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Production *vs.* Respiration in river systems: An indicator of an "ecological status"

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Abstract

The Riverstrahler model of ecological functioning of large drainage networks validated on the Seine river system has been used for calculating the seasonal variations of Production and Respiration at various spatial scales (*e.g.* according to river orders). Based on the measurements of biological processes, the P/R ratio has led to an evaluation of the "ecological functioning", beyond the notion of "good ecological status". Furthermore, the effects, on the P/R ratio, of the geomorphological and climate factors characterizing the Hydro-Eco-Regions (HER) of the Seine watershed have been quantitatively explored with the model. Whereas one finds a typical upstream–downstream pattern of the P/R ratio variations under the traditional rural conditions that prevailed in the Seine basin until the end of the 18th century, this pattern is strongly affected by the changes in urban populations and the implementation of wastewater collection and treatment, more than by the specificity of the physical factors characterizing the different HER. We have also found that autotrophy (a P/R ratio > 1) might leads to eutrophication symptoms when P exceeds 1–2 mg C m^{-2} d^{-1} and that heterotrophy of the system (P/R ratio< 1) would reveal organic pollution when R exceeds 1–2 mg C m^{-2} d^{-1}, stocks and fluxes of organic matter being expressed in carbon unit.

Consequently, the P/R ratio appears as a good indicator of the perturbations caused by human activities in the watershed. The Riverstrahler model is able to quantify this effect.

Keywords: River; Ecology; Production; Respiration; Photosynthesis; Ecological status; Seine

1. Introduction

Whereas organic pollution from domestic and industrial sources is a main cause of oxygenation deficit in surface water, nitrogen and phosphorus inputs from agriculture and urban sources can cause excessive phytoplankton development. An abrupt decline of phytoplankton blooms, with a subsequent heterotrophic consumption of algal biomass leads to severe oxygen depletion. This phenomenon is typically observed in large rivers and/or in their coastal zones (the Rhine: De Ruyter van Steveninck et al., 1992; Admiral et al., 1994; Schöl et al., 2002; the Mosel: Gosselain, 1998; Gosselain et al., 1998, 1999; the Meuse: Descy and Gosselain, 1994; Everbecq et al., 2001; the Seine: Garnier et al., 1998; Billen et al., 2001; Cugier et al., 2005; the Po: Penna et al., 2004; Artioli et al., 2005; The Ebro: Torrecilla et al., 2005; the Danube: Lancelot et al., 2002; the Mississippi: Turner et al., 2006).

The trophic state of a system is classically determined by the equilibrium between the autotrophic metabolism (Production, P) that produces oxygen and the heterotrophic metabolism (Respiration, R) that consumes it (Odum, 1971). In aquatic systems, the ratio of primary production to respiration has been used to characterize the ecological functioning along a river continuum. Vannote et al. (1980) proposed a conceptual scheme of longitudinal variation of the P/R ratio in "natural" river

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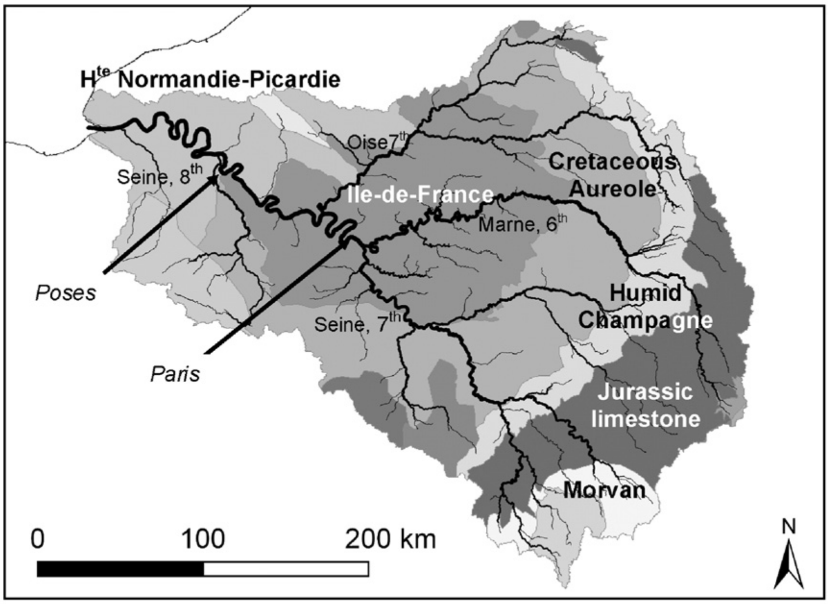

Fig. 1. Hydro-Eco-Regions within the Seine Basin. Main tributaries are indicated, with their river orders. Poses is the downstream limit of the Seine hydrographic network.

systems, starting from values <1 in the headwater tributaries, proceeding to P/R >1 in large rivers and decreasing again to <1 in large fluvial sectors and estuaries. This conceptual scheme has been experimentally confirmed and quantified in many continental aquatic systems at a daily or seasonal scale (Garnier and Lavandier, 1995; Billen et al., 1995; Garnier et al., 1999; Cushing et al., 1995).

To go further in the quantification of this concept, the ecological model RIVERSTRAHLER (Billen et al., 1994; Garnier et al., 1995), developed to study eutrophication and oxygen deficit problems in the Seine River, has proved to be a useful tool (Billen and Garnier, 1997; Garnier et al., 2004). The modelling strategy, which stresses the importance of considering a drainage network as a series of interdependent systems firstly structured by longitudinal interactions changing with increasing stream-orders, is based on the River Continuum Concept by Vannote et al. (1980).

Once validated, the ecological model can be used to calculate the carbon budget, identifying the contributions by the various biological processes (P: net primary production *vs.* R: bacterial and benthic respiration), along the entire river continuum. Besides analysing the P *vs.* R distribution focusing on the human induced nutrient and organic pollution inputs (point and diffuse sources), we have endeavoured to identify the role of the physical variables by means of the Hydro-Eco-Region description (Wasson et al., 2002). Then, the model can be used to explore various environmental constraints, in terms of P *vs.* R responses (autotrophy *vs.* heterotrophy of the system). The aim of this modelling approach was to i) test the P *vs.* R concept, ii) give quantitative support to ecological functioning indicators (rather than targeting

Table 1
Main characteristics of the major Hydro-Eco-Region of the Seine Basin

Hydro-Eco-Region	Surface area, km^2	Water shed area order 5, km^2	Rainfall, mm $year^{-1}$	Arable land, %	Grassland, %	Population density, inhab km^{-1}
Ile-de-France	18478	5850	448	53	8	150–800
Cretaceous aureole	19305	6895	650	74	8	75
Hte-Normandie	8685	5395		45	29	30
Humid Champagne	7428	2710	900	34	33	42
Jurassic limestone	11913	1930	900	40	18	26
Bazoi-Auxois	2276	1995		22	59	21
Morvan	1548	2160	1080	2	47	19