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Response of diatom and dinoflagellate lifeforms to reduced phosphorus loading: A case study in the Thau lagoon, France

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ABSTRACT

The basin of Thau in southern France is a shallow, weakly flushed lagoon which is an important location for oyster cultivation. Phytoplankton analyses were carried out in 1975–1976 and then (almost) continuously since 1987. We report an investigation of 'the balance of organisms' in phytoplankton in relation to reductions in phosphorus loading, using two new tools based on phytoplankton lifeforms: the Plankton Index for Phytoplankton (PIp); Euclidean distance in state-space. Our results show the utility of the tools for analysing changes in the 'balance of organisms' at the level of functional groups (in our study diatoms and dinoflagellates), but also illustrate the difficulties in demonstrating the reversal of human impacts resulting from eutrophication.

The comparison between 1987–89 and 1976 showed the expected 'de-eutrophication' due to the reduction in dissolved inorganic phosphate (DIP), with a decrease in dinoflagellate abundance. Since 1989, year-to-year variation in annual mean concentrations of DIP may have contributed to inter-annual variability in the balance of the two lifeforms, but the data suggest that the system has remained in a dynamically stable regime because: (1) there was no long-term trend in Euclidean distance from the reference; and (2) there was no increase in inter-annual variability about the time-series mean Euclidean distance suggesting there has been no decrease in resilience which might signal a regime change.

Integrated management of human activities will be required to manage (and reduce) total P in the system. Monitoring phytoplankton and nutrients concentrations to determine how primary production and the balance of species respond to further changes in the nutrient status of the lagoon should be an integral part of any management programme.

1. Introduction

Marine eutrophication is considered a recent problem (Nixon, 1995) but one that can potentially impact coastal water bodies world-wide and is of increasing severity (McIntyre, 1995). There is evidence that anthropogenic nutrient enrichment of some northern European coastal regions has increased phytoplankton biomass and production (Radach et al., 1990; Schaub and Gieskes, 1991; De Jonge et al., 1996; Gowen et al., 2000; Ærtebjerg et al., 2001; Conley et al., 2002; Rousseau et al., 2006; Andersen et al., 2011). Cloern (2001) argued that coastal eutrophication involved more than the stimulation of primary production because the input of nutrients to coastal water bodies can disrupt the balance between the production and turnover of organic matter and alter the seasonality of ecosystem functions. Also of concern are changes in the floristic composition of the phytoplankton (Gillbricht, 1988; Lancelot et al., 2006) that can result in: "visible algal blooms, algal scum" (Vollenweider, 1992); "the presence of noxious phytoplankton and bottom water anoxia" (Justic et al., 1995); the occurrence (including an increase in frequency, size and duration) of harmful algal blooms as has been the case in the Seto Inland Sea of Japan and Tolo Harbour, Hong Kong (see Gowen et al., 2012a and references cited therein).

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In many countries, legislation has been introduced to mitigate anthropogenically driven coastal eutrophication. In addition to national legislation, the 28 member states of the European Union are subject to EU directives. In 2004, the European Court of Justice ruled (Case C-280/02: http://curia.europa.eu) that the 'Thau lake', a shallow lagoon in southern France, should be 'identified as an area sensitive to eutrophication within the meaning of Directive 91/271' (the Urban Waste Water Treatment Directive, CEC, 1991). This directive (see also Ferreira et al., 2011) defines eutrophication as a process culminating in an undesirable disturbance to the balance of organisms and to the quality of the water concerned. Stimulation of the growth of one or more phytoplankton species is considered a disturbance and that of a nuisance or harmful species undesirable. However, the populations of species that make up the phytoplankton are not constant in time or space (Gowen et al., 2012b) and against this background of natural variability, quantifying a disturbance to the balance of organisms is not a trivial task.

The Thau lagoon is a small (75 km^2) marine lagoon located on the French Mediterranean coast (Fig. 1). The lagoon is shallow (mean depth 4 m) and is connected to the sea by 3 narrow channels. Approximately 10% of French oyster (*Crassostrea gigas*) production takes place in the lagoon. Picot et al. (1990) reported the production to be 20,000 tonnes per year. A number of studies suggest that the lagoon is a predominantly nitrogen (N) limited system (Collos et al., 1997; Souchu et al., 1998, 2001; Bec et al., 2005). There is an input of N via freshwater inflow during the winter which supports phytoplankton growth and sometimes leads to DIP limitation (Collos et al., 2014), but during the spring and summer the input of N via freshwater inflow is low. The nutrient dynamics of the lagoon are complicated by anoxic events which promote the sediment efflux of nutrients which support enhanced phytoplankton production. During one such event during the summer of 1994, Souchu et al. (1998) measured maximum bottom water concentrations of 24 μM ammonium (NH_4), 5 μM DIP and 57 μM silicate (Si). Phytoplankton biomass measured as chlorophyll concentration reached 10 and 15 mg m^{-3} in surface (1 m) and bottom (8 m) water, respectively.

