Chapter 8

Crystal clear waters filled with microscopic organisms

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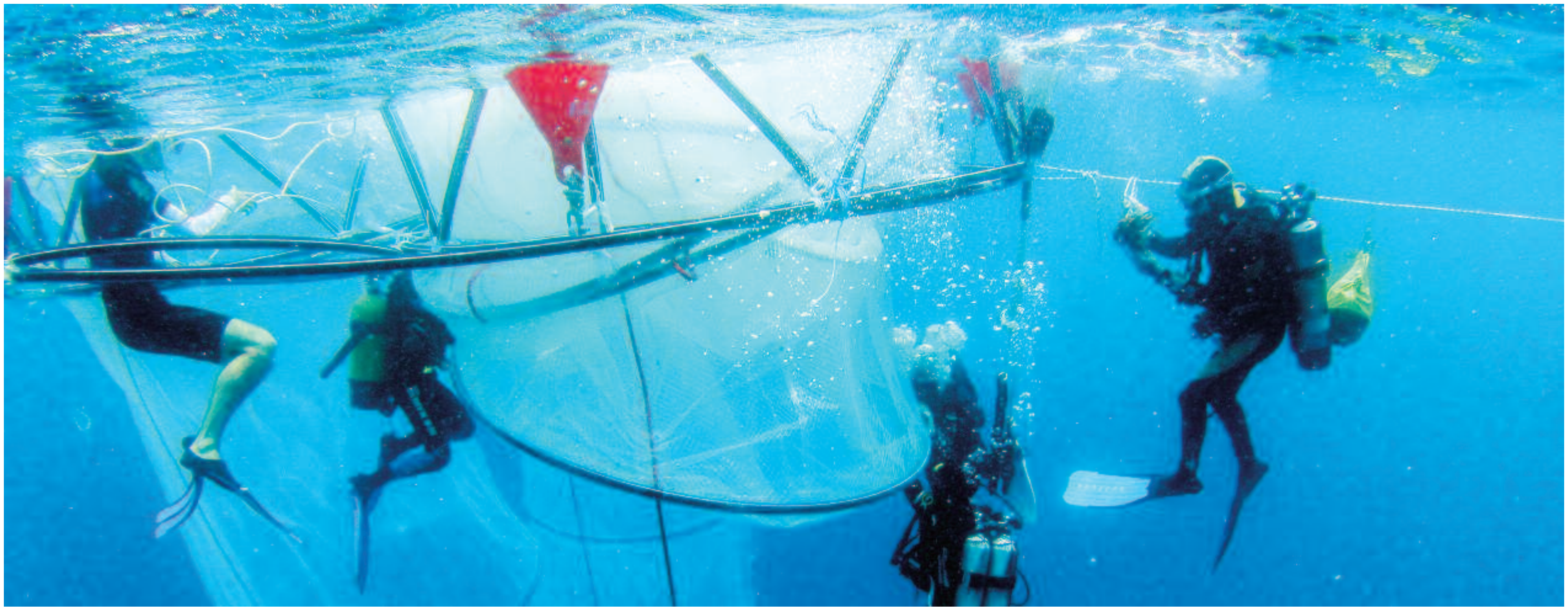

Mesocosms set up for the VAHINE project in New Caledonia. © IRD/J.-M. Boré and IRD/E. Folcher

Most of the water surrounding the coral reefs and lagoons of New Caledonia is crystal clear. The water clarity, or oligotrophy (poor in nutrients, from the Greek "*oligo*": few, and "*trophein*": feeding), is due to the very low nutrient concentration of the oceanic waters that flow into the lagoon with tidal currents or wave-breaking over the reef. Research programs carried out in the lagoon have identified two major factors which explain most of the spatial variability of the waters' characteristics (FICHEZ *et al.*, 2010): a trophic enrichment gradient and a salinity gradient. These two factors testify to the perpetual battle between terrestrial and oceanic influence in the lagoon. While the trophic enrichment at the coast can be due to natural factors, such as long water-renewal time in the most sheltered zones, some sites are markedly different. For instance, near urban zones, abnormal enrichments can be linked to wastewater discharge. Seasonal and interannual temperature and salinity variations are also amplified at the coast. As a result, bays amplify the physical functioning of the lagoon, with implications for the distribution of species and environmental vulnerability.

