in our knowledge. For example, the minute photosynthetic cyanobacteria from the genera *Synechococcus* (about 1µm in diameter) and *Prochloroccocus* (about 0.5µm in diameter) were discovered between the late nineteen seventies and the early nineteen eighties. Later studies revealed that those organisms dominate plankton in the large oceanic deserts that represent about 70% of the open seas and are responsible for almost 30% of oceanic photosynthetic production. The magnitude of this discovery and what it tells us about our degree of ignorance of the ocean can be properly understood if we consider that not knowing about these organisms until the late nineteen seventies is equivalent to not knowing there were tropical jungles on land until that time. The ocean continues to amaze us at higher taxonomic levels—even new phyla are being discovered—and that does not occur on land. These surprises include some of the largest animals on the planet, such as the giant squid, *Magnapinnidae,* with enormous fins, sighted various times in the deep ocean (over 2,000 meters deep); the wide-mouth shark, *Megachasma pelagios,* which can be 4 to 5 meters long—discovered in Indian-Pacific waters in 1983—or the small finback whale, *Balaenoptera omurai,* that reaches lengths of 9 meters and was discovered in the same area in 2003.

The greatest opportunities for new discoveries of marine biodiversity are in remote or extreme habitats. On land, the most spectacular discoveries frequently come from tropical jungles in remote and relatively unexplored parts of Asia (e.g. Vietnam), Africa (e.g. Tanzania), and Oceania (e.g. Papua-New Guinea). In the oceans, the remote areas of Southeast Asia and Oceania have the greatest diversity of all marine groups, while extreme habitats—sea trenches, submarine caves, hyper-saline or anoxic environments, hydrothermal springs, and pockets of hyper-saline or anoxic water—have the most surprises (Duarte 2006), along with the insides of organisms, which are home to symbionts. The latter term refers to guests, mutualists, and parasites, and is not limited to small species. For example, the largest known marine worm—up to six meters long—is a whale parasite.

Discoveries of marine biodiversity go far beyond the description of new species—no matter how surprising they may be—including the discovery of ecosystems with previously unknown communities and metabolic systems. In the late nineteen seventies, scientists aboard the US research submarine, *Alvin*, discovered the ecosystems of hydrothermal springs while making geothermal studies in the Galapagos rise (Lonsdale 1977; Corliss et al. 1979). They found an extraordinary seascape of black chimneys that emitted a smoke-like liquid composed of metals and other materials that precipitated as they cooled, creating those chimneys. The latter were colonized by dense masses of previously unknown animals, such as the giant tube worm, *Riftia pachyptila,* albino crabs, fish, and many other organisms, all new to science.

This discovery was not only an important addition to the inventory of marine species, it was also a complete challenge to our belief that solar light was the energy source that permitted the production of organic material—through plant photosynthesis—needed to maintain ecosystems. In the life-filled reefs around these hydrothermal springs, it is not the plants that transform energy into organic matter to feed the ecosystem. That work is carried out by chemoautotrophic bacteria and Archaea, which synthesize organic matter out of reduced inorganic compounds pushed out of the earth by the hydrothermal fluids (Karl, Wirsen, and Jannasch 1980; Jannasch and Mottl 1985). Those new habitats, where life prospers without the need for solar energy, are known as chemosynthetic ecosystems, where microorganisms establish symbiotic relations with invertebrates. Since they were discovered in 1977, around 600 species of organisms living there have been described. And since then, it has been discovered that other reductive habitats on the sea bed, such as the cold seeps of hydrothermal fluids (discovered in 1983 at a depth of 500 meters in the Gulf of Mexico), remains of whales, and zones with a minimum of oxygen, are also home to communities that depend on chemical energy, with communities similar to those of the animals found at hydrothermal springs.

