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RESEARCH ARTICLE

Physicochemical characterization of the shallow mixing zone of two estuaries, Lesvos Island, NE Aegean, Greece

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Abstract

1 - We assessed the physicochemical status of the mixing zone along two shallow estuaries within a Natura 2000 site, NE Greece, in order to establish a baseline and evaluate their trophic state.

2 - Distribution patterns of dissolved oxygen and chlorophyll a of water and of chlorophyll a, total phosphorus, and percent organic matter of sediment along the mixing zone of the studied estuaries during spring 2005 indicated oligotrophic conditions in autotrophic estuaries.

3 - In both estuarine systems, chlorophyll a concentration of water did not correlate with chlorophyll a of sediment indicating that different processes may control primary production in waters and sediments. Nevertheless, primary production in water was linked to phosphorus pool in sediment.

Keywords: estuary, physicochemical variables, trophic state

Introduction

Trophic state (energy availability) of aquatic ecosystems is determined by autotophic (in situ production through photosynthesis) and heterotrophic (import of allochthonous matter) processes. It ranges from unproductive (oligotrophic) through intermediate productivity (mesotrophic) to highly productive (eutrophic). Chronic, allochthonous, nutrient inputs in aquatic ecosystems either from diffuse sources, such as agricultural fertilizers, or from non-point sources, such as urban and industrial sewage, result in a chain of events starting with accelerated growth of primary producers (phytoplankton, macroalgae, aquatic plants), commencing with oxygen depletion, and culminating in massive kills of aquatic organisms (Cloern, 2001; Hilton *et al*., 2006). This human induced problem, known as eutrophication of fresh, coastal, and marine waters, shifts aquatic ecosystems toward a eutrophic state worldwide (Smith, 2003; Meybeck, 2003). Thus, there have been developed assessment/monitoring (the EU-WFD method, Bald *et al*., 2005; the US-NEEA, Bricker *et al*., 2003) and policy (the European Union Water Framework Directive (EU-WFD), Directive 2000/60/EC) initiatives to evaluate the ecological status and implement measures to improve the physicochemical and biological status of surface waters, respectively. Confronting eutrophication is expected to reduce cleaning costs, protect declining biodiversity, and contribute toward the sustainable provision of goods and services provided by aquatic ecosystems.

Various factors have been demonstrated to affect algal growth in fresh and coastal waters, the most important of which are sunlight, temperature, flow, residence time, turbidity, nutrients concentration, and salinity (David, 1995; Wetzel, 2001) as well as land use (Meeuwig, 1999; Weckström *et al*., 2002) and nutrient management practices (Paerl *et al*., 2004; Lillebo *et al*., 2007). Thus, nutrient (mainly N and P) total loads, chlorophyll *a*, and dissolved oxygen concentration of water constitute popular indicators of eutrophication. Quite recently, chlorophyll *a* (Moreno and Niell, 2003; Kowalewska, 2005) and phosphorus (McComb *et al*., 1998) concentrations in sediment have also been employed since sediment constitutes an important sink and, subsequently, vector of nutrients in aquatic ecosystems.

In this study, we describe for the very first time patterns in spatial distribution of water and sediment physicochemical variables along the mixing zone of two shallow estuaries within a Natura 2000 site, North East Greece, in order to establish a baseline and evaluate their trophic state.

Materials and Methods

Study Sites

The estuary systems studied, Tsiknias and Potamia, discharge at Kalloni bay, Lesvos Island, NE Aegean (Figure 1). The coast of Kalloni bay constitutes an ecological network of wetlands. It has been incorporated into the European Network of protected areas Natura 2000 (GR4110004; Mandylas and Kardakari, 1998), the list of CORINE biotopes, the list of important areas of avian fauna of Greece (SPPE), and the 20 national Ecological Hot Regions (Hotspots) for avian fauna (Troumbis and Dimitrakopoulos, 1998). Tsiknias river is located within the largest catchment (92 km^2) and constitutes the most extensive river (20 km) discharging at Kalloni bay while Potamia river is located within the fourth largest catchment (34 km^2) of Kalloni bay. Agriculture on argilic ground is the prevalent land use at both catchments. Anthropogenic pressures probably affecting Tsiknias river

