4. Scenarios for the evolution of marine ecosystems

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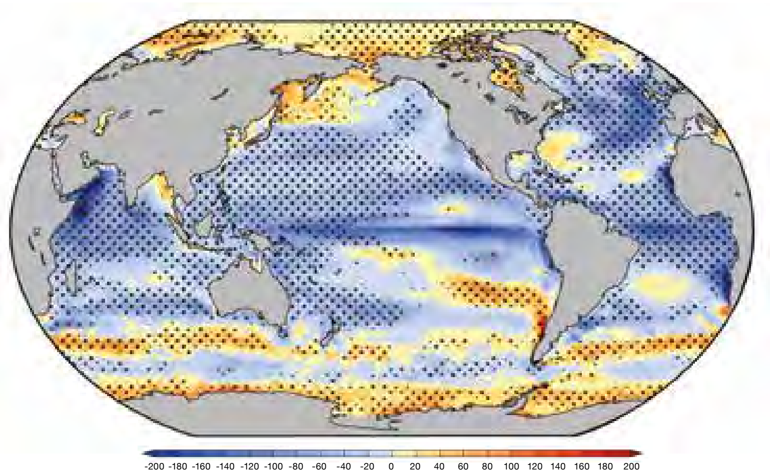
The oceans and their abundant biodiversity provide essential ecosystem services. Responsible for the sequestration of 25% of anthropogenic carbon emissions and the absorption of the majority of excess heat in the atmosphere, they also play a major role in the regulation of atmospheric CO_2 and of the climate (cf. II.14). Their exploitation by fishing is a key source of income and protein for a significant part of the global population. However, climate changes threaten these ecosystems and the valuable services they provide. These changes modify the temperature, stratification and circulation of the ocean. They could lead to the expansion of vast hypoxic regions, while the absorption of anthropogenic carbon causes the waters to acidify (cf. II.9). These changes hinder primary production, which is vital for ecosystems and biodiversity. With marine ecosystems being driven towards unprecedented states, scientists are beginning to quantify the future consequences of this for the climate, fisheries and their economies.

Meanwhile, fish is playing an ever-growing role in the human diet, and consumption has now reached 20 kg per person per year. The importance of marine resources for food security has been established, and looks set to grow in the future, with the human population predicted to reach 9.7 billion in 2050. Pressure on marine resources will therefore also grow, while their ecosystems are already weakened by fishing and threatened by climate change. In this worrying context, it is crucial to define scenarios based on integrated models of marine socio-ecological systems. This is the foundation of the work of the IPCC (Intergovernmental Panel on Climate Change) and the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services), who attempt to anticipate the threats and opportunities generated by the coming changes, and to quantify future vulnerabilities. It is also important to devise prevention, adaptation and governance strategies that will allow us to achieve the ocean conservation and sustainable exploitation objectives set out in SDG 14 (cf. I.14).

More stratified and less prosperous oceans

The warming of the atmosphere is transmitted to the oceans, meaning that their surface temperature could rise by 0.7 to 2.7°C by 2100, according to the forecast climate scenario. However, this warming primarily affects the surface layers, which warm up faster than the deep layers, causing increased stratifi-



Predicted change in primary production (g.C.m^{-2}.year^{-1}) between the start and the end of the 21st century, for climate scenario RCP 8.5: 'business as usual'. The dotted areas are those where the projection is most robust. According to Pörtner *et al.*, 2014. ■

cation of the oceans. This effect is likely to worsen in the future, particularly at low latitudes.

More stratified oceans will be less prosperous. Water layers of different temperatures, and therefore different densities, limit the ascent of deep nutrients towards the surface, where primary production takes place. This will cause phytoplanctonic production to fall by 9% by the end of the century, according to the worst case scenario used by the IPCC (RCP 8.5). Primary production will fall most at low and medium latitudes, where stratification will increase the most. In contrast, models predict that phytoplanctonic production could rise, sometimes significantly, at high latitudes (Fig.).

Deoxygenated and more acidic oceans

The warming of the surface waters reduces oxygen solubility, while increased stratification decreases ventilation of the deeper waters. It is predicted that by the end of the century, these two phenomena will cause a 1.8 to 3.5% drop in the total quantity of dissolved oxygen in the ocean. This decrease will lead to accelerated vertical and horizontal expansion, particularly in temperate and polar zones, and in oxygen minimum hypoxic zones, which today essentially occupy vast regions in the eastern tropical Atlantic and Pacific oceans. It will also contribute to the multiplication of anoxic 'dead' zones in eutrophic coastal zones, where only certain bacteria can survive.

The oceans absorb a significant portion of atmospheric CO_2. This dissolved oxygen forms carbonates and acidifies the waters. Over the century, the increased presence of CO_2 emissions in the atmosphere could cause a 0.07 to 0.33 unit drop in the oceanic pH. This acidification of the oceans is very likely to have major impacts on many calcifying species. This will modify the structure of ecosystems, particularly that of the coral reefs (cf. II.25), which are already affected by rising water temperatures.

Resource decline and redistribution

Several studies show that the drop in primary production could be amplified at the upper trophic levels. Therefore, the global decrease in primary production would cause a 15 to 25% reduction in global fish biomass by 2100. Moreover, temperature is an essential determinant for the physiology of marine organisms, which can only survive in very specific ranges. Increased water temperatures will therefore profoundly modify their spatial distribution. The tropical waters may become deserted because they will grow too hot. When tropical and temperate species can no longer easily colonize the deeper waters, which are cooler but darker and increasingly deoxygenated, they will be pushed towards the poles, where productivity will increase. Meanwhile, polar species will no longer be able to find a suitable habitat, and risk mass extinction.

Today, it is acknowledged that most marine species will undergo radical changes in abundance, geographical distribution, migratory routes and phenology (cf. VI.9). However, these changes will vary from one species to the next, and between regions. Interactions between species and the composition of communities will be distorted. Fisheries will be forced to adapt. Overall, the tropical regions face the biggest losses. Conversely, new exploitation opportunities may appear in the polar regions, but these will need to fit in with the conservation of threatened species. To understand how our choices today influence the ocean that will support our lives tomorrow, it is vital to define scenarios for marine socio-ecological systems. We must not only warn of the dangers to come, but also devise new paths towards sustainability. The stakes are high: we need to build the knowledge that will allow us to avoid the unmanageable, and equip us to manage the unavoidable.

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