Ocean, biodiversity and climate

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THE OCEAN

The ocean is the largest living space on the planet and at present covers 70.8% of the Earth's surface – *i.e.* 361 million km². But we should really think in terms of volume – around 1,370 million km³. The average depth is about 3,800 m and the main feature of this enormous environment is its continuity, leading us to think of a global ocean rather than several individual oceans. The Ocean is unique and ecologically connected! Another specific feature, compared with the rest of the water on the planet, is its salinity. The ocean's salinity offshore is extremely stable (35 psu, 1,050 mOsm.l^{-1}), and seawater composition is almost the same everywhere, as it has been for tens of millions of years. The ocean is therefore much more stable than any other living environment.

Biodiversity cannot be likened to a simple list of species inhabiting a particular ecosystem. It is considerably more than a catalog or inventory, and in fact includes all relationships between living beings, among themselves and with their environment. We can define it simply as being the living part of nature. Biodiversity comes from prebiotic chemistry, built upon earlier geodiversity. It became diversified in the ancestral ocean, around 3.9 billion years ago. Life appeared rather quickly, after the initial cooling and condensation of water masses.

Christian de Duve (Nobel Laureate, 1974) said in "Vital Dust" (1996) that the Earth was so ideally positioned in relation to the Sun, that life could not fail to appear there, and Jacques Monod spoke about an improbable hypothesis. The oldest known sedimentary rocks (Akilia Island, southern Greenland) containing carbon of biological origin date from 3,850 million years (Ma) ago. Imagine the very simple, primitive life that first developed from a world of RNA and protocells. Current deposits of stromatolites – rocks that precipitate bicarbonate, with beautiful deposits in Australia and some recently discovered in Greenland (3,700 Ma) – are very valuable because they contain within their silicified parts the oldest known fossils of microorganisms, cyanobacteria. Cyanobacteria began to conquer the ocean 3,700-3,200 Ma ago, when there was no atmospheric oxygen. Thanks to specific pigments, and in the presence of water, these cells developed photosynthesis more than 3,500 Ma ago, thus producing oxygen and sugar from light and carbon dioxide (CO_2). Oxygen then began diffusing beyond the aquatic environment: the composition of today's atmosphere – with 21% oxygen – dates from the Cretaceous period (~100 Ma ago).

In this ancient ocean, certain events occurred that proved crucial for living organisms and biodiversity:
(1) the emergence of a nuclear membrane and an individualized nucleus (prokaryote-eukaryote transition) around 2,200 Ma ago; (2) the capture of ambient cyanobacteria that became symbionts and cell organelles, mitochondria and plastids, with their own little DNA, around 2,100 and 1,400 Ma ago, respectively, and (3) the emergence of multicellular organisms and metazoans ~2,100 Ma ago.

An exceptional event then occurred in this ancient ocean: the emergence of sexuality – first in prokaryotes, later in eukaryotes. This would prove vital for the explosion of biodiversity. Sexual reproduction leads to genetic mixing, generating new traits and unprecedented diversity: all individuals are different. A population equipped with sexuality evolves much faster. In addition, the prevalence of sexuality encourages the development of an "arms race" between parasites and their hosts (co-evolution and molecular dialog), with genetic mixing ultimately resulting in faster "disarmament" of the parasite and sexual selection that is very different from natural selection.

The physical consequences of osmotic fluxes (water and electrolytes) in the marine environment led living organisms to develop two types of strategies: (1) in the vast majority of cases – from the first initial cell to shellfish – intracellular isosmotic regulation provided living organisms, separated from seawater by a biological membrane, with the same osmotic pressure (about 1,000 mOsm.l^{-1}) on the inside (intracellular, internal and extracellular media) as that of the seawater outside; (2) later on, starting with arthropods, extracellular anisosmotic regulation developed, where cellular and internal fluids are much less concentrated (3-400 mOsm.l^{-1}) than seawater. This enabled living organisms to leave the ocean. The perpetual drinking behavior at sea, found in bony fish for example, associated with very active mechanisms of electrolyte excretion through gills, constantly leads to a delicate compromise between developing maximum gill surface for capturing oxygen in a poor and highly variable environment and, on the other hand, minimum gill surface to avoid serious hydro-mineral imbalances.

Much later, during the Triassic period (~210 Ma ago), after the third major mass extinction around 251 Ma ago, the beginnings of thermoregulation developed and found their optimal efficiency among large dinosaurs, then in birds and mammals. Today 12 phyla are exclusively marine animals and have never left the ocean (echinoderms, brachiopods, chaetognaths, etc.). Furthermore, biomass can be considerable in the sea: the bacteria in the ocean subsurface layer alone accounts for over 10% of all carbon biomass on the planet. The marine environment has therefore played a key role in the history of life, and the ocean today still has a crucial role in life and climate evolution.