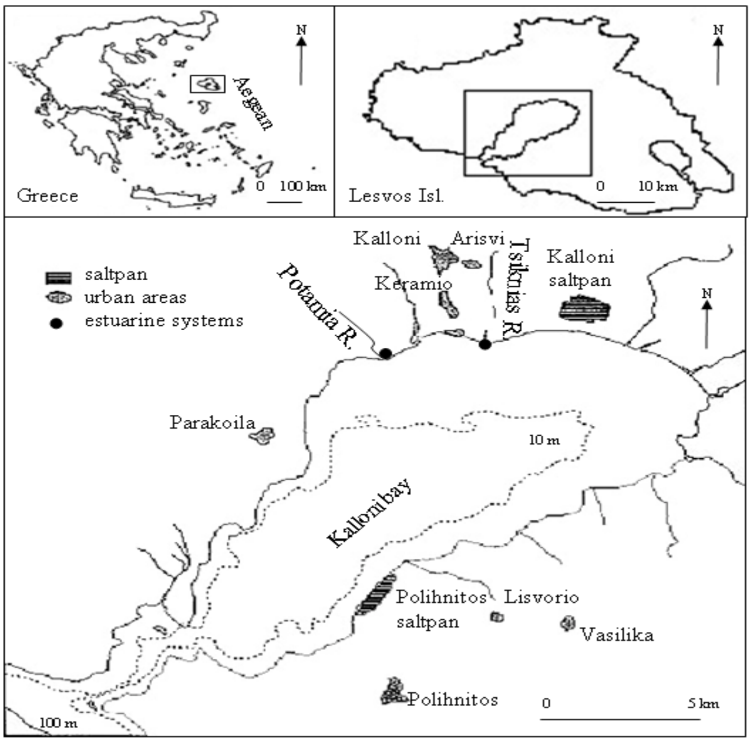

Figure 1. Location of Tsiknias and Potamia estuarine systems at Kalloni bay, Lesvos Island, Greece.

include wastewater discharge from three oil presses, five human settlements, one stable, and two cheese factories while those probably affecting Potamia river include wastewater discharge from two oil presses, one human settlement, and a concrete factory. There is a water-collecting impoundment at Tsiknias river. Both riverine systems are active for at least half of the year.

Sampling and Field and Laboratory Analysis
Systematic sampling of surface water and surface (0-2 cm) sediment at 100 m intervals took place along the centreline of Potamia and Tsiknias estuaries. There were a total of 11 stations at each estuarine system, covering the gradient from marine through brackish to freshwaters. Sampling took place in May 2005. At each station, instantaneous measurements of water Temperature (T), Dissolved Oxygen (DO) concentration, pH, and Electrical Conductivity (EC) were obtained with a portable electrometric unit Consort 932. Chlorophyll *a* ($CHLA_W$) concentration of 1 lt water samples (n=2) was measured following the standard procedure of Parsons *et al*. (1984).

Also, at each station, 3 surface (0-2 cm) sediment samples were scooped, dried in room temperature, crashed and sieved through 2mm mesh size siever. These samples were used to determine Total Phosphorus (TP) concentration using Olsen's method (Olsen *et al*., 1954) and percent Organic Matter (OM) using the method of wet oxidation. Chlorophyll *a* ($CHLA_S$) concentration of sediment (n=3) was measured following the standard procedure of Parsons *et al*. (1984).
Relationships among water and sediment variables were explored using Spearman correlations (r_s).

Results
Mean chlorophyll *a* concentration of water along the studied gradient was 50.7 and 62.7 times greater than chlorophyll a concentration of sediment at Tsiknias and Potamia estuary, respectively. Trends in spatial distribution of the physicochemical variables studied differed between the two estuarine systems (Figure 2).
There was a gradual increase in temperature of water and in chlorophyll a and phosphorus concentrations of sediment at both estuarine

