Ocean & Coastal Management 78 (2013) 45–55

Contents lists available at SciVerse ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Analysis of the effects of wet and dry seasons on a Mediterranean river basin: Consequences for coastal waters and its quality management

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ARTICLE INFO

Article history:
Available online 2 April 2013

ABSTRACT

Rivers play a major role in the delivery of nutrients to coastal ecosystems which are essential for ecosystem productivity. However, the increase of nutrients due to anthropogenic activities can cause eutrophication problems. This study analyzes the seasonal variation of phytoplankton communities in the coastal receiving waters of a Mediterranean river. Two scenarios are compared: the wet and the dry season with distinctive characteristics. During the wet season agricultural runoff and combined sewer overflows (CSO) were responsible for nutrient discharges, while during the dry season partially treated effluent from wastewater was the main nutrient source. In the receiving waters, diatoms typical seasonal cycle was modified by CSO discharges during rain episodes, while dinoflagellate abundance was higher in the dry season due to partially treated effluents discharges and low turbulence. We recommend that the design of the Water Framework Directive monitoring programs should take into account wastewater treatment plants and combined sewer systems located near the coast. Management decisions should take into account that only reductions in CSO and partially treated summer effluent are likely to be efficient in the short term. Analyzing the corrective measures cost through a cost–benefit analysis would help to determine whether the costs are excessive or not.

1. Introduction

Estuaries and coastal areas receive high loads of nutrients of terrestrial origin, either from point sources, which flow out at discrete and identifiable locations (e.g. rivers, submarine wastewater outfalls) or non-point sources, which are rather diffuse and highly variable from year to year depending on climate and rainfall (e.g. surface and groundwater runoff) (Paerl, 2006). Among nutrients, nitrogen and phosphorus are both required to support marine productivity and are the key limiting nutrients in most aquatic and terrestrial ecosystems. However, the increase in these nutrients due to anthropogenic activities requires their inputs into coastal marine ecosystems to be reduced in order to minimise eutrophication problems (Paerl et al., 2010). The influence of these terrestrial inputs is especially important in the marine oligotrophic areas, such as the Mediterranean Sea (Romero et al., 2007).

Several policies have been adopted to reduce nutrient inputs with varying degrees of success depending on the source (Artioli et al., 2008). While improvements in wastewater treatment have achieved reductions in inputs of phosphorus and nitrogen from point sources, the largest nutrient contribution for coastal marine environments is from diffuse sources, especially those from agricultural land runoff (fertilizers), and reducing this is a difficult and slow process (Carstersen et al., 2006). Then, there is a tendency to focus European Union (EU) policies on non-point sources rather than on point sources, which are supposed to have been successfully addressed in past legislation (Torrecilla et al., 2005).

Rivers play a major role in the delivery of nutrients to coastal ecosystems, both from natural (e.g. silicates weathering) and anthropogenic (urban and industrial wastewater, agriculture runoff) sources. Wastewater treatment plants (WWTPs) can discharge treated effluent to rivers or to coastal areas through submarine wastewater outfalls. The objective of the 91/271/EEC Council Directive, concerning urban wastewater treatment, was to protect the environment from the adverse effects of wastewater discharges. Different studies have demonstrated that the submarine outfall discharges of treated effluent which comply with the Directive, have either no significant effects or only minor effects on the quality of receiving waters (Juanes et al., 2005). However, wastewater discharge can cause water quality problems in rivers and this is especially relevant in Mediterranean rivers because of the hydrologic singularities of the Mediterranean climate and fluvial regime (Torrecilla et al., 2005).

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http://dx.doi.org/10.1016/j.ocecoaman.2013.03.012

In Mediterranean-type climate regions (areas surrounding the Mediterranean Sea, parts of western North America, parts of western and southern Australia, the south-west of South Africa, and parts of central Chile), characteristic precipitation is scarce and torrential and has an extremely high spatial and temporal variability. Natural river discharge, driven by precipitation variability, has two distinct seasons: wet and dry (Gasith and Resh, 1999; González-Hidalgo et al., 2005). Thus, wastewater discharges present different problems depending on the season.

During the wet season combined sewers overflows (CSO) can reach receiving waters without treatment (Clark et al., 2007). The importance of storm overflows for water quality have been recognized by the 91/271/EEC Directive: "the design, construction and maintenance of collecting systems shall be undertaken in accordance with the best technical knowledge not entailing excessive costs, notably regarding limitation of pollution of receiving waters due to storm water overflows" (Annex I, 91/271/EEC Directive). This importance is also recognized by the USA legislation in the CSO Control Policy which was published on April 19, 1994 by the United States Environmental Protection Agency (USEPA).

During the dry season, urban sewage effluents are the main freshwater source in ephemeral streams in arid to semiarid areas of the world (Brooks et al., 2006; García-Pintado et al., 2007) and can account for up to 90% of the total river flow in some Mediterranean rivers such as the Serpis River (Molinos-Senante et al., 2011). In addition, fluctuating winter and summer populations in tourist areas, typical on Mediterranean coasts, provoke significantly variable wastewater loadings that can exceed the capacity of the treatment facilities (Aguilera et al., 2001; García-Pintado et al., 2007).

