Effects of sewage effluent diversion on nutrient and phytoplankton dynamics in French Mediterranean lagoons: results from a ten-year survey

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Abstract

Along the French Mediterranean coast, many lagoons are subjected to increasing anthropogenic pressure and appear to be particularly sensitive to climate change. Since 2001, the trophic state of 8 lagoons has been followed based on monitoring of physical, chemical and biological (phytoplankton) variables of the water column. Initially, summer phytoplankton chlorophyll a (Chl a) maxima reached 20 to 413 µg/l depending on lagoons. In 2005, the implementation of a 10 km offshore outfall system diverted secondarily treated waters from the sewage treatment plant of the Montpellier district (450 000 inhabitants) and led to a major decrease in nutrient inputs to those lagoons located in the vicinity of the previous outfall. This anthropogenic decrease also corresponded to a natural decrease related to 4 consecutive dry years limiting nutrient inputs from point and non-point sources. Total nitrogen (TN) and phosphorus (TP) as well as suspended Chl a were used as integrating variables allowing to show an improvement in lagoon water quality. Five years after implementation of the outfall, summer concentrations of TN and TP were decreased by factors of 1.5 to 4, and Chl a concentrations were decreased by factors of 10 to 55 depending on lagoons. In response to decreased anthropogenic inputs, the structure of phytoplankton communities, in terms of pigment composition (diatoms, dinoflagellates, cyanobacteria), densities (pico- and nanoplankton) and diversity, has also changed. The Chl a decrease in particular was associated with a decrease in diatom pigment markers and an increase in dinoflagellate pigment markers.

Keywords: Mediterranean, lagoons, phytoplankton, water quality improvement

Introduction

Along the Mediterranean coast of Southern France, lagoons show a great variety of habitats, ranging from freshwater to hypersaline and from oligotrophic to hypertrophic (Souchu et al. 2010¹, Bec et al. 2011²). Among the more eutrophic ones are the so-called Palavasian lagoons, located near the Montpellier district sewage outfall and connected to the Lez river. In 2005, the diversion of this outfall directly out to sea offered the opportunity to follow improvements in water quality of those lagoons as these were expected to recover with time. Here we report changes in summer physical, chemical and biological (phytoplankton) variables of the water column over 5 years before and 5 years after sewage diversion.

Materials and Methods

We used a database developed in the framework of the French Mediterranean Lagoon Monitoring Network operated since 1998, and obtained from 8 Mediterranean coastal lagoons (called Palavasian lagoons) located in the Languedoc-Roussillon region in southern France. The objective of Lagoon Monitoring Network is to evaluate the lagoon trophic status based on variables characteristic of the water column, sediment and macrophytes. These shallow and confined lagoons were particularly impacted by eutrophication processes because they received effluents from the sewage treatment plants of the Montpellier city district (450 000 inhabitants). In December 2005, the implementation of a 10 km offshore outfall system diverted secondarily treated waters from this sewage treatment plant.

¹ Souchu et al. (2010) Patterns in nutrient limitation and chlorophyll a along an anthropogenic eutrophication gradient in French Mediterranean coastal lagoons. 67:743-753 Can J Fish Aquat Sci
² Bec et al. (2011) Distribution of picophytoplankton and nanophytoplankton along an anthropogenic eutrophication gradient in French Mediterranean coastal lagoons. 63:29-45 Aquat Microb Ecol
The lagoon data were collected monthly during summer (June, July and August) from 2001 and 2010. The following water column parameters were measured: temperature, salinity, nutrients (dissolved inorganic nitrogen and phosphorus, DIN and DIP), total nitrogen and phosphorus (TN and TP) and phytoplankton (total chlorophyll a concentrations and pico- and nanophytoplankton abundances). Since 2006, phytoplankton community composition based on HPLC pigment analysis was also monitored. Pigment markers (fucoxanthin, peridinin, alloxanthin, zeaxanthin and chlorophyll b) have been used to estimate the taxonomic composition of phytoplankton. Rainfall data were provided by Météo France (Fréjorgues station).