Although, waters surrounding the coral reefs and lagoons of New Caledonia are mostly crystal clear, each of the water drops that fill the lagoon is packed with millions of microscopic organisms called plankton (from the Greek *"planktos*" meaning "errant" or "drifter"). These organisms are remarkably adapted to their very specific environment, where they live suspended, and drift with currents.

Barely known, because they are invisible to the naked eye, they are mostly made of bacteria, microalgae (or "phytoplankton"), and microscopic animals (or "zooplankton"). Like terrestrial plants, phytoplankton is made of photosynthetic organisms that contain chlorophyll, with which they can absorb solar energy. Sunlight, carbon dioxide (CO_2) and minerals dissolved in seawater (nitrogen, phosphorus, and micronutrients) are sufficient for phytoplankton to grow and develop. Phytoplankton plays a key role for several reasons. Firstly, it is at the base of the marine food chain and it also produces large quantities of oxygen through photosynthesis. At the global scale, it is estimated that phytoplankton generates over half the oxygen of our planet, while it represents only 1% of the biomass of all photosynthetic organisms (most being terrestrial plants). Lastly, it plays a role in climate regulation, as it uptakes atmospheric CO_2 through photosynthesis. When it dies, part of the phytoplankton sinks to the bottom of the oceans, allowing for the durable sequestration of CO_2 through a process known as the "biological carbon pump". In the lagoons, the planktonic organisms that sink to the bottom contribute to feeding benthic organisms such as corals (chap. 7).

The Western Tropical South Pacific Ocean, including New Caledonia and archipelagos between Australia and Tonga, are unique because they harbor the largest biomass of nitrogen-fixing microalgae in the world (BONNET *et al.*, 2017) (Fig. 1). These microalgae, also called "diazotrophs" are very competitive organisms in these oceanic deserts. They are capable of living in waters that are very poor in mineral nitrogen elements because they can use atmospheric dinitrogen (an unlimited resource) and fix nitrogen themselves. This process fertilizes surface waters with nitrogen, acting like a natural fertilizer, and sustains other organisms that, otherwise, would not have been able to live in these deserts.

The filamentous cyanobacteria *Trichodesmium* are found throughout the year in tropical waters. Aggregated in fusiform colonies, they accumulate at the surface to look like gold dust (or sawdust). They are often observed by ships that navigate in the region and recorded as "colored waters" on the most ancient nautical charts. Samples collected by the national navy, stretching all the way to Vanuatu, Fiji and Tonga, revealed an important species diversity,