These discoveries were a revolutionary milestone that completely modified our ideas about how ecosystems function and are organized. The microorganisms found in hydrothermal springs have also brought about a small revolution in biology and biotechnology, as many of them have proteins that are stable at 100ºC and that catalyze reactions at a vertiginous speed. *Pyrococcus furiosus* is a species of Archaea discovered in marine trenches off the island of Vulcano (Italy) that stand out because their optimum growth temperature is 100º C. At that temperature, they duplicate themselves every 37 minutes. They also possess enzymes that contain tungsten, which is rarely found in biological molecules. At that temperature, the polymerases of *Pyrococcus furiosus* DNA (Pfu DNA) operate at an enormous velocity, so they are often used in the chain reaction of the polymerase (PCR) that makes it possible to mass produce DNA fragments. It is the fundament of most biotechnology applications that require DNA sequencing.

New discoveries in marine biodiversity also depend on developments in the field of molecular techniques that make it possible to establish the taxonomic position of organisms by analyzing sections of their genome. For example, the use of massive sequencing techniques allowed the American biologist, Craig Venter—leader of the Celera Genomics Project that first sequenced the human genome—to sequence DNA fragments from 1 cubic meter of surface seawater from the Sargassos Sea. That exercise turned up a surprising inventory of 1,214,207 new genes, and close to 1,800 new species of microbes (Venter et al. 2004). Sadly, these techniques do not make it possible to identify the new species, but they are revealing that many anatomically similar marine species are actually different species. Moreover, they are also demonstrating that some species considered different due to their morphological dissimilarities are actually variants of the same species subjected to very different environmental conditions.

**The biosphere under pressure: the Anthropocene**

The Industrial Revolution, which increased the human capacity to transform the environment, was not only a milestone in the history of our species, but in the history of the planet, which has been transformed by human activity. Any objective study of planet Earth—its climate, the configuration and dynamics of its ecosystems, its basic functional processes—shows that they are affected by human activity. The importance of human activity's impact on the essential processes of the biosphere is reflected in certain indicators, such as the fact that 45% of the Earth's surface has already been transformed by human activity, passing from wild ecosystems to domesticated ones such as farm land, pastures and urban zones. Humanity uses more than half the available flow of fresh water in the world, modifying the amount of water that flows through rivers, and also altering its quality, enriching it with nutrients, nitrogen and phosphorus, organic matter, and contaminants following its use by humans. In fact, human activity notably accelerates the cycles of elements of the biosphere. It has mobilized over 420 gigatons of coal since the Industrial Revolution and—using the Haber Reaction patented by Fritz Haber in 1908—it has fixed 154 megatons per annum of atmospheric nitrogen gas in the form of ammonia for use in fertilizers. That is more atmospheric nitrogen than the processes of nitrogen fixation that occur as a result of nitrogenase activity from plants, terrestrial, and marine microorganisms. Carbon dioxide emissions due to the use of fossil fuels, the production of cement, and fires, along with the release of other greenhouse gasses such as methane, are raising the planet's temperature. When those gasses dissolve in the ocean, they increase its acidity. Those processes have important consequences for the Earth's climate and for the ecosystems it contains. It has also been calculated that human agriculture, forestry and fishing account for approximately 40% of land-based photosynthesis and 20% of costal photosynthesis, worldwide.

These data, to which many others could be added, are sufficient to substantiate the affirmation that our species has become an essential element of change in the basic processes of the biosphere. In 2000, this led the atmospheric chemist and Nobel prizewinner, Paul Crutzen, and his colleague, E. Stoermer, to propose the name *Anthropocene* to designate a new geological era in the history of the planet. An era in which humanity has emerged as a new force capable of controlling the fundamental processes of the biosphere (Crutzen and Stoermer 2000), causing Global Change.

