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Effects of pulsed nutrient inputs on phytoplankton assemblage structure and blooms in an enclosed coastal area

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Abstract

The response of phytoplankton assemblage structure to terrestrial nutrient inputs was examined for the Gulf of Kalloni in the Northern Aegean Sea, a productive semi-enclosed coastal marine ecosystem. The study was focused on a typical annual cycle, and emphasis was placed on the comparative analysis between blooms developing after significant nutrient inputs from the watershed, and naturally occurring blooms. Baseline information was collected on a monthly basis from a network of stations located in the oligotrophic open sea and the interior and more productive part of the embayment. Intensive sampling was also carried out along a gradient in the vicinity of a river which was the most important source of freshwater and nutrient input for the Gulf. Phytoplankton assemblage structure was analyzed from 188 samples using diversity indices (Shannon and Average Taxonomic Distinctness), multivariate plotting methods (NMDS), multivariate statistics (PERMANOVA), and canonical correspondence analysis (CCA). Three characteristic assemblages were recognized: (1) an autumn assemblage developed under nutrient depleted conditions, having low diversity due to the dominance of two small diatoms, (2) a winter bloom of the potentially toxic species *Pseudo-nitzschia calliantha* occurring immediately after a nutrient peak and characterized by very low diversity, and (3) a naturally occurring early summer bloom of centric diatoms with relatively high diversity. The results of the study support the view that moderate nutrient inputs may have a beneficial effect on the functioning of coastal ecosystems, stimulating the taxonomic diversity through the growth of different taxonomic groups and taxa. On the other hand, a sudden pulse of high nutrient concentrations may greatly affect the natural succession of organisms, have a negative effect on the diversity through the dominance of a single species, and can increase the possibility of a harmful algal bloom development.

Keywords: phytoplankton blooms; assemblage structure; coastal waters; diversity; terrestrial runoff; Greece; Lesvos Island; Kalloni Gulf (26°04′–26°18′ E, 39°04′–39°12′ N)

1. Introduction

Coastal marine ecosystems are becoming increasingly affected by nutrient loadings from a variety of anthropogenic sources, including domestic wastes and agricultural runoff (Justic et al., 1995a; Nixon, 1995; Smith et al., 1999). Enclosed coastal embayments and estuarine systems are particularly susceptible since they have high water residence times and are subject to nutrient inputs from rivers, particularly nitrogen (Paerl, 1997). Nutrient enrichments can cause major changes in the stoichiometric nutrient balance and have a significant effect on phytoplankton community by altering its composition and diversity (Taslakian and Hardy, 1976; Garcia-Soto et al., 1990; Padisak, 1993; Justic et al., 1995b; Piehler et al., 2004; Buyukates and Roelke, 2005). In some extreme cases these nutrient discharges may lead to the development of massive

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phytoplankton blooms (Beman et al., 2005) as well as harmful algal blooms (HABs) (Anderson et al., 2002).

Field and laboratory studies have demonstrated that whether these nutrient additions are continuous or pulsed can have a profoundly different effect upon the structure of phytoplankton assemblages (Gaedeke and Sommer, 1986; Capblancq, 1990; Buyukates and Roelke, 2005). It is argued that a continuous nutrient supply results in steady state assemblages, where some species able to compete for limiting nutrients develop in high abundances, while weaker competitors are scarce or completely excluded (Hardin, 1960; Sommer, 1985; Capblancq, 1990). On the other hand, a discontinuous nutrient supply would enhance the coexistence of species and thus would support high species richness. Indeed interspecific interactions are less likely to occur in ecosystems under frequent disturbance (Margalef, 1978; Harris, 1986). However, according to the intermediate disturbance hypothesis (IDH) described by Connell (1978), when disturbance becomes very strong, most species are exterminated and diversity decreases (Polishchuk, 1999).

Phytoplankton blooms have been associated to both natural and anthropogenic nutrient inputs. Natural phytoplankton blooms occurring in coastal areas during spring and autumn have been thoroughly investigated with respect to community structure (Townsend and Spinrad, 1986; Zingone et al., 1995; Carstensen et al., 2004) and in relation to environmental parameters (Townsend et al., 1992, 1994; Kawamiya et al., 1996; Huisman et al., 1999). However, the mechanisms responsible for the initiation of phytoplankton blooms (including HABs) associated with anthropogenic nutrient inputs remain less understood. The impact of HABs on public health and economy has increased in intensity, frequency and geographic range size during the last two decades, and it therefore appears of critical importance to better understand the processes underlying these toxic events (Cembella et al., 2005). Furthermore, a deeper insight may be gained on the principles and processes regulating phytoplankton growth, by contrasting the structure and characteristics of anthropogenically derived to natural occurring blooms (Smayda, 1997).

