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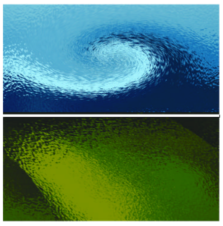

RESEARCH ARTICLE

The biological system of the lower salinity ponds in Kalloni Saltworks (NE. Aegean Sea, Greece): phytoplankton and macrobenthic invertebrates

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Abstract

1 - Spatial and seasonal variations of two important biological quality elements (phytoplankton and macrobenthic invertebrates) in Transitional Water (TW) ecosystems were studied in Kalloni Saltworks, located at the island of Lesvos (NE. Aegean Sea, Greece).

2 - A total of 36 phytoplankton taxa, belonging to 5 classes, were collected in the study area during both seasonal samplings. Many of the species found in the study area are coastal/brackish waters species that are commonly encountered in transitional waters ecosystems. A substantial seasonal change in species composition, as well as in the observed trends in density and biomass variations along the salinity gradient was revealed. Blooms of *Euglena acusformis*, *Mesodinium rubrum* and phytoflagellates were recorded in the study area.

3 - A total of 43 macrobenthic invertebrates taxa, belonging to 6 major groups, were collected in the study area during both seasonal samplings. Most of the abundant macrobenthic invertebrate species in the study area were typical lagoonal or marine/estuarine species commonly occuring in coastal lagoons, whereas typical marine species gradually disappeared downstream the pond sequence. The patterns of variation of macrobenthic invertebrates' density and biomass along the salinity gradient were different between seasons, partly due to the strong dominance of *Hydrobia acuta* in autumn, while species richness declined along the salinity gradient in both seasons.

Introduction

Solar saltworks are man-made systems for the extraction of salt from seawater, by means of solar and wind evaporation. They are also coastal aquatic ecosystems of great ecological importance, as they are characterised by considerable habitat heterogeneity. They combine a spectrum of aquatic environmental types along a long salinity gradient (seawater salinity – 300 ppt). Solar saltworks are closely related to natural transitional water (TW) ecosystems, as they are located at the land – sea interface and their lower salinity part (seawater salinity – 100 ppt) presents many similarities with coastal lagoons, regarding both the abiotic environment and the biota.

Phytoplankton communities have been documented in several solar saltworks due to their importance for salt production (Davis 1990), although the spatial resolution of the data in the saltworks ecosystems studied was usually low. On the other hand, community structure and ecological functions of macrobenthic invertebrates in solar saltworks ecosystems are poorly documented, as very few studies currently exist in the literature (e.g. Britton & Johnson 1987; Evagelopoulos & Koutsoubas 2007).

The aim of the present paper is to outline the main trends in the variations of widely applied descriptors of phytoplankton and macrobenthic invertebrates in TW ecosystems (i.e. composition, density, biomass and phytoplankton bloom parameters; EC 2003) along the salinity gradient at the lower salinity ponds in Kalloni Saltworks, Greece.

Material and methods

Kalloni Saltworks constitute part of a NATURA 2000 network site in Lesvos Island, NE. Aegean Sea, Greece (Figure 1). The study areas were restricted to the lower salinity ponds (salinity<80 ppt) of Kalloni Saltworks, where benthic macrofauna was present. Two samplings were carried out for both phytoplankton and macrofauna, the first in autumn 2004 (phytoplankton & macrofauna) and the second in late spring 2005 (macrofauna) or early summer 2005 (phytoplankton). Ten sampling stations in total were selected along the salinity gradient (47 – 72 ppt in autumn 2004 and 38 – 55 ppt in spring and summer 2005). Different subsets of the sampling stations were sampled for the phytoplankton (Figure 1a) and the macrobenthic invertebrates (Figure 1b) analyses. Phytoplankton density was measured with the Utermöhl method (Utermöhl 1958). Phytoplankton biomass was measured indirectly, by the measurement of chlorophyll *a* concentration with the fluorometric method developed by Neveaux & Panouse (1987). Macrofauna biomass was measured as wet biomass (including molluscan shells). The statistical significance of the descriptors' variations was tested with the Kruskal-Wallis and Mann-Witney non-parametric tests.