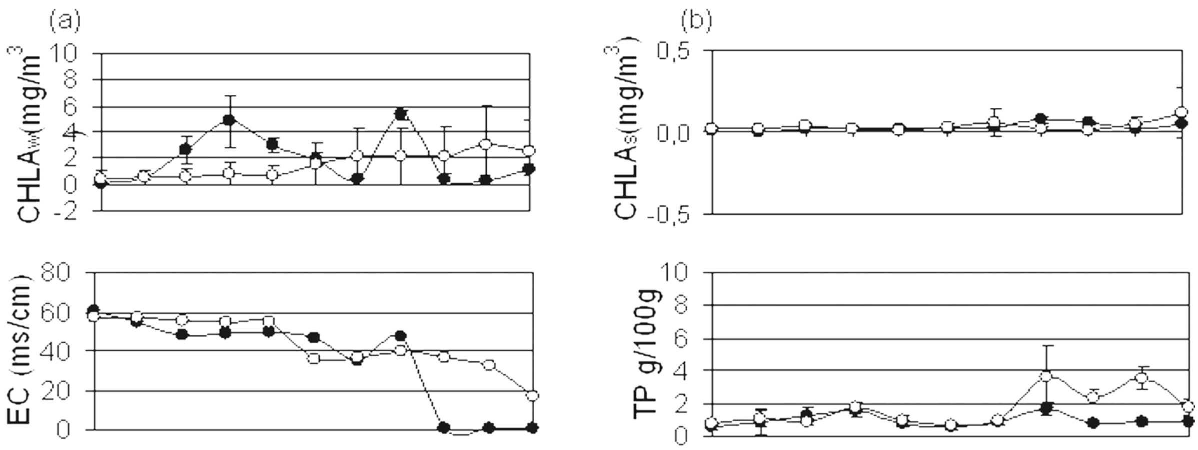

Figure 2

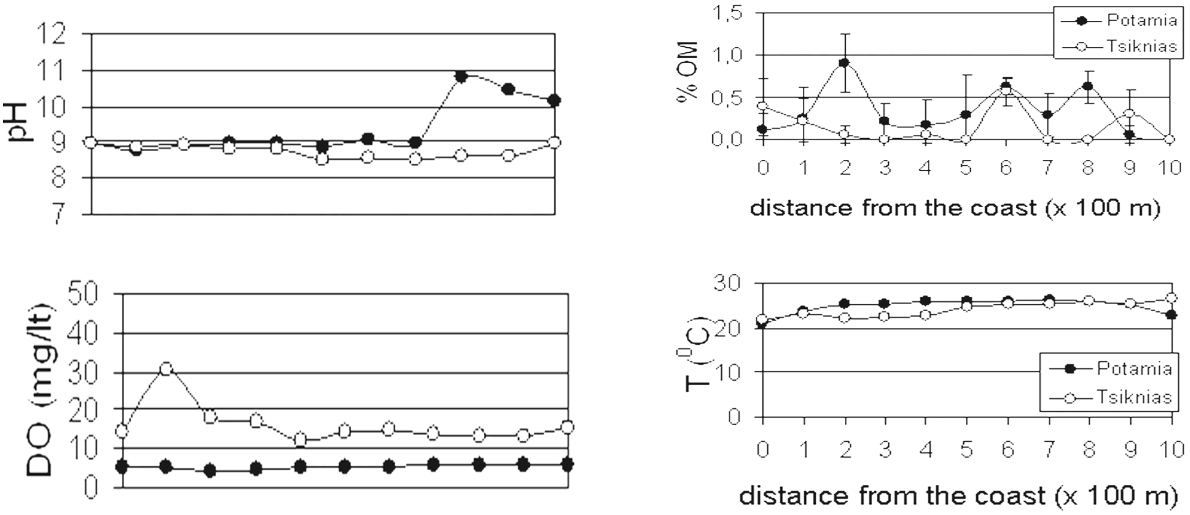

Figure 2. Variation (mean±stdev) in (a) water (n=2) and (b) sediment (n=3) variables along Potamia and Tsiknias estuaries, Kalloni bay, Lesvos Island in spring 2005. CHLA: chlorophyll a concentration in waters (w) and sediment (s); EC: electrical conductivity; DO: dissolved oxygen concentration; T: temperature; TP: total phosphorus concentration; OM: organic matter.

systems and in chlorophyll *a* concentration of water at Tsiknias esturary from the coast and inwards. The reverse trend appeared for electrical conductivity of water at both Tsiknias and Potamia estuarine systems. Percent organic matter of sediment and dissolved oxygen of water fluctuated along the same gradient at both estuaries as did chlorophyll *a* concentration of water at Potamia estuary. Tsiknias, which carries a larger water volume than Potamia, exhibited larger changes in electrical conductivity and dissolved oxygen concentration of water and in total phosphorus concentration of sediment compared to Potamia, which, in turn, showed larger changes in pH and chlorophyll *a* concentration of water and in percent organic matter of sediments along the studied gradient (Figure 2).

Subsequently, patterns of significant correlations among water and sediment variables differed between the two estuarine systems (Table 1). At Tsiknias estuary, chlorophyll *a* of water correlated significantly and positively with temperature of water but negatively with electrical conductivity of water. At Potamia, chlorophyll *a* of sediment correlated significantly and positively with pH, dissolved oxygen and temperature of water but negatively with electrical conductivity of water. Nevertheless, chlorophyll *a* of water correlated significantly and positively with total phosphorus concentration of sediment at both estuarine systems.