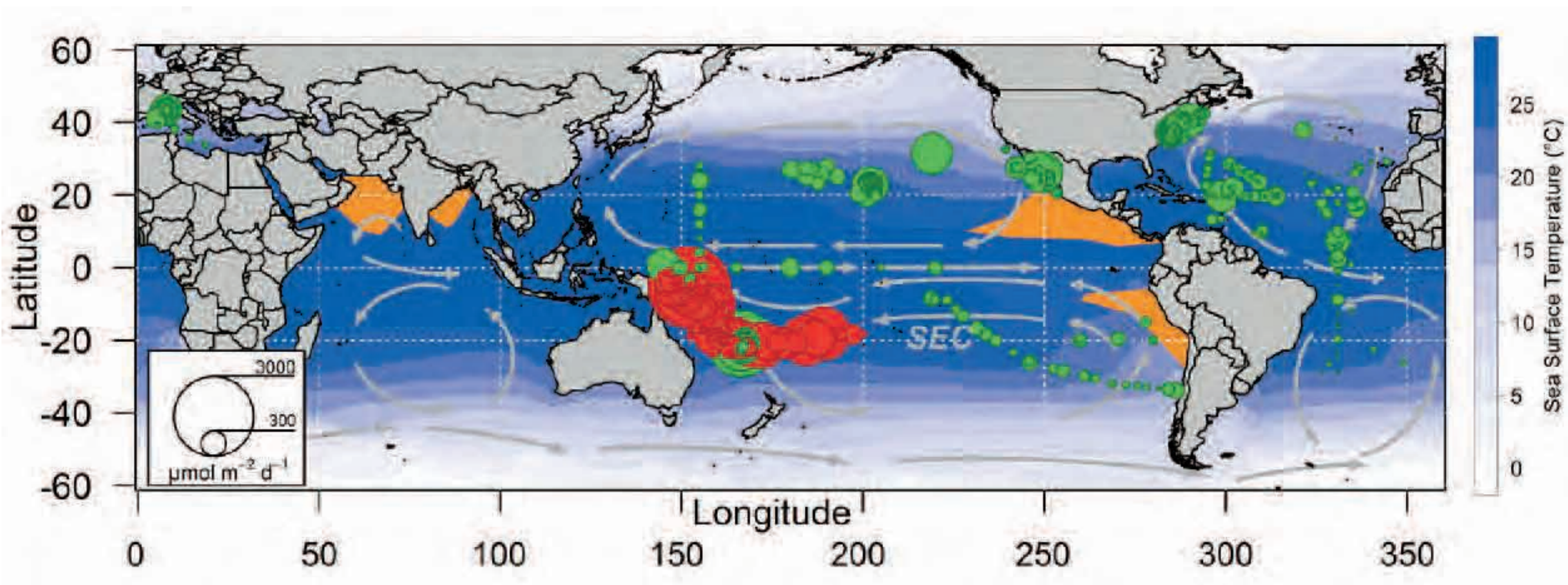

Figure 1: Nitrogen fixation rate (µmol N m^{-2} j^{-1}) in the Southwest Pacific (in red) and in the rest of the world (in green). Adapted from BONNET *et al.*, 2017

which is similar to what is found in New Caledonia. These 98 surface water samples have been used for the calibration of an automated detection algorithm (DUPOUY *et al.*, 2011). Algal blooms seen on satellite images can cover thousands of square kilometers. Assuming a homogeneous distribution of *Trichodesmium* across the areas where it is detected (90,000 km^2), and an average nitrogen fixation rate, it has been estimated that a bloom of diazotrophs can fix between 0.02 and 1.17 x 109 g of nitrogen over a period of 10 days (DUPOUY *et al.*, 1988).

In the lagoons of New Caledonia, the growth of *Trichodesmium* increases during summer. Blooms approximately a week-long are triggered by the combination of weak winds and nutrient enrichment on the west coast in the Sainte-Marie Bay (*T. erythraeum*), and on the east coast in the Ouinné Bay (*T. thiebautii*, oceanic species) (RODIER and LE BORGNE, 2010).

In order to study the role of these organisms on the functioning of the New Caledonian lagoon ecosystem in detail, a team from the IRD research center has led experiments in the lagoon over a month. They used mesocosms, giant 50,000 L test tubes, for the study of organisms that form the base of the marine food chain. The objective was to answer the question: Who benefits from the fertilization provided by diazotroph microalgae? The main results of this project highlighted that most of the new biological production in the water column in the New Caledonian lagoon, is supported by the activity of diazotroph microalgae during the summer. Within the mesocosms, blooms increased the system's productivity by two-fold, and its carbon export by five-fold (BERTHELOT *et al.*, 2015). The fate of nitrogen produced by fixation in the ecosystem appeared to be dependent on the organisms that were present.

When the dominant organisms in the community were diazotrophs living in symbiosis with microalgae that are incapable of fixing dinitrogen (diatoms), the nitrogen derived from diazotrophy (NDD) was exported (directly) (BERTHELOT *et al.*, 2015). In this case there was no transfer to the organisms at the base of the planktonic food chain (phytoplankton/bacteria), but instead the NDD was transferred to zooplankton through direct grazing (HUNT *et al.*, 2016).

When free and unicellular diazotrophs (UCYN, *Cyanobacterium*) were dominant, about 20% of the NDD was rapidly (in 24 hrs) transferred to non-diazotrophic plankton (BONNET *et al.*, 2016), and to zooplankton. For the latter, nitrogen demand was sustained at 35 % by nitrogen fixation (HUNT *et al.*, 2016), either directly by grazing on diazotrophs, or indirectly by grazing on plankton that developed on NDD. The efficiency of the system in exporting carbon, relative to the fixation of carbon by phytoplankton (primary production) (e-ratio), was higher when UCYN were dominant. This export was both direct, with the high sedimentation rate of UCYN small cells (5.7 ± 0.8 µm) aggregated in large particles (100-500 µm), or indirect, through the sedimentation of non-diazotrophic plankton that developed on NDD (BONNET *et al.*, 2016). In total, 60% of the exported production was supported by diazotrophy.