Since the 1960s there has been a programme to reduce anthropogenic waste input to the lagoon. A gradual increase in the number of houses connected to waste water treatment culminated in approximately 95% of houses in the catchment having been connected by 1990 (La Jeunesse and Elliott, 2004). Collectively, the installation of a waste water treatment plant for the city of Sète in 1972 (designed to divert waste water from the lagoon), the introduction of activated sludge treatment between 1975 and 1987 and the establishment of a French national limit on phosphorus (P) in detergent in 1990, have contributed to the reduction in P loading to the lagoon (Souchu et al., 1998; La Jeunesse and Elliott, 2004). Water-column concentrations of DIP have decreased by 90% between 1971 and 1994 (La Jeunesse and Elliott, 2004). The reductions in domestic N and P loading were expected to have brought about a reduction in bacterial biomass and anoxic events (which caused mortality of oysters) in the Thau lagoon. Thirty years later, that particular goal was reached (Souchu et al., 1998), but one unexpected consequence was the emergence of picocyanobacteria and the toxic dinoflagellate *Alexandrium catenella* (Collos et al., 2009).

In this paper we report an investigation of this 'balance of organisms' using two new tools. One tool, the Plankton Index for Phytoplankton (PIp) is derived from the Phytoplankton Community Index of Tett et al. (2008). The second involves the calculation of Euclidean distance in state-space (Tett et al., 2013). There are few records of phytoplankton composition before nutrient enrichment of the lagoon and so we did not initially hypothesize what the 'natural balance' would be. Instead, the study focussed on changes over the period of data availability.

2. Methods

2.1. Data sets

The data sets used in the study are summarised in Table 1. Diatom and dinoflagellate abundance data were taken from phytoplankton counts from Hénard (1978) for the years 1975–1976

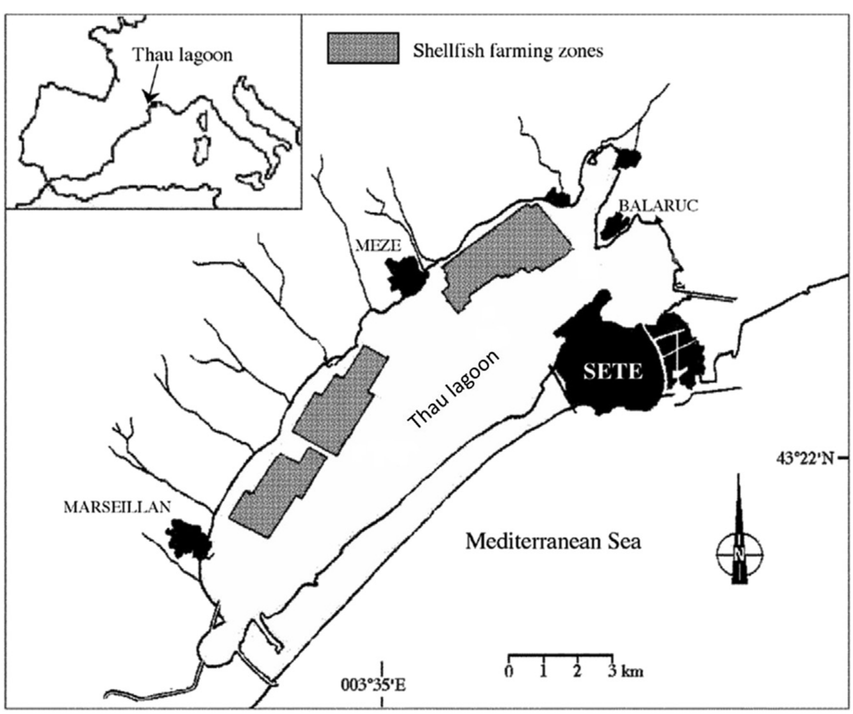

Fig. 1. A map of the Thau lagoon in southern France. Urban areas are shaded black and areas of the lagoon that are used for oyster growing are shaded grey.