PARTICULARITIES OF MARINE BIODIVERSITY

Marine biodiversity is very special. The recognized species diversity in the oceans does not exceed 13% of all living species currently described - fewer than 280,000. This is very little, for two reasons. Firstly, our knowledge, especially about deep zones and microorganisms, various bacteria and protists is still very partial, so we significantly underestimate oceanic biodiversity. New techniques, such as coupling flow cytometry with molecular probes, are allowing us to discover extraordinary biological diversity. At present, the "random genome sequencing" of ocean water masses (C. Venter, sequencing of all the DNA in a volume of filtered seawater) provides scientists with data that appear to be mostly unknown. Since 2015, the circumnavigation of the world oceans carried out during the Tara Oceans expedition has produced valuable information on the abundance and variety of viruses, bacteria and protists, in particular dinoflagellates. Protists alone may account for almost one million species.

Molecular approaches (sequencing of 16S or 18S ribosomal RNA, among others) applied to all prokaryotes and very small eukaryotes generate remarkable new knowledge every day. Secondly, it is clear that marine ecosystems and species living in a continuous medium, through gamete dispersal and larval stages, are less predisposed to strict endemism than in terrestrial habitats. There are many more obstacles and isolates contributing to speciation (the evolutionary process by which new living species appear) on land than at sea. This results in significant differences in species diversity: marine ecological niches offshore do not approach the richness of land niches, which are much more fragmented and encourage greater speciation. The stability of the open ocean, at least for the past 100 million years, is quite extraordinary: small changes in pH, osmotic pressure and salinity, temperature, hydrostatic pressures associated with depth, dissolved gas content, etc. Human activities are changing all this, and we will discuss this later. This stability generates fewer new species.

In contrast, marine biomass can be considerable: the performance of phytoplankton alone (in its ability to renew itself) can account for more than 50% of the planet's total productivity. Today, there are 5 to 7 times more identified taxa on land than at sea. We can, of course, wonder about this, since initially life was exclusively marine before organisms left the ocean, several times in different places and different forms (~440 Ma ago for complex metazoans). The major Permian-Triassic mass extinction (~251 Ma ago) played a key role, with an extinction rate of 96%, both on land and at sea. The explosion of flowering plant species, insects, and many other groups on Earth around 130-110 Ma ago was decisive after the initial radiations (process in which organisms diversify rapidly from an ancestral species) beginning in the Devonian and especially the Carboniferous period.

Co-evolution between plants and pollinators, and the appearance of an infinite number of new niches have often been put forward to explain the accelerated speciation in continental environments during this period. It is also clear that the dispersal of sexual products and larvae in the ocean plays a significant role in current species distribution and biogeography. Endemism is much more limited in the open sea, due to the stability and continuity of this enormous environment. On land, species often live on only a few km², but there are no known examples of marine species with such limitations. The huge variety of marine reproduction modes also takes advantage of dispersal phenomena in water masses: males and females do not need to be close to reproduce! Thus, connectivity and many small variations in environmental factors create the great stability of the open ocean, and the very specific characteristics of the marine biodiversity it hosts. In contrast, coastal and intermediate systems with strong terrigenous influences, are subject to much greater variations.

Finally, let's not forget that biodiversity is much more than just species diversity, including both the species and their relative abundance. The meaning of the word "biodiversity" has been variously explained, but overall it expresses "the genetic information contained in each basic diversity unit, whether of an individual, a species or a population". This determines its history, past, present and future. What's more, this history is determined by processes that are themselves biodiversity components. In fact, today, we group together various approaches under this term: (1) the basic biological mechanisms explaining species diversity and characteristics, and leading us to further investigate speciation and evolution mechanisms; (2) more recent, promising approaches in functional ecology and bio-complexity, including the study of matter and energy flows, and major bio-geochemical cycles; (3) research on natural resources considered "useful" to humanity, providing food, or highly valuable substances for medicines, cosmetics, molecular probes, or ancient and innovative models for academic and applied research in order to find answers to agronomic and biomedical issues; and finally (4) the implementation of conservation strategies to preserve and maintain our planet's natural heritage, which is the birthright of future generations.