Several studies have addressed the quality problems of Mediterranean rivers receiving wastewater discharges, for instance, on the Mediterranean coast of the Iberian Peninsula, Torrecilla et al. (2005) studied the Ebro River (NE Spain) and Molinos-Senante et al. (2011) studied the Serpis River (Eastern Spain). On the other hand, studies on receiving coastal waters have mainly addressed the water quality in the submarine outfall areas (Aguilera et al., 2001) and not river mouths. Some studies of Californian recreational bathing beaches have addressed the effects of CSO discharges but have focused on fecal indicator bacteria (total coliforms, fecal coliforms and enterococci) and benthic invertebrates (Schiff et al., 2003; Clark et al., 2007).

Nutrient inputs into coastal ecosystems can induce eutrophication problems, among these, harmful algal blooms of species responsible for the synthesis of toxins and high-biomass producers that can cause hypoxia and anoxia and indiscriminant mortalities of marine life after reaching dense concentrations (Heisler et al., 2008). As regards marine recreational bathing beaches, these effects can cause beach closures that negatively impact the local economy of tourist areas. Thus, adequate management of nutrient sources is essential because clean water and healthy coastal habitats are clearly fundamental to successful coastal tourism which is characteristic of the Mediterranean climate regions (Hall, 2001). However, to develop appropriate management strategies, it is necessary to fully understand how ecosystems function by first of all establishing the relationships between phytoplankton and nutrient sources and patterns.

This study analyzes the seasonal variation of phytoplankton communities in the coastal receiving waters of the Serpis River input, which is a Mediterranean river basin in Spain. A comparison is established with marine waters to assess different patterns between high and low terrestrial influence areas. Two scenarios are analyzed: the wet and the dry season with distinctive characteristics. The aim is to provide information about ecosystem functioning that could help management decisions and could be extrapolated to other Mediterranean climate areas with similar characteristics.

2. Materials and methods

2.1. Study area

The study area (Fig. 1) is located in the East of the Iberian Peninsula, at the southernmost sector of the Valencian Gulf (Western Mediterranean Sea) on the coast of the Safor County (Spain). The main annual rainfall is above 600–650 mm in the entire County, with values above 800 mm in the rainiest areas, with most precipitation concentrated into short-episodic storm events in autumn (Hermosilla, 2005). For a 10-year return period daily rainfall is expected to be higher than 200 mm (Hermosilla, 2005) (Fig. 2).

The main river draining this area is the Serpis River which has a basin of 753 km^2 and is 74.5 km in length (Hermosilla, 2005). The Serpis River receives freshwater from its tributary the Vernissa River (150 km^2). Both rivers have a Mediterranean regime characterized by a high seasonality, with a dry period during summer, and a wet period mainly in autumn (Hermosilla, 2005). These rivers are artificially regulated by a complex system of weirs and irrigation channels that provide freshwater for the irrigated crops of the Safor County. The Beniarrés reservoir (30 hm^3 maximum capacity) (Fig. 1) was built in the second half of the 20th century to increase the regularity of the Serpis River (Hermosilla, 2005).

In the Serpis basin, there are 30 WWTPs that receive wastewater from the main urban and industrial areas, treating around 31 Mm^3 per year (Molinos-Senante et al., 2011). In total, 24 of the 30 plants discharge treated water to the Serpis River, while the remaining six plants discharge treated water into the sea (Molinos-Senante et al., 2011). Downstream of the Beniarrés reservoir, the most important WWTP is the Gandia plant (Fig. 1) which serves a total of 133,300 inhabitants from 17 municipalities of the Safor County (EPSAR, 2013). This plant discharges 17 million m^3 of treated wastewater per year to the sea through a submarine outfall (approximately 1900 m from the Serpis river mouth); however it also has two overflow channels that discharge directly to the river. One channel discharges besides the plant and the other near the river mouth.

The first overflow channel is used when the plant capacity is exceeded due to rain episodes. The plant treats an average flow of 46,350 m^3 day^{-1} and its design flow is 60,000 m^3 day^{-1} (EPSAR, 2013), which makes a difference of 13,650 m^3 day^{-1}. But the urban area without wastewater and pluvial waters separation amounts to nearly 15 million square meters (see areas in Fig. 1) with almost zero infiltration. So, even small rain episodes cause combined sewer overflows because the plant capacity is exceeded. The wastewater collector is parallel to the Serpis River and combined sewer is also discharged into the Serpis directly from the collector when its capacity is exceeded.

The second overflow channel is generally used in summer, when the plant capacity is exceeded due to the population increase and the effluent is partially evacuated without treatment. The average density in the coastal municipalities of the Safor county is 963 inhabitants km^{-2} in winter (1314 inhabitants km^{-2} in Gandia city) (INE, 2009), but that figure triples in summer due to tourism activity which is mainly based on residential development (Mantecón and Huete, 2007). According to Ariza et al. (2008) urban beaches are much more likely to be closed, compared with natural beaches, mainly due to the presence of sewer systems. Beach closures adversely affect tourism, which is one of the main economic sectors in these coastal municipalities, based on the "sun & beach" product (Yepes and Medina, 2005). In August 2007, Venecia and Marenys de Rafalcaid beaches, which are located next to the mouth of the Serpis River, were closed due to fecal contamination and high bacteria levels (Santacreu, 2008). These two beaches only form a small part of the Gandia coastline. However tourism is mainly