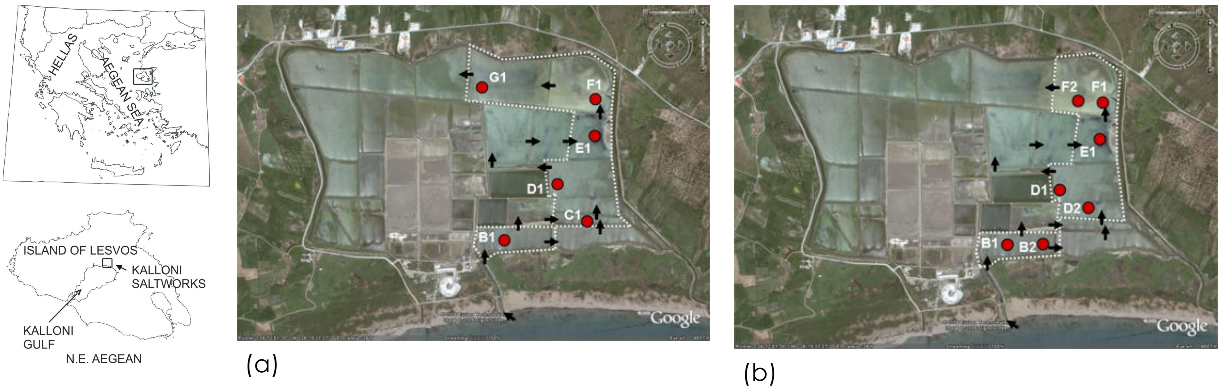

Figure 1. Maps of the study areas (delineated by dotted curves) for (a) the phytoplankton and (b) the macrobenthic invertebrates' analyses, indicating the sampling stations. The arrows indicate the course of seawater flow in the ponds.

Result and discussions

Phytoplankton

Phytoplankton in the Utermöhl samples collected in the study area during both seasonal samplings were identified into a total of 36 taxa, belonging to: Bacillariophyceae (13), Dinophyceae (14), Euglenophyceae (1), Cryptophyceae (2), Cyanophyceae (3), autotrophic flagellates (2) and a group of unidentified nanophytoplaktonic species. The photoautotrophic ciliate Mesodinium rubrum was also recorded in the study area in autumn. The abundant phytoplankton species (i.e. collectively constituting at least 75% of the total phytoplankton density at each station and sampling) are shown in Table 1. Benthic microalgae were usually present in the samples (as tychoplankton), but were less abundant than truly planktonic species, with the exception of Cylindrotheca closterium at the E1 station in autumn.

In autumn, mean total phytoplankton density and biomass maxima were recorded at the B1 station, due to a bloom of the euglenophycean species Euglena acusformis (mean density 1968 cells mL-1). A bloom of Mesodinium rubrum was also recorded (mean density 406 cells mL-1 at the D1 station). Mean total phytoplankton density and biomass decreased along the salinity gradient (Figure 2a).

In summer, mean total phytoplankton density and biomass maxima were recorded at the most remote ponds (F1, G1), mainly due to two phytoflagellate species (comprising together 43% of a mean total density of 1830 cells mL-1 at the G1 station). Mean total phytoplankton density and biomass generally increased along the salinity gradient, with the exception of a decrease in biomass between the F1 and G1 stations (Figure 2a).

Phytoplankton species richness, as measured from the Utermöhl samples, increased along the salinity gradient in autumn (mean species richness ranged from 4 to 10 taxa), whereas it initially decreased and then increased along the salinity gradient in summer (mean species richness ranged from 6 to 12 taxa) (Figure 2a).

Despite the shallowness of the water column, truly planktonic microalgal species were generally more abundant than benthic species in the study area in both seasons. Phytoplankton in the study area was found to have common characteristics with lagoonal phytoplankton: typical neritic species were rare after the B1 station, whereas the groups of dinoflagellates, cryptophyceans and other flagellated and nanophytoplanktonic species that were found to be abundant in the study area, are commonly encountered in semi-enclosed and enclosed coastal lagoons (Guelorget & Perthuisot 1992; Nicolaidou et al. 2005). The spatial scale of sampling in this study was finer than in other studies in the literature and revealed a substantial change of the abundant species along the salinity gradient in both seasons. An important seasonal change of the abundant phytoplankton species was also observed. The patterns of variation of phytoplankton density, biomass and species richness along the salinity gradient were different between seasons, partly due to the strong dominance of Euglena acusformis at stations B1 and C1 in autumn. The Euglena acusformis and Mesodinium rubrum blooms in autumn may be considered as indicating eutrophication in the study area (Reynolds 2006).

Macrobenthic Invertebrates

The macrobenthic invertebrates collected in the study area during both seasonal samplings were identified into a total of 43 taxa, belonging to: Mollusca (19), Polychaeta (10), Crustacea (10), Insecta (2), Phoronida (1) and Anthozoa (1). The abundant macrobenthic invertebrate species (i.e. collectively constituting at least 75% of the total macrofauna density at each station and sampling) are shown in Table 1.

In autumn, mean total density of macrobenthic invertebrates increased along the salinity gradient, to reach its maximum at the D2 station, mainly due to *Hydrobia acuta* (mean density 2434 ind. sample^{-1}). Mean total biomass also increased along the salinity gradient, to reach its maximum at the D1 station, mainly due to *Cerastoderma glaucum* (mean biomass 32 g sample^{-1}). Both mean total density and biomass gradually declined after the D1 and D2 stations, to reach their minima at the F1 station (Figure 2b).

