Ocean, Biodiversity and Climate

Gilles Bœuf

The marine environment has played a key role in the history of life and today's ocean continues its primordial function in the evolution of life and climate. The recognized species diversity in the oceans does not exceed 13% of all currently described living species - fewer than 250,000 - but this can be due partly to our lack of knowledge, especially concerning deep zones of the oceans and micro-organisms, and partly to the fact that marine ecosystems and the way of life in such a continuous medium disperse more easily species and they are less predisposed to endemism. In contrast, marine biomass can be considerable. Climate disturbance has a direct role in the loss of biological diversity, and this loss contributes in turn to the deregulation itself.

OCEAN

The ocean is the largest living space in the world and covers at present 70.8% of the surface of the Earth – 361 million km². But we should really think of the ocean in terms of volume – around 1,370 million km³. The average depth is about 3,800m and the main feature of this gigantic environment is its continuity, which leads us rather to think in terms of global ocean. Another special feature is, compared to the rest of the water on the planet, its salinity. The ocean's salinity offshore is extremely stable (35 psu[1], 1050 mOsm.l^{-1}) and the composition of ocean water is the same everywhere, as it has been for tens of millions of years; consequently the ocean is a very stable milieu.

Biodiversity cannot be likened to a simple list of species that inhabit a particular ecosystem. It is considerably more than a catalog or inventory, and in fact includes the entire set of 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 pre-biotic chemistry, built upon earlier geo-diversity, and became diversified in the ancestral ocean, around 3.9 billion years ago. Life finally appeared rather quickly, after the initial cooling and condensation of water bodies.

C. de Duve (Nobel Laureate, 1974), said in "Dust of Life" (1996) that the Earth was so ideally positioned relative to the sun, that life could not avoid appearing. And J. Monod spoke about an improbable hypothesis! The oldest known sedimentary rocks (Akilia Island, southern Greenland) containing carbon from biological origins date from 3,850 million years (Ma). Imagine the very simple, primitive life that first developed from a world of RNA and proto-cells. Current deposits of stromatolites, those rocks that precipitate bicarbonate (with beautiful deposits in Australia, and some recently discovered in Greenland (3700 Ma)) are very valuable because they contain within their silicified parts the oldest fossils of known micro-organisms – cyanobacteria. These cyano-bacteria began to conquer the ocean from 3,700 to 3,200 Ma when there was no atmospheric oxygen. Thanks to their specific pigments, these cells, when exposed to water, have developed photosynthesis which

1 Practical salinity unit

produces oxygen and sugar by using light and carbon dioxyde (CO_2) before 3 500 Ma.

Oxygen then began diffusing beyond the aquatic environment: the composition of today's atmosphere – with 21% oxygen – dates from the Cretaceous, around 100Ma. In this ancient ocean, certain events occurred that proved crucial for living organisms and biodiversity: *(1)* the emergence of the nuclear membrane, and the individualized nucleus (prokaryote-eukaryote transition) around 2,200Ma; *(2)* the capture of ambient cyanobacteria that became symbionts and organelles of the cell, mitochondria and plastids, with their own little DNA, around 2,100 and 1,400Ma respectively; *(3)* the emergence of multicellular organisms and metazoans around 2,100Ma.

Then an exceptional event occurred in this ancient ocean: the emergence of sexuality – first in prokaryotes, later in eukaryotes. This proved vital for the explosion of biodiversity. Sexual reproduction allows for 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" among parasites and their hosts: co-evolution, molecular dialogue, and genetic mixing eventually allow for faster "disarmament" of the parasite and a sexual selection, very different from natural selection.

The physical consequences of osmotic flux (water and electrolytes) in the marine environment led living organisms to two types of strategies: *(1)* in the vast majority of cases – from the first initial cell to shellfish – an intracellular, isosmotic regulation provided living organisms, separated from seawater by a biological membrane, the same osmotic pressure (about 1,000 $mOsm.l^{-1}$) on the inside (intracellular milieu and extracellular "interior") 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 to 400 $mOsm.l^{-1}$) than sea water. This gave life a way out of the ocean.