The human capacity to alter the planet begins with the Holocene, at the end of the last ice age, about 10,000 years ago. This was followed by the development and rapid expansion of agriculture, animal husbandry, and the first urban centers. The first indications of this new emerging force are the extinction of large mammals and birds hunted by the first inhabitants of islands and continents. The development of agriculture and animal husbandry led to the transformation of land, converting forests and other ecosystems into farmland and pastures. And those changes were strengthened by the work capacity generated by domesticating beasts of burden (oxen, horse, etc.) and technological developments such as the plow and the wheel. The human capacity to transform the planet experimented a notable push with the Industrial Revolution, which increased the capacity to use energy to transform the planet. It also generated residues such as gasses and synthetic compounds that alter natural processes. Humanity has radically transformed the planet's territory, converting around 45% of the Earth's surface into pastures—they occupy around 30% of the Earth's surface—farmland—another 10%—and urban areas, that occupy approximately 2% of the Earth's surface. Other infrastructures, such as reservoirs, roads, electric lines, railways, etc., occupy another 3% of the planet's surface, approximately. Costal zones are experiencing the highest rates of population growth on the planet. About 40% of the human population lives less than 100 kilometers from the coast, with a population density three times greater than that of continental territories. And the coastal population is growing much more rapidly than the continental one, due to migration, the increased fertility of coastal zones, and increased tourist flow to those areas (Millennium Assessment 2005b). Moreover, the coastline itself is being rapidly occupied by infrastructures (housing, streets and roads, ports, and so on).

Human activity has accelerated the cycles of elements in the biosphere—processes central to the regulation of how this system, and life itself, function. The acceleration of elemental cycles affects practically all chemical elements, but it has more important consequences for those involved in processes essential to the regulation of life—carbon, nitrogen, phosphorus, iron, calcium, and other oligoelements—and of the climate, including carbon—through $CO_2$ and methane—and nitrogen—through nitrous oxide. The transformation of forests into pastures and farmland accelerates the carbon cycle. No longer trapped in forest biomass, it is rapidly recycled in annual harvests. Agricultural land has less capacity to retain carbon than forested land, and the destruction of wetlands has released carbon retained by those systems, which are important carbon sinks. The extraction of fossil fuels and gasses also mobilizes carbon that had accumulated during epochs in which the biosphere generated an excess of primary production.

The use of fossil fuels, along with the production of $CO_2$ in cement making, deforestation, and forest fires, has led to emissions of around 450 gigatons of $CO_2$ into the atmosphere, which has led to a rapid increase in the atmospheric concentration of $CO_2$, along with other greenhouse gasses such as methane and nitrous oxide. Human activity also generates an excessive mobilization of nitrogen, fundamentally through the production of some 154 million tons of this element every year in the form of fertilizers made from atmospheric nitrogen gas. That nitrogen is mobilized by its transportation in rivers, in the atmosphere, and also as nitrate contamination in the aquifers. Atmospheric transportation allows nitrogen to be carried long distances, so that it also deposits on the open seas. The production of fertilizers requires the extraction from mineral deposits of a quantity of phosphorus proportional to the amount of nitrogen produced in fertilizers. The acceleration of the cycles of those elements has important consequences for the ecosystems, which are altered by a process called eutrophization. That process is caused by an excessive contribution of nutrients to ecosystems and has significant consequences for them.

Humanity currently uses 50% of the fresh water available in the biosphere. In 1995, we extracted over 3,000 cubic kilometers of water for irrigating crops. Food production, including pastures, annually consumes around 14,000 cubic kilometers of water. As a consequence of this agricultural water use, large lakes such as the Aral Sea, in Central Asia, have lost most of their extension and water volume. The Aral Sea's water level drops by 0.6 meters each year, while the surface area of Lake Chad, in Africa, has shrunk by a factor of 20 in just 15 years. Human water use and the transformation of land have resulted in significant changes in the water cycle. Approximately 60% of the marshes existing in Europe in 1800 have disappeared. Construction of reservoirs grew rapidly during the twentieth century, at a rate of 1% per year, and these now rZXetain approximately 10,000 cubic kilometers of water, which is five times as much water as is contained in rivers.

Human activity has synthesized millions of new chemical compounds that were inexistent in the biosphere. They often act as contaminants that harm organisms, including our own species, or they interfere with other processes. For example, Freon and Halon gases used in industry and refrigeration are responsible for the destruction of the ozone layer, which has decayed at an annual rate of around 4% over the last two decades, causing the hole in the ozone layer to expand in the Southern Hemisphere. These compounds have now been controlled—by the Montreal Protocol of 1987—but every year, thousands of new substances are released into the biosphere without any previous testing to determine what impact they may have on human health and the biosphere. Some of them behave like greenhouse gasses and exacerbate the process of global warming. Many such compounds are volatile or semi-volatile and are transported by the atmosphere to areas thousands of kilometers from their sources, so there are no places left in the biosphere that are free of them.