Humans have been fishing in this biodiversity since ancient times, probably for tens of thousands of years. As soon as they reached coasts, humans started collecting seafood, algae, and catching fish. Just as we farm on land, we have been raising certain marine species along the coastlines for at least 4,000 years (Egypt, China, etc.). The exploitation of renewable, living aquatic resources is booming, but there are serious concerns about its sustainability. The latest figures available from the FAO in 2013 (for the year 2012) indicate 79.9 million tonnes (Mt) for marine fisheries, 11.5 Mt for continental fisheries, 19 Mt for algae (including only 1 Mt for harvesting at sea), and 65.6 Mt for aquaculture (including 20.3 Mt at sea). This makes a grand total – for all groups and all aquatic environments – of about 176 Mt. As a result of the global warming of ocean water masses, fish stocks move on average 72 km northwards every 10 years in the northern hemisphere. Global overfishing is now a matter of great concern: 50-90% of all large pelagic fish have been caught over the past 15 years! Three quarters of all marine stocks have been fully exploited and 31% overexploited. Aquaculture is growing rapidly, but still raises questions of environmental impacts, species transplantations and, for some types of activities, the use of animal protein to feed carnivorous species of interest. The ocean is not only these living resources. There are also about 26,000 molecules of pharmacological (anti-cancer agents, antibiotics, immunosuppressant drugs, growth promoters, molecular probes, etc.) or cosmetic interest, and some extremely relevant models for scientific research, with potential biomedical and agricultural applications.

For example, phagocytosis and key molecules of carcinogenesis have been discovered thanks to sea urchins and sea stars, the molecular basis of memory thanks to a sea slug, the transmission of nerve impulses thanks to the squid, anaphylactic shock thanks to jellyfish venom, etc. All these discoveries have earned their authors a Nobel Prize.

OCEAN & CLIMATE

The ocean and the atmosphere are closely connected and exchange energy in the form of heat and moisture. The ocean absorbs heat (93%) much more readily than ice or land surfaces, and stores energy much more efficiently. In addition, it returns heat to the atmosphere more slowly than continents and contributes to the more temperate climate of coastal areas. The ocean is thus a formidable climate regulator. Changes in energy balance between atmosphere and ocean play an important role in climate change. Ocean circulation is affected by atmospheric circulation, and surface marine currents depend on winds. Winds mix surface waters down to the thermocline, below which basic circulation forces are related to temperature and salinity, influencing water density. The ocean thus contributes to the huge amounts of energy released into the atmosphere during storm and cyclone formation, affecting both continents and human populations. Upwellings – cold, nutrient-rich water masses coming up from the depths near the coasts – profoundly alter coastal climate. Taking into account their fluctuations is essential for understanding the climate system. The first three meters of the ocean surface alone store as much energy as the entire atmosphere. Moreover, the ocean has huge thermal inertia and dynamic capabilities. The action of redistributing water masses by carrying warm water from the tropics to the poles (and vice versa) is fundamental. The deep ocean plays a significant role in storing and releasing heat. In fact, this huge heat reservoir gives the ocean a crucial role in moderating climate variations. It also controls the formation of wind and rain.

The ocean traps and stores CO_2 (26-30%), thereby preventing an extreme atmospheric greenhouse effect. However, as a result, it acidifies due to the production of carbonic acid. It is now 30% more acidic than 250 years ago. Oceanic phytoplankton also stores CO_2 in the surface layer, as do all the biocalcifiers. Ocean circulation redistributes heat and salinity – both important factors in controlling the climate machine. Currents along the eastern and western borders of the continents are critical, and past fluctuations led to the alternation of glacial and temperate periods.

The ocean thus plays an essential role in climate regulation, but biodiversity loss and pollution also affect it and create conditions for climate change. The amount of carbon dioxide in the atmosphere and the ocean is increasing. Average temperatures of the lower atmospheric layer and of the ocean surface are rising. Moreover, mean sea levels are rising three times faster than 50 years ago. Rapid changes in seawater chemical composition have a harmful impact on ocean ecosystems, already stressed by overfishing and pollution. This massive and widespread pollution affects all parts of the world, because humans have managed to contaminate areas where they do not even live (including the Arctic ice pack and Antarctica)! Plastic microparticles, carried by ocean gyres, have accumulated in huge concentrations in five areas of the world ocean. No contaminated effluents should reach the sea ever again! Only a healthy ocean can fulfill all these functions.

Climate change has a direct role in biological diversity loss, and, in turn, this loss contributes to the very problem!

Moreover, let's not forget that the impacts of rapid climate change are compounded by other severe problems: destruction and pollution of coastlines, accelerating systematic overexploitation of living resources, and the uncontrolled spread of species (including in the ballast water of large ships). It is also very important to better legislate and regulate actions before allowing deep sea mineral exploration and mining, as the deep ocean is particularly fragile (and is stable in the very long term).

That is a lot for the ocean to handle and it is high time to take action!