The perpetual drinking behavior at sea, found in bony fish for example, associated with very active mechanisms of electrolyte excretion by the gill, 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 in order to avoid serious hydro-mineral imbalances.

Much later, during the Triassic, around 210 Ma, after the third major species extinction crisis around 251 Ma, the beginnings of thermoregulation developed and found their optimal efficiency among large dinosaurs, and especially 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: just the bacteria in the sub-surface layer of the ocean accounts for over 10% of all carbon biomass of the planet. The marine environment has played a key role in history.

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 – less than 270,000. This is very little, and may be explained by two things. The first is that our knowledge, especially for deep zones and for microorganisms, various bacteria and protists is still only very partial, so we significantly underestimate oceanic biodiversity. New techniques, such as coupling between flow cytometry and molecular probes, are allowing us to discover extraordinary biological diversity. At present, widespread sequencing of the ocean water mass, "random genome sequencing" (C. Venter, sequencing of all the DNA in a volume of filtered seawater) provides data that seems to be mostly unknown. The Tara Oceans expedition's circumnavigation provided us, in 2015, with some very valuable information on the profusion and variety of viruses, bacteria and protists, in particular dinoflagellates. These protists could represent nearly one million species. For all prokaryotes and very small eukaryotes, molecularapproaches (sequencing of 16S or 18S ribosomal RNA among others) bring surprising new information every day. Moreover, and this is the second reason, it's clear that marine ecosystems and species living in a continuous medium, through the dispersal of gametes and larval stages, are less predisposed to strict endemism than in terrestrial habitats. There are many more barriers and favorable speciation isolates (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 – much more fragmented and encouraging greater speciation. The stability of the open ocean, at least for the past 100 million years, is quite extraordinary: pH, osmotic pressure, salinity, temperature, hydrostatic pressures of the depths and dissolved gas content. Human activities are changing all this, and we will discuss this later. This stability is generating 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 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 (around 450 Ma for complex metazoans). The great Permian-Triassic extinction played a key role, with 96% extinction of species, both marine and on land (around 251 Ma). The explosion of flowering plant species, insects, and many other groups on Earth (around 130-110 Ma) was decisive after the initial radiations (explosions in species from a single ancestor) beginning in the Devonian and especially the Carboniferous. Co-evolution between plants and pollinators, and the appearance of an infinite number of new niches have often been proposed to explain the acceleration of speciation in continental environments during this period. It is also clear that the dispersion of sexual products and larvae in the sea plays an important role in the distribution of species and current bio-geography. Endemism is much more limited in the open sea, due to the stability and continuity of this gigantic environment. On land we often find species living on only a few km². No examples of marine species with such limitations are known. The enormous variety of marine modes of reproduction also take advantage of the phenomena of dispersion in water masses: males and females are not always obliged to be close! Thus, connectivity and many fewer variations in environmental factors create the great stability of the open sea, and the very specific characteristics of marine biodiversity. 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 unit of diversity, whether of an individual, a species or a population." This determines its history, past, present and future. What's more, this story is determined by processes that are themselves components of biodiversity. In fact, today we group together various approaches under this term: *(1)* the basic biological mechanisms that explain diversity of species and their characteristics and force us to further investigate the mechanisms of speciation and the evolution; *(2)* more recent and promising approaches in functional ecology and bio-complexity, including the study of matter and energy flows, and the major bio-geochemical cycles; *(3)* research on things in nature considered "useful" to humanity, providing food, or highly valuable substances for medicines, cosmetics, molecular probes, or to provide ancient and innovative models for basic and applied research, in order to solve agronomic and biomedical issues; *(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 the coasts, humans started collecting seafood, shells and algae, and catching fish. Just as they do agriculture on land, humans have been raising certain marine species on the coasts for at least 4,000 years (Egypt, China, etc.). The exploitation of renewable, living aquatic resources is booming, but with serious concerns about its sustainability. The latest figures available from the FAO in 2013 (for the year 2012) gave values of 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). The grand total – for all groups and all aquatic environments – was about 176 Mt. As a response to water mass warming, halieutic stocks swim up in average 72 kms to the North every ten years in the Northern hemisphere. Overfishing is also worrisome: in 15 years, between 50 to 90% of all large pelagic fish individuals were eliminated! Around three quarters of the stocks are fully or over-exploited