The present work studies phytoplankton community structure and dynamics during an annual cycle in an enclosed coastal system influenced by periodic nutrient enrichments from terrestrial sources. Special emphasis is placed on the investigation of potential differences between naturally (due to physical factors) and anthropogenically (associated with terrestrial inputs) driven blooming assemblages in terms of their structure, species composition, diversity and relationship to environmental factors. Furthermore, insights are provided in the light of latest ecological views, into the possible drivers of bloom formation, considering interactions with environmental parameters and species ecological requirements.

2. Methodology

2.1. Study area

The Gulf of Kalloni (Fig. 1) is a semi-enclosed shallow water body (average depth of 10 m), located in Lesvos island,

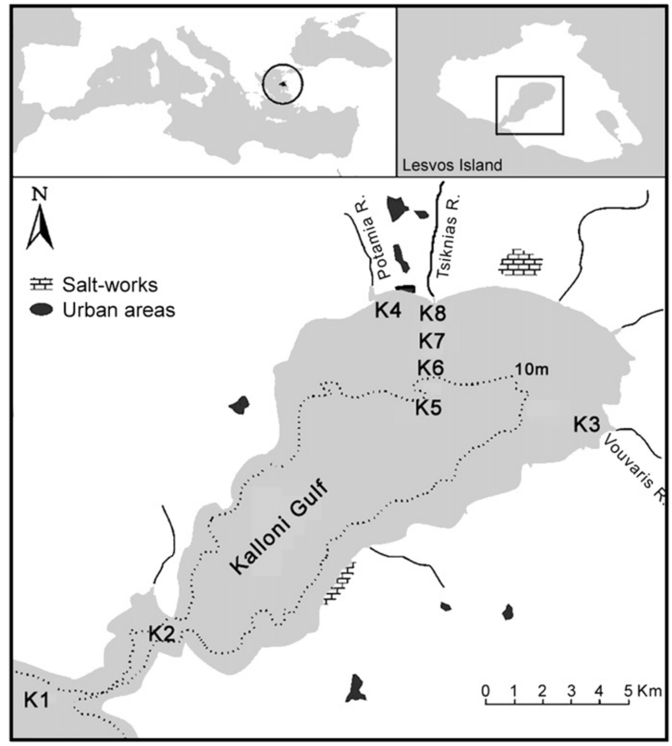

Fig. 1. The Gulf of Kalloni with location of sampling stations.

Greece, in the Eastern Mediterranean (26°04′–26°18′ E, 39°04′–39°12′ N). The gulf is connected to the open sea through a narrow (2 Km wide), shallow (25 m deep) and long channel (length of 4 Km) (Millet and Lamy, 2002). The gulf is highly productive, sustaining large populations of planktivorous fish (sardines) and shellfish (mussels, scallops and clams), exported nationally and internationally (Paspatis and Maragoudaki, 2005). The surrounding watershed of 413 Km^2 is used for horticulture (18.4%) and agriculture (16.6%), mainly of olive trees. These cultivations involve the application of fertilizers, usually from December to February, coinciding with the period of high precipitation. The watershed is drained through a number of intermittent rivers flowing from November to April, located mainly in the northern part of the gulf. These rivers drain an area of about 213 Km^2, and their total discharge rate is about 1632 m^3 per day. It has been estimated that the main exogenous sources of inorganic nitrogen for the gulf are runoff from the surrounding agricultural land (59%) and untreated domestic wastes (37.5%), whereas for inorganic phosphorous, the main sources are sewage (59%), agricultural runoff (19%) and the by-products of olive press industries (19%) (Panayotidis and Klaudatos, 1997). The climate of the area is typical Mediterranean, i.e., hot and dry summers and mild and rainy winters.

2.2. Analytical methods

Samples were collected on two networks of stations (Fig. 1). The first network (Network A), covering the whole area of the Gulf of Kalloni, consisted of six stations which were sampled on a monthly basis from August 2004 to July