Emissions of greenhouse gasses are causing a strong increase in the planet's temperature, which has already risen by 0.7°C. The temperature is expected to rise another two to seven degrees centigrade over the course of the twenty-first century (Trenberth et al. 2007, Meehl et al. 2007). Besides the temperature increase, other components of the climatic system will also be affected. Important changes in the water cycles are expected, with an increase of precipitation in some parts of the planet and a decrease in others, as well as more frequent and prolonged extreme events such as droughts and flooding (Meehl et al. 2007). The intensity of the wind will increase and extreme events such as tropical cyclones are expected to increase in intensity, reaching areas that have been free of such phenomena until now (Meehl et al. 2007).

Global warming led to an average rise in sea levels of 15 centimeters during the twentieth century, and an additional increase of between 30 and 80 centimeters is projected for the twenty-first century (Bindoff et al. 2007). The increase of partial $CO_2$ pressure in the atmosphere and its penetration in the ocean has led the latter's pH to drop by approximately 0.15 units. Given that the pH scale is logarithmic, that indicates a 60% increase in oceanic acidity. The increase of partial $CO_2$ pressure predicted for the twenty-first century will lead to an additional drop of between 0.3 and 0.4 units, which means that the ocean's acidity will have tripled by then.

**The impact of Global Change on the ecosystems**

The transformation of land by the expansion of pastures, farmland, and urban and industrial areas has been carried out at the expense of ecosystems such as wetlands—many have been drained—tropical forests and other habitats essential to the conservation of biodiversity. Wetlands represent 6% of the Earth's surface, and more than 50% of the wetlands in North America, Europe, Australia, and New Zealand have already been lost. A large part of these and other regions have broken down. In the Mediterranean basin, more than 28% of wetlands were lost in the twentieth century. Forests have suffered important losses as well, as about 40% of the planet's forested area has disappeared in the last three centuries. Forests have completely disappeared in 25 countries, and another 29 have lost over 90% of their forested land. Forested areas are currently expanding in Europe and North America, but they continue to diminish in the tropics at a rate of 10 million hectares per year, which is about 0.5% a year (Millennium Assessment 2005b). The intense occupation of costal zones is causing important losses of coastal ecosystems, which are experiencing the greatest loss rates of all: about 25% of mangrove swamps have been lost, about a third of all coral reefs have been destroyed (Millennium Assessment 2005b), and undersea prairies are shrinking at a rate of two to five percent per annum (Duarte 2002).

Planetary warming is making spectacular changes in the areas of our planet occupied by frozen surfaces, such as the sea ice in the Arctic, which suffered a catastrophic decrease in 2007, and the extensions of Alpine glaciers, which are clearly receding as a result of global warming.

The increase of partial $CO_2$ pressure will increase rates of photosynthesis, especially by aquatic photosynthetic organisms, as the enzyme responsible for fixing $CO_2$ evolved when the concentration was much greater than it now is, and its activity is relatively inefficient at current $CO_2$ levels. Photosynthetic activity will also be increased by temperature increases, as the latter accelerate metabolic rates. However, breathing is a process that is much more sensitive to temperature increases and, in the biosphere, which is dominated by microbe processes, breathing is expected to increase by as much as 40% in the current warming scenario, while primary production would increase by around 20% (Harris et al. 2006). This could lead to a net $CO_2$ production in aquatic ecosystems—including the oceans—that would worsen the greenhouse effect.

The process of eutrophization resulting from human activity's mobilization of large quantities of nitrogen and phosphorus is leading to an increase in primary production on land and in the seas. Eutrophization implies a breakdown in water quality, the loss of submerged vegetation and the development of alga proliferations, some of which are toxic. When other circumstances coincide with it, such as poor ventilation of water, hypoxia can also spread. Eutrophization is not limited to the continents. It can also affect the open seas, where atmospheric nitrogen contributions have doubled, undoubtedly with significant consequences for the functioning of the oceans, although there is not yet enough research to clearly establish this.