Results

In 2001, the 8 Palavasian lagoons were mesotrophic (North and South Ingril lagoon) eutrophic (Vic, Pierre Blanche and Prevost lagoons) and hypertrophic (Mejean, Arnel and Grec lagoons) (Souchu et al. 2010). Effluents from the sewage treatment plants supplied 60% of total nutrient loads in the lagoons. In the eutrophic and hypertrophic ones, high phytoplankton biomasses (up to 413 µg Chl a/l in summer in Méjean lagoon) could considerably reduce the light penetration in the water column, limiting or preventing the development of macroalgae. In most lagoons, the steady-state nutrient conditions led to the dominance of small (ca. 2-6 µm) eukaryote phytoplankton (Bec et al. 2011).

The comparison of the 5-year periods before (2001-2005) and after (2006-2010) the implementation of sewage effluent diversion shows a high and positive impact on water quality of Palavasian lagoons. First, the decrease of nutrient concentrations is weak (divided by 1.3 and 1.2, respectively for DIN and DIP) because of the steady-state nutrient conditions of lagoons, and the summer nutrient release from sediments (particularly for DIP). Second, the sewage diversion has mainly impacted eutrophication parameters such as TN and TP (divided by 1.9 and 2.1, respectively) and strikingly Chl a concentration (divided by 8.6). The anthropogenic nutrient decrease corresponded to a natural decrease related to 4 consecutive dry years (from 2005 to 2008) limiting nutrient inputs from point and non-point sources. These weather conditions could have amplified the apparent impact of sewage diversion on water quality.

The comparison also shows the high impact on the phytoplankton community, in terms of cell abundances and pigment concentrations. The Chl a concentration is the main impacted parameter. The stronger impact is observed in hypertrophic lagoons where the Chl a concentrations are divided by a factor of 20 (up to 49 for the most hypertrophic ones) but there is no relationship between the Chl a decrease and the trophic status of the lagoons. The phytoplankton has declined from summer 2006, and generally decreased during two consecutive years. From 2008 to 2010, phytoplankton biomasses appear stabilized. In spite of a rainy 2009 weather that could have increased nutrient inputs, there was no negative impact on water quality (i.e. an increase of Chl a biomass). The ecosystem response to sewage diversion, in terms of Chl a biomass, is spectacular for all lagoons. Five years after the diversion of the main nutrient source, median summer values of Chl a concentration are lower than 5 µg Chl a/l, even in hypertrophic lagoons. For example, for the most hypertrophic lagoon (Méjean lagoon), the summer median value decreased from 200 µg Chla/l in 2001 to 2 µg Chla/l in 2010.

The abundances of pico- and nanophytoplankton have also declined. In particular, the abundances of autotrophic picoeukaryotes have dramatically decreased and have been divided by 14 since the implementation of sewage diversion. In all lagoons, the autotrophic picoeukaryotes are always numerically dominant since the abundances of picocyanobacteria
are negligible. The abundances of nanophytoplankton weakly decreased (divided by 1.4). The strong decrease of autotrophic picoeukaryotes that were particularly adapted to steady-state nutrient conditions (Bec et al. 2011) could correspond to a shift in the lagoon ecosystem functioning following environmental changes.

In terms of HPLC pigment markers, in 2006, fucoxanthin was the dominant carotenoid pigment (up to 30 µg/l), corresponding to 62% of pigment marker concentrations. Among the phytoplankton community, all pigment markers decreased from 2006 to 2010 in the 8 Palavasian lagoons. However, the relative decrease in fucoxanthin (diatom) coincided with the relative increase in peridinin (dinoflagellate) and alloxanthin (cryptophyte). These pigment changes during the 5-year survey period were associated with an increase of Shannon’s diversity index and equitability.

**Conclusion**

The implementation of sewage diversion has a strong and positive impact on the water quality of studied lagoons. The major ecosystem response is the striking decrease of total phytoplankton biomass. This decrease is associated to changes in phytoplankton diversity and pigment composition, suggesting a shift in the phytoplankton community structure. In coastal ecosystems, succession of primary producers (phytoplankton-macroalgae-seagrasses) is a major pathway in restoration process. In response to environmental changes, a shift in dominance patterns of primary producers (from phytoplankton to macroalgae) may arise. This study case offered the rare opportunity to explicit the first steps of the lagoon ecological functioning restoration. We showed a set of reversible responses and the possibility of ecosystem rehabilitation through appropriate management actions in order to reduce (drastically) nutrient inputs to sensitive coastal ecosystems.