Assessing and managing the risks of hypoxia in transitional waters: a case study in the Gironde estuary (South-West France)

Évaluer et gérer les risques d'hypoxie des eaux de transition : étude de cas sur l'estuaire de la Gironde (Sud-Ouest France)

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RÉSUMÉ

L'estuaire de la Gironde (France S-O), formé par la confluence de la Garonne et de la Dordogne, est un des plus grands estuaires macrotidaux européens. Dans la Garonne tidale, des épisodes temporaires d'hypoxie ont déjà été enregistrés autour de Bordeaux. Les changements environnementaux à long terme (augmentation de la température et de la population, diminution du débit) laissent présager l'installation d'une hypoxie saisonnière permanente dans l'estuaire fluvial dans les prochaines décennies. L'évaluation et la gestion de ce risque sur un si vaste système fluvio-estuarien est complexe, en raison des pressions multiples (température, débit, turbidité, rejets urbains) agissant sur une large gamme d'échelles spatiales et temporelles. Dans un tel contexte, nous illustrerons l'intérêt du réseau MAGEST de surveillance de la qualité des eaux, qui enregistre en continu depuis 2004 la température, la salinité, la turbidité et l'oxygène dissous des eaux girondines. Ce réseau est financé et géré par un consortium qui réunit un laboratoire de recherche et des autorités publiques locales. A travers des résultats à des différentes échelles de temps (marée; saison), nous démontrerons l'intérêt d'une telle base de données pour mieux comprendre les facteurs qui contrôlent l'oxygénation des eaux. Cette surveillance en temps réel est également utilisée pour le développement d'outils de gestion de la qualité des eaux de l'estuaire de la Gironde.

ABSTRACT

The Gironde estuary (S-W France), formed by the confluence of the Garonne and Dordogne Rivers, is one of the largest European macrotidal estuaries. In the tidal Garonne, episodes of borderline dissolved oxygen concentrations have been occasionally recorded close to Bordeaux. Long-term environmental changes (increase in temperature and population, decrease in river discharge) suggest the establishment of a permanent seasonal hypoxia in the fluvial estuary in the next decades. Assessing and managing the risk of hypoxia on such a large, hyper-turbid fluvio-estuarine system is complex, due to the different pressures (temperature, river discharge, turbidity, urban wastes) acting over a wide range of temporal and spatial scales. In this context, we show the interest of a real-time monitoring of the water quality, the MAGEST network, which continuously records since 2004 temperature, salinity, turbidity and dissolved oxygen (DO) in the Gironde waters. This network is funded and managed by a consortium that brings together a research laboratory and local public authorities. Through examples of results from intratidal to seasonal time scales, we demonstrate how this database is used to better understand the factors controlling DO concentrations and saturations. This real-time monitoring is also of great interest for the development of manager's oriented-tools and the follow-up of DO objectives in the fluvial Gironde estuary.

KEYWORDS

Gironde estuary, dissolved oxygen, hypoxia, monitoring, management.

1 INTRODUCTION

The fluvio-estuarine system of the Gironde (S-W France), formed by the confluence of the Garonne and Dordogne Rivers, is one of the largest European macrotidal estuaries in term of surface area (625 km^2) (Fig. 1). This estuary is characterized by a well-developed turbidity maximum zone (TMZ), with concentrations of suspended particulate matter in surface waters higher than 1 g L^{-1}, which has a direct impact locally (siltation, limitation of primary productivity, oxygen consumption). Dissolved oxygen (DO), an essential factor for aquatic live, is a key indicator of water quality. Episodes of hypoxia have been already recorded in the tidal Garonne, close to the Bordeaux urban area (730 000 inhabitants) during warm and dry periods (Lanoux et al, 2013). In a context of long-term environmental changes (increase in temperature and population, decrease in river discharge), the establishment of a permanent seasonal hypoxia in the fluvial estuary is predicted in the next decades, that could be problematic for instance for downstream migration of juvenile fishes, such as shads or sturgeon. Assessing and managing the risks of hypoxia on such a large, hyper-turbid fluvio-estuarine system is complex, because it is contextual with several processes (temperature, river discharge, turbidity, urban wastes) acting over a wide range of temporal and spatial scales. After a short description of the MAGEST network, which records continuously water quality of the Gironde estuary, we illustrate the interest of such a real-time monitoring for a better understanding of the factors that control dissolved oxygen concentration, and for the development of manager's oriented-tools.