The effects of climate change are particularly clear in the phenological patterns of organisms. Behavioral and reproductive patterns are also suffering, and will suffer, alterations, with earlier flowering in temperate zones and alterations in birds' migratory periods. Activities that organisms begin to carry out in spring in temperate zones are already causing changes in the biogeographic ranges of organisms, with a displacement towards higher latitudes. This displacement includes pathogenic organisms, so the range of tropical or subtropical diseases is also expected to move to higher latitudes. Besides these latitudinal displacements, different organisms also change their range of altitudes. The tree line on high mountains is reaching higher elevations and alpine organisms are extending their upper limit by one to four meters per decade. These changes are leading to relatively important alterations in the makeup of communities in almost every ecosystem on the planet.

Global Change and the conjunction of its multiple effects (warming and eutrophization) seem to be leading to an increase in the problem of hypoxia in coastal waters, where affected areas are increasing by 5% annually (Vaquer-Sunyer and Duarte 2008). Hypoxia is when oxygen levels in coastal waters drop below two to four milligrams per liter, leading to the death of many groups of animals and plants and the release of sedimentary phosphorus. Three circumstances must coincide in order for hypoxia to occur: a) an excess of photosynthetic production that sediments waters in contact with the sea floor; b) stratification through a density gradient due to a thermal gradient, a salinity gradient, or both, between surface water in contact with the atmosphere, and deeper coastal water in contact with marine sediment, so that this stratification creates a barrier that keeps water from ventilating and renewing its oxygen content; and c) increased respiration in the deepest layer of water. Those three processes are affected by Global Change: global eutrophization is increasing coastal production on the basis of increased nitrogen and phosphorous; rising temperatures increase the stratification of the water column, reducing the ventilation of underlying gasses and increasing the breathing rate. Thus, Global Change is expected to considerably increase the breadth and intensity of hypoxia problems and the mortality of marine organisms affected by it in coastal regions (Vaquer-Sunyer and Duarte 2008).

The acidification of the ocean mainly affects organisms with carbonate skeletons. Those in cold oceans are particularly vulnerable to this process, so the polar oceans will be the first to be affected by this oceanic acidification, with problems for the development of organisms with calcified structures. These difficulties will later affect organisms in temperate seas as well, and will eventually reach the tropics.

Coral reefs are particularly vulnerable to temperature increases, as the photosynthetic symbionts that live there and depend on them for adequate growth, die when water temperatures surpass 29ºC. This will be more frequent in the future. In fact, the coral reefs in South East Asia have recently experience massive episodes of whitening (i.e. loss of zooxanthellae symbionts). Coral reefs also suffer the consequences of global eutrophization and the acidification of seawater, and are thus thought to be among the ecosystems most gravely affected by Global Change.

Finally, the accelerated loss of surface ice during the Arctic summer is seriously endangering species that depend on ice for their habitat, including polar bears, seals, and walruses.

The ecosystems' responses to these simultaneous pressures are frequently manifested as abrupt changes of communities. These are known as regime changes and constitute brusque transitions between two states (e.g. shallow lakes dominated by vegetation rooted on the bottom becoming lakes dominated by phytoplankton due to eutrophization, and sea floors with vegetation and fauna that become sea beds dominated by microbe carpets due to hypoxia). These transitions occur following a small increase of pressure that pushes them over a threshold, triggering the change. The first theoretical speculation about these abrupt regime changes in the state of ecosystems dates from the nineteen seventies (May 1977). Since then, it has been shown that these changes are not the exception, but rather the most frequent response by ecosystems subjected to pressure (Scheffer and Carpenter 2003; Andersen et al. 2008). It has also been shown that once the threshold that triggers the regime change is crossed, it is very difficult to return the system to its previous state. That is why it is so important to determine the position of those thresholds. Sadly, at present we are only able to identify those thresholds when they have been crossed (Strange 2008).

