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Simulation of an artificial upwelling using immersed in situ phytoplankton microcosms

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ABSTRACT

The inflow of deep seawater in the surface layer by an Ocean Thermal Energy Conversion (OTEC) plant will generate artificial upwelling. In order to study the potential impact on biogeochemical processes that could result, in situ microcosms were designed to simulate seawater plant discharge and these were deployed off the Caribbean coast of Martinique. Seawater was collected in ultra-clean conditions at maximum chlorophyll *a* concentrations (45 m depth). The water was then mixed with either 2% or 10% deep seawater (1100 m depth) and put in 2.3 L polycarbonate bottles. These microcosms were immersed for 6 days at 45 m depth on a 220 m mooring. Samples from the surrounding environment and from the microcosms were analyzed by pigment quantification, counting of picophytoplankton groups and macronutrient analyses. Similar trends in the evolutions of the phytoplankton populations were observed over time between the control microcosms (without addition of deep seawater) and the surrounding environment, suggesting that these microcosms can be used as a realistic representation of the natural surrounding waters over a 6-day incubation period. Microcosm enrichment with 10% deep seawater induced a shift in the phytoplankton assemblage towards the development of diatoms, haptophytes, and *Prochlorococcus*, whereas 2% enrichment only led to an increase in the *Prochlorococcus* population.

1. Introduction

Today's crucial need for energy transition has stimulated growing interest in new methods for renewable energy production. The solar energy absorbed by oceans is one of the most important potential sources of energy. Part of this energy can be harvested and used for processes such as operating a heat engine. By exploiting the natural temperature gradient between the surface and the deep ocean, the Ocean Thermal Energy Conversion (OTEC) process achieves this objective. Warm surface seawater passing through a heat exchanger will cause the evaporation of a low boiling working fluid (frequently ammonia), while cold deep seawater will be pumped at around 1100 m depth and used to condensate this working fluid in another exchanger. The pressure gradient will generate mechanical energy through a turbine, converted in electrical energy through a turbo-generator. The intertropical zones in the global ocean, which are typically at 5 °C at 1000 m depth and 25 °C at the surface, are well suited to OTEC, since such systems require a minimum temperature difference of 20 °C.

In an OTEC plant, due to efficiency questions, the deep seawater has to be rejected close to the surface. So the cold water pumped from the deep sea towards the upper ocean (at about 100 000 $m^3.h^{-1}$) can be compared to an upwelling, such as those naturally occurring at the eastern boundary of the oceans. In such natural systems, due to strong winds, Coriolis effects, and Ekman transport, the surface waters are moved offshore creating a low pressure area and resulting in nutrient-rich deep water upwelling. This phenomenon is observed in a number of different oceanic regions, including the four most active eastern boundary upwelling systems: the Benguela, Humboldt, California, and Canary systems (Capone and Hutchins, 2013; Chavez and Messié, 2009). The cold deep waters lift macronutrients and trace metals up to the photic zone (Anderson and Lucas, 2008; Bruland et al., 2005), sustaining intense phytoplankton development (Chavez and Toggweiler, 1995) and making upwelling systems the most productive marine ecosystems (Carr, 2002). These systems are therefore often involved in the development of oxygen minimum zones (Helly and Levin, 2004). Thus, in an OTEC system, the artificial upwelling created by the inflow of bottom water into the surface layer (whose temperature and chemical composition are quite different) could locally alter the structure and functioning of the ecosystem. Hence, the artificial upwelling linked to the use of an OTEC plant in oligotrophic surface waters could even strongly impact key biogeochemical processes (like primary production) and induce modifications in the phytoplankton community. To

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assess the anticipated effects on the phytoplankton community, the release of bottom water under the operating conditions of an OTEC needs to be reproduced experimentally.

Experimental simulation of an upwelling has already been conducted, for example by injecting deep water into the surface with an artificial upwelling platform (Aure et al., 2007; Handå et al., 2014), or using incubations of oligotrophic plankton communities with deep water nutrient enrichment under artificial light and temperature conditions (McAndrew et al., 2007). Microcosms and mesocosms are classically used to assess nutrients and light limitations or to test perturbation on biogeochemical parameters (Escaravage et al., 1996; Herut et al., 2005; Kress et al., 2005; Petersen et al., 1997; Thingstad et al., 1999). According to Leffler (1984), a microcosm is a "small, living model of ecosystem processes", that allows the temperature and light of the natural environment to be reproduced as closely as possible. Usually, for practical reasons, microcosm experiments are carried out under artificial temperature and light conditions but, in order to conduct experiments with conditions close to natural temperature and light, in situ microcosms were developed (De La Broise and Stachowski-Haberkorn, 2012; De La Broise and Palenik, 2007; Stachowski-Haberkorn et al., 2008). By immersing the microcosms at the depth of phytoplankton sampling, the phytoplankton populations within them are thus exposed to similar temperature and light conditions as in the natural environment. Such *in situ* microcosms have been previously used in toxicity experiments, conducted close to the surface (between 4 and 6 m depth) in eutrophic waters (Stachowski-Haberkorn et al., 2008). Because the maximum chlorophyll *a* concentration is typically deeper in tropical waters, occurring near the base of the euphotic zone (McManus and Dawson, 1994), new *in situ* microcosms were designed that could be immersed much deeper (down to 80 m), in order to simulate upwelling conditions like those generated by the implementation of an OTEC in oligotrophic waters. Small volumes allowed a large number of microcosms to be run simultaneously, making it possible to examine different conditions and include several replicates. In the present work, the evolutions in the phytoplankton community and macronutrient concentrations were compared between the *in situ* microcosms and surrounding surface waters and, over the course of the experiment (6 days), to assess the representativeness of these microcosms. Furthermore, the use of these microcosms to simulate an artificial upwelling was evaluated, and compared to natural upwelling records.