Discussion

Distribution patterns of dissolved oxygen and chlorophyll *a* concentrations of water and of chlorophyll *a* concentration, total phosphorus concentration, and percent organic matter of sediment along the mixing zone of Tsiknias and Potamia estuaries during late spring indicated oligotrophic conditions in autotrophic estuaries (absence of riparian canopy) (Dodds, 2007). Values of chlorophyll *a* concentration of water alone indicated oligotrophic to mesotrophic conditions (Wasmund *et al.*, 2001) during a season when yearly maximum values are expected for temperate estuarine systems

Table 1. Results of Spearman correlations (n=11) among physicochemical variables of water and sediment along a) Tsiknias and b) Potamia estuaries in May 2005. CHLA: chlorophyll a concentration; EC: electrical conductivity; DO: dissolved oxygen concentration; T: temperature; TP: total phosphorus concentration; OM: organic matter. * significance at p<0.05; ** significance at p<0.01.

a)

		SEDIMENT							
		EC	pH	DO	T	CHLA	OM	TP	CHLA
WATER	EC		0.32	0.35	-0.82**	-0.93**	0.37	-0.35	-0.48
	PH			0.36	-0.34	-0.37	0.22	-0.31	0.17
	DO				-0.25	-0.37	0.03	-0.24	0.30
	T					0.88**	-0.33	0.58	0.25
	CHLA						-0.26	0.61*	0.42
SEDIMENT	OM							-0.29	0.27
	TP								-0.11
	CHLA								

b)

		WATER					SEDIMENT		
		EC	pH	DO	T	CHLA	OM	TP	CHLA
WATER	EC		-0.72*	-0.54	-0.36	0.18	-0.11	-0.10	-0.69*
	PH			0.64*	0.11	-0.38	-0.22	0.05	0.65*
	DO				0.16	-0.26	-0.54	-0.10	0.67*
	T					0.35	0.52	0.08	0.63*
	CHLA						0.21	0.61*	0.23
SEDIMENT	OM							0.15	0.06
	TP								0.26
	CHLA								

(Dame *et al*., 1986; De Jong and De Jonge, 1995; Moreno and Niell, 2004).

Low values of percent organic matter in sediment may be the result of marine sedimentation and mixing processes at the sediment water interface where rates of delivery and degradation by microbial-mediated processes can be high (Canuel and Martens, 1993; Sarkar *et al*., 2004). The significant positive relationship between total phosphorus of sediment and chlorophyll *a* concentration of water in both estuaries was expected since phosphorus concentration, either already dissolved in waters (Furrer *et al*., 1996; Van Nieuwenhuyse and Jones, 1996) or released from sediments (Rosensteel and Strom, 1991; Clavero *et al*., 1992; 1997; 2000; Ingall and Jahnke 1997; Pallomo *et al*., 2004), constitutes limiting growth factor of primary producers in aquatic ecosystems. Total phosphorus concentration and percent organic matter are properties of the nutrient status of sediment. The organic matter content of sediment, which consists of autotrophs and heterotrophs residues at various stages of decay, represents the dominant source of microbial nutrition. During decomposition of organic matter by micro-organisms, nutrients are liberated in forms which can readily be absorbed by autotrophs. Thus, organic matter is indicative of the sediment condition and decomposition rate. Furthermore, many nutrients, particularly nitrogen, phosphorus and sulphur, are involved in cycles from decaying debris of autotrophs and heterotrophs, through sediment organic matter and back to the autotrophs. Thus, phosphorus may constitute limiting growth factor for autotrophs (phytoplankton and aquatic plants) depending on its concentration and biochemical stability.

The negative relationship of chlorophyll *a* concentration of water with electrical conductivity of water and its positive relationship with temperature of water at Tsiknias estuary, indicated the presence of freshwater phytoplankton communities along the estuary. At Potamia estuary, on the other hand, chlorophyll *a* concentration of sediment related positively with pH, dissolved oxygen concentration, and temperature of water and negatively with electrical conductivity of water. Interestingly, it was not related to chlorophyll a concentration of water or total phosphorus concentration and percent organic matter of sediment.

Apparently, the oxygen-liberating photosynthesis in the small freshwater pools at the low-salinity inward stations of Potamia estuary leads to highly alkaline conditions. Temperature affects chemical processes and dissolved oxygen concentration in water, which constitutes one of the primary indices of eutrophication.

Electrical conductivity and pH are chemical properties of the water column. Electrical conductivity is the net result of many hydrodynamic factors, including tides, rainfall, freshwater and groundwater inputs. pH most markedly affects growth of autotrophs through control of nutrient availability and decomposition. In both estuarine systems, chlorophyll *a* concentration of water did not correlate with chlorophyll *a* of sediment indicating that different processes may control primary production in water and sediment.

Differences in trends and relationships among water and sediment variables between the two estuaries may be attributed to differences in their water volume and/or anthropogenic effects upstream. Management for the early detection and combat of eutrophication necessitates an integrated geographical (catchment scale) and physicochemical (local scale) assessment of riverine conditions and the development of indicators of the status and function of riverine systems relevant to eutrophication (Aspinall and Pearson, 2000).

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