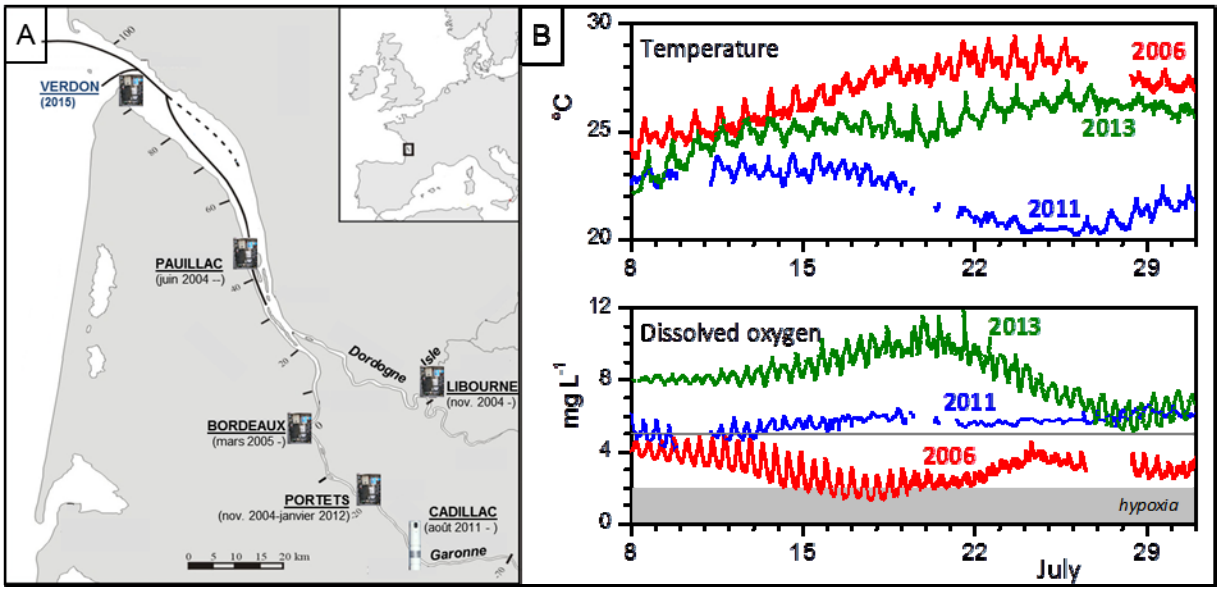

Figure 1 : A : The Gironde estuary and location of the instrumented sites. B : Comparison of temperature and dissolved oxygen (DO, concentration) at Bordeaux from 8 to 31 July 2006, 2011 and 2013. The line highlights the threshold of 5 mg L^{-1}, the shaded area the range of DO concentrations corresponding to hypoxia.

2 MATERIALS ET METHODS

The MAGEST network includes 4 sites equipped with real-time, automated monitoring systems of water quality in the central (Pauillac) and fluvial (Garonne : Bordeaux, Portets ; Dordogne : Libourne) estuary (Fig. 1A). These devices, installed on floating pontoons, measure each 10 min temperature, salinity, turbidity and dissolved oxygen of waters pumped 1 m below the surface (Etcheber et al, 2011). Data are stored each 6 hours by cellular transmission in a database server (http://www.magest.u-bordeaux1.fr/). Since 2013, sensors of turbidity and dissolved oxygen are placed during from April to November at Cadillac, about 30 km upstream to Bordeaux. This network is funded by the following organisms: AEAG (Agence de l'Eau Adour-Garonne); SMIDDEST (Syndicat MIxte pour le Développement Durable de l'ESTuaire de la Gironde); SMEAG (Syndicat Mixte d'Etudes et d'Aménagement de la Garonne); EPIDOR (Etablissement Public Interdépartemental de la Dordogne); EDF; GPMB (Grand Port Maritime de Bordeaux); CUB (Communauté Urbaine de Bordeaux); Conseil Régional Aquitaine; CG-33 (Conseil Général de Gironde); CNRS; Université de Bordeaux. The laboratory EPOC is responsible of the network for the aspects of maintenance, sensor calibration, data validation and interpretation.

3 RELEVANCE OF CONTINUOUS MONITORING OF WATER OXYGENATION

3.1 Analysis of seasonal changes in dissolved oxygen

During the period 2004-2014, daily-averaged dissolved oxygen concentrations are the highest in winter, between 8 and 12.5 $mg.L^{-1}$, when low water temperatures (1.4 – 10°C) promote oxygen solubility, and the lowest in summer, between 1.8 and 10 $mg.L^{-1}$, when waters are warmer (20 – 28.5°C). There is a large interannual variability in DO during summer, as illustrated by the high-frequency record of the MAGEST station at Bordeaux in July 2006, 2011 and 2013 (Fig. 1B); the lowest concentration is 1.22 mg L^{-1} the 17 July 2006. Statistical treatment of the MAGEST database had allowed to rank the parameters that control oxygenation of Bordeaux waters, in the order: water temperature, directly linked to regional meteorology, particulate load, related to the Garonne discharge, river flow, which depends on the regional meteorology and use in the watershed, and sewage inputs. These results contributed to make recommendations on the conditions of effluents discharges from sewage treatment plants of the metropolis Bordeaux.

3.2 Follow-up of DO objectives in the fluvial Gironde estuary

Adopted in 2013, the Plan of Development and Sustainable Management (*PAGD in French*) describes the objectives of the schema of development and management of Gironde waters (SAGE *Estuaire de la Gironde*) and the conditions of their achievements. This plan has ambitious criteria of minimum DO levels of 5 $mg.L^{-1}$ in the tidal Garonne and Dordogne Rivers to significantly improve water quality for the ecosystems and for downstream migration of juvenile fishes (SMIDDEST, 2013). The MAGEST network is in charge of the follow-up and analysis of this objective. Table 1 compares the number of days the daily-averaged DO was below this threshold of 5 mg L^{-1} in the tidal rivers from 2012 to 2014. In 2012, the total amount of days at Bordeaux far exceeds the objectives (ie < 9 days per year): this is explained by a marked low water of the Garonne and a heat wave in August.

Dissolved oxygen in the tidal rivers **Consecutive days per year**		**SAGE objectives :** **max. number of days**	**2012**	**2013**	**2014**
with dissolved O_2 below < 5 mg L^{-1}	Bordeaux	9	46 days *	7 days *	13 days
	Libourne	4	0	0	0

Tableau 1: Dissolved oxygen and follow-up of the DO objectives: rating of the years 2012, 2013 and 2014. *: this number of days corresponds to the sum of several periods of consecutive days below the threshold.

4 CONCLUSION

The real time, continuous MAGEST monitoring is an essential tool for understanding the changes in dissolved oxygen of estuarine waters, from tidal to seasonal timescales, and for assessing the risk of hypoxia in the Gironde estuary in a context of environmental change. It is also of valuable interest for the development of manager's oriented-tools and the follow-up of DO objectives in the fluvial Gironde estuary. The originality of this network is the strong interactions between academic research and local public authorities.

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