In spring, maxima of mean total density were recorded at the B1 station, mainly due to *Bittium reticulatum*, *Hydrobia acuta, Hediste diversicolor* and *Microdeutopus gryllotalpa* (mean total density 129 ind. sample^{-1}), and at the F2 station, mainly due to *Capitella capitata* and *Cerastoderma glaucum* (mean total density 111 ind. sample^{-1}). Maximum of mean total biomass was recorded at the B2 station, mainly due to *Abra ovata* and *Cerastoderma glaucum* (mean total biomass 17 g sample^{-1}). Both mean total density and biomass minima were recorded at the D2 station (Figure 2b). Spring total density and biomass levels were much lower than in autumn.

Species richness of macrobenthic invertebrates gradually declined along the salinity gradient in both seasons (mean species richness ranged from 3 to 15 species in autumn and from 5 to 13 in spring) (Figure 2b).

Most of the abundant macrobenthic invertebrate species in the study area were typical lagoonal or marine/estuarine species commonly occuring in coastal lagoons, whereas typical marine species gradually disappeared downstream the pond sequence. The detected pattern of spatial variability in the composition of the macrobenthic community in the study area was thus similar to that usually observed in coastal lagoons of the Mediterranean (Guelorget & Perthuisot 1992; Nicolaidou *et al*. 2005). Variation of macrobenthic community structure between seasons was partly determined by the life cycle of *Hydrobia acuta*: It was dominant in autumn, when its main growth period takes place. On the other hand, its density was low in late spring because the adults die after reproduction in May (Britton 1985). Therefore, the examination of autecological aspects of the abundant species may be useful in order to achieve a better insight of the dynamics of macrobenthic invertebrate communities in solar saltworks, similarly to natural TW ecosystems (Nicolaidou *et al*. 2005). The change of the abundant species along the salinity gradient was more important in summer than in autumn due to the strong dominance of *Hydrobia acuta* in autumn, whereas the seasonal change of the abundant species was considerable. The patterns of variation of macrobenthic invertebrates' density and biomass along the salinity gradient were different between seasons, partly due to the strong dominance of *Hydrobia acuta* in autumn, while species richness declined along the salinity gradient in both seasons.

Table 1. The abundant phytoplankton and macrobenthic invertebrate taxa at the lower salinity ponds in Kalloni Saltworks in each season.

Phytoplankton

TAXA	AUTUMN	SUMMER
Bacillariophyceae		
Cylidrotheca closterium	+	+
Pleurosigma sp.		+
Thalassionema spp.		+
Bacillariales spp.		+
Dinophyceae		
Gymnodinium sanguineum	+	
Gymnodinium spp.		+
Oxyrrhis marina	+	+
thecate dinophyceae spp.	+	+
Euglenophyceae		
Euglena acusformis	+	
Cryptophyceae		
Cryptophyceae sp. 1	+	
Cryptophyceae sp. 2	+	
Cyanophyceae		
Nostocaceae spp.		+
Autotrophic flagellates		
autotrophic flagellate sp. 1		+
autotrophic flagellate sp. 2		+
Misc. phytoplankton		
nanophytoplankton spp.	+	+
Ciliates		
Mesodinium rubrum	+	

Macrofauna

TAXA	AUTUMN	SPRING
Mollusca		
Bittium reticulatum		+
Cerastoderma glaucum		+
Hydrobia acuta	+	+
Pirenella conica		+
Polychaeta		
Capitella capitata	+	+
Hediste diversicolor		+
Malacoceros fuliginosus	+	
Crustacea		
Corophium orientale		+
Gammarus aequicauda		+
Microdeutopus gryllotalpa	+	+
Decapoda		+

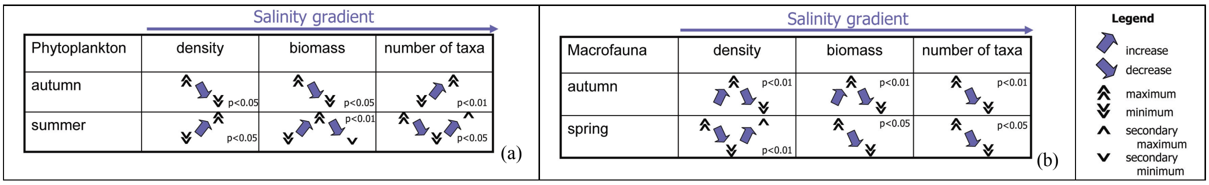

Figure 2. Trends of variation of (a) phytoplankton and (b) macrobenthic invertebrates' descriptors along the salinity gradient at the lower salinity ponds in Kalloni Saltworks in each season

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