2. Materials and methods

2.1. Site of study and water sampling

Microcosm experiments were conducted for 6 days at the end of the dry season (12 to 18 June 2014) off the Caribbean coast of Martinique, opposite Bellefontaine (Fig. 1).

Surrounding surface waters were collected on days 0 and 6 (12 and 18 June 2014, respectively) of the experiments on the site of the future offshore OTEC demonstration plant (at 14°37′57″N-61°11′52″W, where the seafloor is at around 1300 m depth) from the vessel *Pointe d'Enfer* of the Martinique Lighthouses and Beacons Service.

Four other stations, located at 0.54 nautical miles SE, NE, NW and SW away from the future OTEC site, were sampled on 11, 13, 16, and 19 June (ST4, ST2, ST3 and ST1, respectively, Fig. 1).

For practical reasons, the mooring was located closer to the coast (14°39′8″N-61°10′9″W, where the seafloor is at around 220 m depth, Fig. 1).

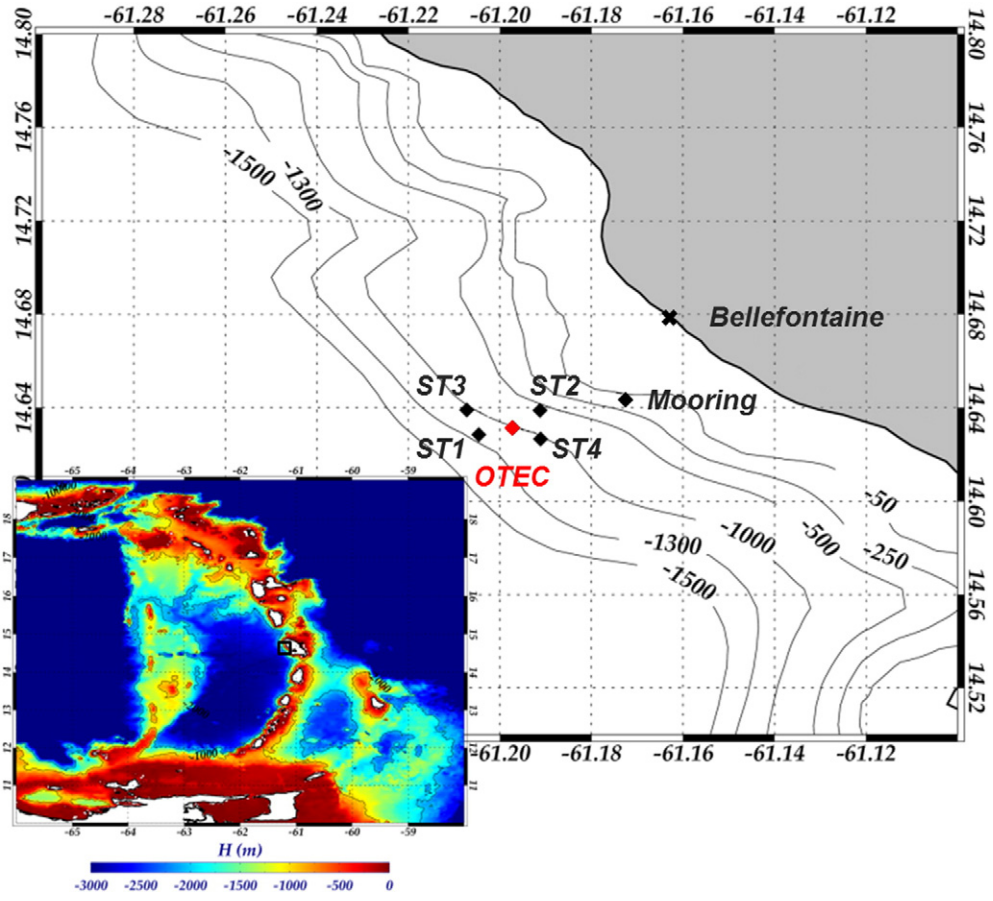

Fig. 1. Location of the OTEC station and mooring where nutrient enrichment experiments were conducted, and location of the four other sampling stations (ST1, ST2, ST3, and ST4).