**Toward the sixth extinction? Extinctions and the biodiversity crisis**

The extinction of species is as natural as the emergence of new ones resulting from the slow process of evolution. Fossil evidence indicates there were five great extinctions in our planet's turbulent past. The first took place about 440 million years ago and was apparently due to a climate change that led to the loss of 25% of existing families. The second great extinction, with a loss of 19% of species, took place 370 million years ago, possibly due to global climate change. The third and greatest extinction took place 245 million years ago, possibly due to climate change caused by the impact of a large meteorite. It led to the loss of 54% of existing families. The fourth great extinction, 210 million years ago, caused the loss of 23% of existing families, and its causes are the source of speculation, including a possible increase in ultraviolet radiation due to a supernova. The fifth, and most famous, of the great extinctions took place 65 million years ago. It was caused by the impact of a large meteorite, followed by a series of large volcanic eruptions that caused the loss of 17% of living families, including the dinosaurs.

The database of the International Union for the Conservation of Nature (IUCN, www.iucnredlist.org) reports 850 species already extinct, most on land (583 species) or in fresh water (228 species), with just 16 marine species extinct. The number of species that the IUCN has classified as critical is 3,124, and another 4,564 species are in danger of extinction.

These estimates of the number of endangered species are conservative because only known species can be considered, and we only know about ten percent of the existing species. Moreover, in order for a species to be considered extinct, more than ten years has to have passed since the last time the organism was observed. So some species may well have been extinct for some years now, but have not yet been cataloged as such. Every year, the disappearance of close to 200 species is documented worldwide, although this number is thought to be much greater, if we include species that have disappeared before they were ever described. Some authorities, including biologist, E. O. Wilson, the father of conservation biology, consider that several tens of thousand of species grow extinct every year. That means that, by the end of the twenty-first century, between a third and half of the total number of species on the planet will have disappeared. Unquestionably, we are experiencing—and causing—a grave crisis of biodiversity (Eldredge 1998). The extinction of species due to human activity is not, however, a recent phenomenon. Fossil evidence offers abundant information about many species, especially large mammals and birds, that became extinct following the arrival of humans, especially in America and Australia, as well as the extinction of fauna in the Pleistocene due to hunting.

The transformation of land is one of the leading causes of extinction, as it constitutes an enormous loss of habitat that has led to the extinction of many species. The loss of wetlands, in particular, has had a devastating effect on numerous species of trees, plants, birds, fish, amphibians, and insects living there. Many of the contemporary extinctions affect species in island settings, where the processes of speciation have been particularly important, leading to a high number of endimisms that are always more vulnerable to human action. The human introduction of species that behave as invaders has also led to a significant loss of species. Thus, the introduction of foxes and cats to the Australian continent decimated small marsupials, many of which are now extinct. Others are gravely endangered. Invading species affect local biodiversity, displacing indigenous species. Their aggressive behavior is frequently attributable to the absence of predators or parasite in the areas to which they have been newly introduced. Human activity has introduced, for example, over 2,000 plant species to the US and Australia and some 800 in Europe (Vitousek et al. 2003). In some cases, the invading species can have positive effects on the ecosystem. Thus, or example, the zebra mussel that invades rivers and estuaries in Europe and North America can attenuate the effects of eutrophization on those ecosystems.

Human activity has also significantly affected marine diversity. Over-fishing has particularly reduced the biomass of fish in the ocean, which is a tenth of what it was at the beginning of the twentieth century (Millennium Assessment 2005). Growing pressure on coastal ecosystems is generating a biodiversity crisis of global dimensions, with a loss of habitats of great ecological value (coral reefs, wetlands, mangrove swamps, and undersea prairies), along with the biodiversity living there.

Available analyses indicate that a temperature increase of over 2ºC would cause extinctions of amphibians and corals and that an increase of more than 4ºC—which is within the predictions of climate scenarios for this century—could cause massive mortality that would affect one of every three species (Fischlin et al. 2007), making it comparable to the great extinctions of the past. A recent analysis (Mayhew et al. 2007) compared the rate of extinctions with the average rate of global temperature change, revealing the existence of a correlation between climate change and four of the five great extinctions of the past. This correlation reinforces predictions indicating that current climate change could cause a new massive extinction (Thomas 2004).