(29%). Aquaculture is booming but this raises questions on environmental impacts, species transplants and - for certain types of activity - the use of animal protein to feed species of interest (they are carnivorous). The living ocean is not only these resources. There are also about 25,000 molecules of pharmacological or cosmetic interest, and some extraordinary, extremely relevant models for scientific research, with potential biomedical and agricultural applications. Key molecules of carcinogenesis have been discovered thanks to sea urchins and sea stars, the molecular basis of memory thanks to a sea slug and the transmission of nerve impulses thanks to the squid.

OCEAN AND CLIMATE

The ocean and the atmosphere are intimately connected and exchange energy in the form of heat and humidity. The ocean absorbs heat (93%) much more readily than ice or land surfaces, and stores energy much more efficiently. It returns the heat more slowly than the continents, and contributes to the more temperate climate of coastal areas. The ocean is thus a formidable regulator of climate. Changes in energy balance between atmosphere and ocean play an important role in climate change. Ocean circulation is affected by atmospheric circulation, and surface currents are dependent on the winds. Winds mix the surface waters down to the thermocline, below which the basic forces of circulation are related to temperature and salinity, influencing the density of water. The ocean contributes to the huge amounts of energy released at the genesis of storms and cyclones, affecting both continents and human populations. Upwellings – cold water coming up from the depths near the coasts – are rich in nutrients, profoundly altering coastal climates; taking into account their fluctuations is essential for understanding the climate system. Just the first 3 meters of the ocean store as much energy as the entire atmosphere, and the ocean has huge thermal inertia and dynamic capabilities. This 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 these capacities for storing and releasing heat. This huge reservoir of heat gives the ocean an extraordinary role in moderating climate variations. It controls the formation of wind and rain. The ocean traps and stores CO_2 (26%), thereby preventing an extreme greenhouse effect in the atmosphere. But as a result, the ocean becomes acidic, due to the production of carbonic acid. Oceanic phytoplankton also stores CO_2 in the surface layer, as do all the bio-calcifiers. 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 fluctuations in the past led to the alternation of glacial periods.

The ocean plays a vital role on the climate, but the loss of biodiversity and also pollution affect the ocean and cause conditions for climate change. The amount of carbon dioxide in the atmosphere and in the ocean is increasing. Average temperatures of air in the lower layer of the atmosphere – near the land surface and near the ocean's surface – are rising. And average sea-level is rising faster than ever since the end of the last ice age. Rapid changes in the chemical composition of sea water have a harmful effect on ocean ecosystems that are already stressed by overfishing and pollution. This pollution is massive and widespread worldwide as humans are able to contaminate unoccupied areas (Arctic and Antarctica)! Plastic microbeads have accumulated, under the influence of ocean gyres in gigantic concentrations in five areas of the global ocean. Contaminated effluents should no longer reach the sea!

Climate change has a direct role in the loss of biological diversity, but this loss contributes in turn to the very problem! Biodiversity loss severely affects climate change! Phytoplanktonic chains in the sea are deeply influenced by climate change and their changes affect in return the capacity of the ocean to dissolve CO_2. Moreover, let's not forget that the effects of rapid climate change are added to other severe problems: destruction and pollution of the coasts, accelerating systematic exploitation of living resources, and the uncontrolled spread of species (including from the ballasts of large ships). It is also very important to legislate cleverly before any deep mineral exploitation, the deep sea being particularly fragile due to its stability on the very-long term.

This is a lot for the ocean to handle, and it is high time we took action !