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Variability of CO_2 emissions during the rearing cycle of a semi-intensive shrimp farm in a mangrove coastal zone (New Caledonia)

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ABSTRACT

In New Caledonia, shrimp ponds are built not on cleared mangroves but on salt flats behind the mangroves. The objectives of this study were to determine the variability of CO_2 fluxes from a semi-intensive shrimp pond during active and non-active periods of the farm and to determine the carbon dynamics from the upstream tidal creek to the downstream creek, which receives the farm's effluents. CO_2 emissions from the active pond were estimated at 11.1 ± 5.26 mmol CO_2 m^{-2} d^{-1}. By modifying the hydrodynamics of the creeks, farm practices also influenced CO_2 emissions from both the upstream and downstream creeks. After tillage, all the organic carbon deposited at the pond bottom during the active period was mineralized, resulting in CO_2 emissions to the atmosphere estimated at 7.9 TCO_2 ha^{-1}. Therefore, shrimp farming is an anthropogenic source of CO_2 to the atmosphere, but suitable and optimized rearing practices limit these emissions.

1. Introduction

Tropical and subtropical coastal ecosystems have a high capacity to fix and store carbon and were thus recently named "blue carbon" sinks (Mcleod et al., 2011). Among these coastal ecosystems, mangroves are considered very efficient due to their high productivity and the anoxic character of their substrate (Bouillon et al., 2008; Kristensen et al., 2008; Alongi, 2014). In addition, they have important ecological, sociological and economical roles (Walters et al., 2008; Lee et al., 2014). However, due to the increased demographic pressure in emerging countries, mangroves are disappearing worldwide at a rate similar to tropical rainforests and coral reefs (Duke et al., 2007; Hamilton and Casey, 2016). Notably, shrimp farming alone accounts for 38% of mangrove deforestation (Alongi, 2002; Wilkie and Fortuna, 2003). Mangrove deforestation leads to a loss of CO_2 fixation, and aquaculture may emit CO_2 to the atmosphere. As a result, shrimp farming may turn tropical coastal systems from a CO_2 sink into a CO_2 source. To our knowledge, few studies have been interested in this topic, but some recently published studies confirmed that aquaculture ponds are a source of CO_2, during both the active period (Vasanth et al., 2016) and the non-active period due to the mineralization of organic matter (OM) deposited at the pond bottom during rearing (Sidik and Lovelock, 2013). In their study, Vasanth et al. described the influence of shrimp species and stocking density on CO_2 emissions. However, given the numerous other variables that can differentiate aquaculture practices (*e.g.*, aeration, feeding, water renewal) and the continuous development of this industry, it has become increasingly important to accurately determine CO_2 emissions generated by aquaculture.

In New Caledonia, shrimp farming was developed at the beginning of the 1980s and now represents the second largest export activity of the archipelago, after nickel mining (IEOM, 2010). Only one species is bred: *Litopenaeus stylirostris*, commonly called the "blue shrimp". The sector responded to many zootechnic and socio-economic issues, but many questions about its environmental footprint remain. Indeed, New Caledonia has important ecological wealth to be preserved: the longest barrier reef in the world (1600 km), which delimits a lagoon of

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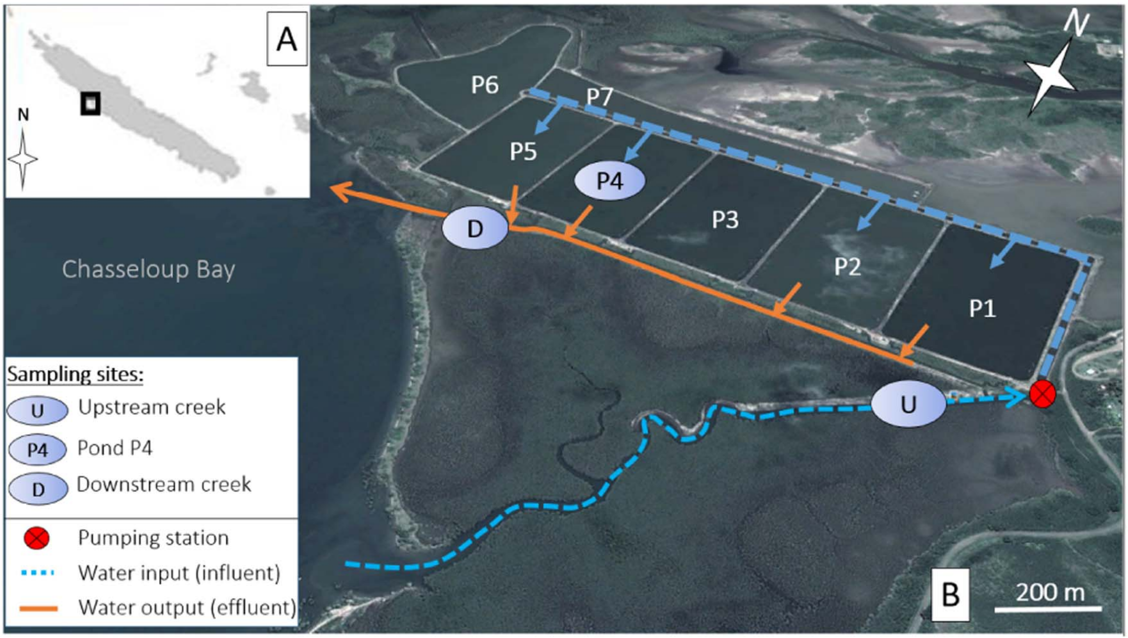

Fig. 1. Map of the study area. A: Map of New Caledonia and the location of the shrimp farm. B: Satellite picture of the shrimp farm with the sampling sites (During the study, there were four active ponds: P1, P2, P4 and P5) (Google Earth©).