Results obtained during the VAHINE (Variability of Vertical and Trophic Transfer of Diazotroph-derived Nitrogen in the Southwest Pacific) project provided the first quantitative data on the fate of nitrogen fixation in the marine ecosystem, as well as a classification of the dominant types of organisms involved. These were integrated into a model that enables numerical simulations to predict the evolution of productivity in the lagoon and the surrounding waters (GIMENEZ *et al.*, 2016). Numerous studies show that diazotrophy should increase in the warmer, more acidic and stratified oceans predicted to exist in the future, reinforcing the relevance of these simulations.

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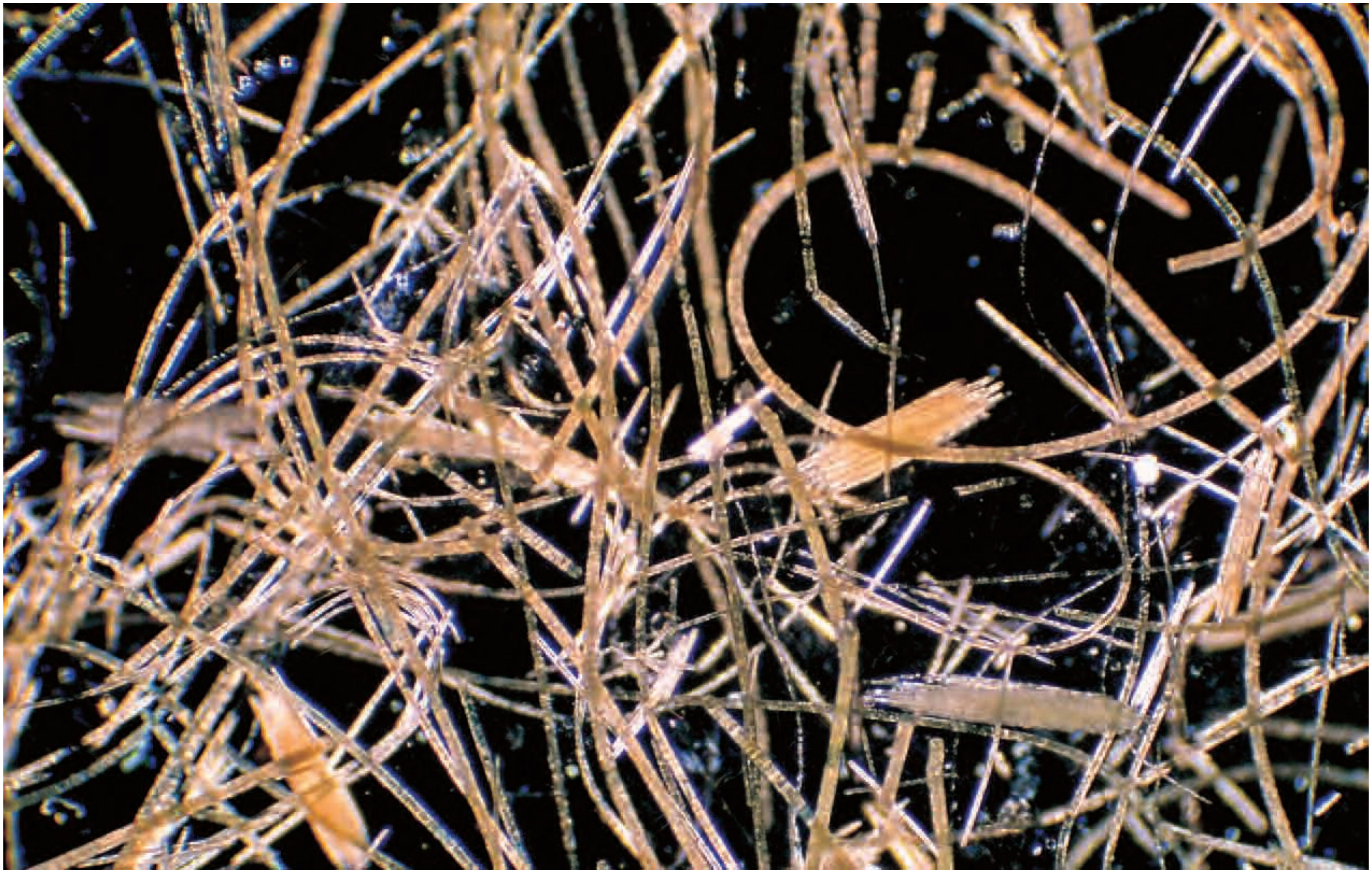

Trichodesmium seen through a microscope. © IRD/G.Dirberg and C. Dupouy

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