The synergic action of the different forces responsible for Global Change is the force that drives the notable erosion of biodiversity. For example, amphibians seem to be declining on a global scale for as yet unclear reasons that seem to have to do with a group of causes: loss of habitat, acid rain, environmental pollution, increasing ultraviolet radiation, and climate change. In fact, the current rate of species extinctions has reached sufficiently high levels for some researchers to postulate that we are already in the sixth great extinction.

## The ecology and biology of conservation: the keys to our future

Awareness of the loss of species and ecosystems on scales reaching from local to global has sparked intense research activity over the last twenty years. Scientists seek to evaluate the consequences of extinctions, the role of biodiversity in the functioning of ecosystems, and the benefits biodiversity may have for society. At the same time, a greater knowledge of the biology of species has permitted improvements in the possibility of conserving them. During this period, ecology and the biology of conservation were born.

Large-scale experiments have shown that, in general, greater biodiversity corresponds with greater biological production, a more efficient recycling of nutrients, and a greater capacity by ecosystems to resist perturbations (Schwartz et al. 2000). The goods and services that ecosystems bring to society have been evaluated, including their added value (e.g. food supplies, water purification, regulation of atmospheric gases and of the climate, pollination, control of pathogens and their vectors, and so on), which is more than twice the combined gross national product of all nations (Costanza et al. 1988). The loss of those functions due to the deterioration of ecosystems and the loss of biodiversity would constitute a loss of natural capital with grave economic consequences, and a loss of our quality of life.

The Convention on Biological Diversity (www.cbd.int) signed by most nations—with notable exceptions—in Rio de Janeiro in 1992, is a reaction to this crisis of biodiversity. It is based on the recognition of the intrinsic value of biodiversity, its importance for the maintenance of life-support systems on which society depends, and evidence that biodiversity is being eroded by human activity. The Convention seeks to insure the conservation of biodiversity on the planet and a fair distribution of the wealth generated by its use. One of its objectives is to achieve a protected status for 10% of the Earth's surface. With this impetus, the number of protected areas has proliferated. On land, the objective is slowly drawing closer, but the ocean is still very far from the 10% goal.

Territorial protection is complemented with special measures to protect endangered species. Many are charismatic species whose conservation is energetically pursued with increasingly sophisticated and costly reproductive plans, including the consideration of advances in cloning techniques for their conservation. Cloning is a technique first developed through experimentation with amphibians, and it has been proposed as a possible contribution to the conservation of these species, that are in grave danger of extinction (Holt et al. 2004). A recent initiative was the inauguration on a Norwegian Arctic island of the Svalvard Global Seed Dome, a world bank that preserves seeds of agricultural interest from all over the world as protection against possible catastrophes (see: www.nordgen.org/sgsv/). Both this infrastructure and the risk it addresses were the stuff of apocalyptic science fiction until very recently.

The rate of extinctions and loss of ecosystems grows unstoppably, despite advances in the protection of natural areas and the conservation of specific species. It is increasingly clear that protected areas and efforts to protect individual species can only be understood as partial solutions in the face of impacts responsible for the loss of ecosystems and biodiversity—they must be completed with other strategies and techniques. It is necessary to better understand why species are being lost, the relations between different pressures that lead to their extinction, the possibilities of a domino effect in species extinctions (Rezende et al. 2007), and the relations between the deterioration of ecosystems and the loss of biodiversity. Without such understanding, it will be impossible to formulate more effective conservation strategies. Greater knowledge of the bases on which ecosystems resist pressures is essential to direct actions designed to reinforce that capacity to resist or, when the impact has already occurred, to catalyze and reinforce ecosystems' capacity to recover.

The promotion of scientific knowledge is essential to the generation of new conservation strategies, but it is not enough. The success of any strategy requires the reduction of pressure derived from human activity. Our society is behaving in a seriously irresponsible fashion, eroding and wearing down the natural capital base on which our quality of life, and the future of our species rest. Scientific knowledge must reach beyond the scientific community to inform society, contributing to the creation of better-informed and more responsible citizens. We must cross the frontiers of knowledge, and those that separate it from our society. Our future will be largely determined by the success or failure of our efforts.

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