15,000 km^2 that is classified as a World Heritage site by the UNESCO. In New Caledonia, shrimp farms are located along the west coast of the main island, 88% of which is covered by mangrove forests. Unlike in Asian countries, shrimp ponds are located behind mangrove areas in unvegetated salt flats. However, even if mangroves were preserved from deforestation, aquaculture impacts the ecosystem by using it as a natural filter of effluents to reduce the impact of effluents on the adjacent lagoon. To fill the ponds and maintain good water renewal, farmers pump water in the lagoon and release the effluents into the adjacent mangrove. Recently, several studies were developed to assess the impact of this practice on water and sediment quality of the receiving mangrove (Molnar et al., 2013, 2014; Aschenbroich et al., 2015) and on the meiobenthos biodiversity and biomass (Debenay et al., 2015; Della Patrona et al., 2016). These studies demonstrated that mangroves act only as a partial filter of the effluents because increased levels of nutrients were measured outside the mangrove (Molnar et al., 2013). Additionally, inputs of organic matter from the ponds led to an increase in phytobenthic production within the mangrove, even after the cessation of the effluent release (Molnar et al., 2014). However, there were no signs of eutrophication or anoxia of the sediment in the effluent-receiving mangrove (Debenay et al., 2015; Della Patrona et al., 2016). Nevertheless, the influence of rearing practices on CO_2 emissions in this specific system has never been studied. Therefore, obtaining data on CO_2 fluxes from the ponds to the atmosphere and from the mangrove tidal creeks connected to the ponds at different periods of the rearing cycle would be relevant.

The objectives of this study were thus to determine i) carbon dynamics in the different compartments of this coastal system, namely, the upstream creek, shrimp pond and downstream creek, and ii) the influence of rearing practices on CO_2 emissions at the water-air interface and from the pond bottom during the drying period. Because CO_2 emissions from salt flats are low (Leopold et al., 2013), notably due to their low OM content (Marchand et al., 2011a), our hypothesis was that the installation of ponds in this zone would strongly increase CO_2 emissions. Our second hypothesis was that the release of effluents into tidal creeks would also lead to higher CO_2 emissions from this adjacent ecosystem. To reach our goals, a typical shrimp farm was studied in northern New Caledonia during active and non-active periods of the rearing cycle.

2. Material and methods

2.1. Study site

Webuihoone farm is located on the northwest coast of New Caledonia (southwest Pacific). This farm is near the village of Voh and in front of the Chasseloup Bay (20°57′15″S, 164°40′19″E). The climate is semi-arid to sub-tropical and presents two main seasons. The warm season, from December to March, is characterized by high temperatures with an annual maximum temperature of 29 °C. The fresh season, from June to September, is characterized by lower temperatures with an annual minimum temperature of 18 °C. The annual precipitation in this area is 1100 mm. The study was undertaken between May and August 2015, when the precipitations were low (< 80 mm per month, data from meteo.nc).

The 55.1 ha farm was built in 1993 and has seven rearing ponds of 7.7 ha each. The farm seeds 23 to 24 shrimp post-larvae per square meter, representing a total of 1.8 million larvae per pond. The rearing capacity of the farm is evaluated at 12.6 million shrimps. The production system of Webuihoone is semi-intensive but is better characterized as an intensified semi-intensive (ISI) system, which is common in New Caledonia. Upstream, the farm is surrounded by unvegetated salt flats, while downstream, it is surrounded by mangroves, mainly *Rhizophora* spp. and some *Avicennia marina* trees. The water to fill the ponds is pumped from the upstream creek for several hours each day. However, effluents are continuously released into the downstream mangrove creek (Fig. 1).

The rearing cycle of the farm is divided into two main periods: the active period (AP) and the non-active period (NAP) (Fig. 2).

The AP includes seeding, production and harvests. Rearing practices increase in intensity with shrimp size during production (P): the water renewal rate increases (up to 45% per day, when shrimp density is important); feeding increases (up to 400 kg per day per pond); and the aeration rate increases to maintain high oxygen concentrations (avoiding any concentrations lower than 3 mg L^{-1}). Once a week, the farmers check some physico-chemical parameters in the ponds such as pH, oxygen and chlorophyll-*a* concentrations in the water as well as the mean biomass of shrimps. In this way, they can modify their practices (water renewal rate, feeding and aeration) depending on the survey, in