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Disturbance caused by freshwater releases of different magnitude on the aquatic macroinvertebrate communities of two coastal lagoons

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ABSTRACT

The response of the aquatic macroinvertebrate communities to freshwater releases of different magnitude and persistence was investigated in two Mediterranean coastal lagoons (Ca l'Arana and Ricarda). The study was carried out during 14 months (June 2004–July 2005) in which different environmental variables and the macroinvertebrate communities associated with two different habitats, the *Phragmites australis* belt and the deep area of the lagoons, were sampled monthly. Additionally, potential colonizing sources were identified through the analysis of Chironomidae pupal exuviae. The initial response of the communities to the freshwater releases was similar, being characterized by a peak of opportunistic taxa (mainly Naididae), but the late response was different for each lagoon. In the Ca l'Arana, the magnitude of the freshwater release was higher (salinity dropped below five, which is the limit commonly established for most freshwater species) and its persistence was also higher, allowing the colonization of the lagoon by new insect taxa, which replaced the brackish water species. In the Ricarda, the salinity never dropped beyond five and pre-disturbance conditions were rapidly re-established. This, together with the acclimatizing mechanisms showed by the species *Chironomus riparius* and *Hediste diversicolor*, permitted the recovery of the pre-disturbance macroinvertebrate community.

1. Introduction

The coastal areas are the most populated areas in the world and, consequently, they are subjected to multiple human impacts. Freshwater releases account for a substantial part of those impacts in terms of quantity and frequency. The coastal zone is the last stop for all of the water fluxes coming from the land, and almost every human activity (including agricultural, industrial, management, recreational and urban activities) generates a daily quantity of wastewaters. These releases have a considerable potential effect over the aquatic macroinvertebrate communities established in the brackish coastal waters, since differences in salinity have been registered to be responsible for the structure of these communities on a regional scale (Basset et al., 2006; Cañedo-Argüelles and Rieradevall, 2009; Cognetti and Maltagliati, 2000). Moreover, relatively small changes in salt concentrations have been reported to cause large modifications in zooplankton trophic structure in coastal lagoons (Jeppesen et al., 1994), and to drive the ecosystem to regime shifts when a threshold is exceeded (Jeppesen et al., 2007). This has been commonly related to the osmotic restrictions of freshwater and marine invertebrates, and a salinity of five has been fixed as the limit beyond which they can no longer survive (Barnes, 1989; Pinder et al., 2005; Remane and Schlieper, 1971). Nonetheless, the existence of this limit has been usually studied under a comparative and gradient analysis approach or through laboratory assays, and there is a lack of knowledge concerning the response of the macroinvertebrate communities to sudden changes in salinity around this limit.

In spite of their importance and their potential effects, freshwater releases have been usually neglected as a source of disturbance in transitional waters, where attention has been mainly focused on the organic enrichment of waters that these fluxes usually involve (Pearson and Rosenberg, 1978; Zaldívar et al., 2008), rather than on possible direct impacts. Results from previous investigations suggest that aquatic macroinvertebrate communities of brackish waters are significantly affected by freshwater releases (Frantzen et al., 1994; Stora and Arnoux, 1983). Nonetheless, there is very little information concerning the colonizing sources for the incoming species and whether differences in the magnitude of the freshwater releases and the persistence of the effects would affect the communities' response. It is known that the ability of the species to occupy empty niches after disturbance is linked to the time of disturbance (Zajac and Whitlatch, 1982). Consequently, it would be reasonable to suppose that the persistence of the freshwater conditions could also influence species replacement.

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In the present study, the effect of freshwater releases of different magnitude over the aquatic macroinvertebrate communities of two Mediterranean lagoons was investigated.

We tested the following hypotheses: (1) that freshwater releases have a significant effect over the aquatic macroinvertebrate communities inhabiting coastal lagoons; (2) that the response of the aquatic macroinvertebrate communities depends on the magnitude of the release and the persistence of its effects; and (3) that the freshwater releases can create new niche opportunities for freshwater taxa to colonise the lagoons.

2. Study site

The Llobregat Delta is an important natural reserve which has been highly modified because of the proximity of different urban areas (including Barcelona city) and the existence of extensive crop fields and of a large infrastructure (Barcelona's airport) within the area. The activities that take place in the delta have altered the natural hydrological regime. This was the case of the Ca l'Arana and Ricarda lagoons (Fig. 1) which, during the study period (June 2004–July 2005), were subjected to large freshwater releases. Both are microtidal Mediterranean lagoons with a dense mono-specific belt of the helophyte *Phragmites australis*, and they are separated by a distance of 1.60 km from two other lagoons (Cal Tet and Magarola) (Fig. 1).

The Ca l'Arana lagoon was created in the late 1960s by quarrying activities. It is small (area = 1 ha) and deep (maximum depth = 7 m), and it is exclusively fed by runoff discharges and groundwater coming from the superficial aquifer. The over-exploitation of the aquifer in the last decades has led to the salinization of the lagoon and the establishment of a permanent halocline characterized by a deep layer of seawater and a surface layer of brackish waters (Cañedo-Argüelles et al., pers.comm.). In November 2004, a large amount of freshwater was released into the lagoon as a consequence of the massive irrigation of a surrounding pine tree area.

The Ricarda lagoon is one of the last remains of the natural lagoons that once covered the deltaic plain. This lagoon is larger (area = 8 ha) and shallower (maximum depth = 2 m) than the Ca l'Arana, and there is a good mix of water and oxygenation of the water column along the year (Cañedo-Argüelles et al., pers.comm.). It is intermittently connected to the sea by a narrow channel in its mouth, and the seawater percolates into it through a sand barrier. The seawater inputs are counteracted by freshwater discharges occurring in the inland side of the lagoon. In January 2005 freshwater was released into the lagoon due to the prolonged drought of 2004.

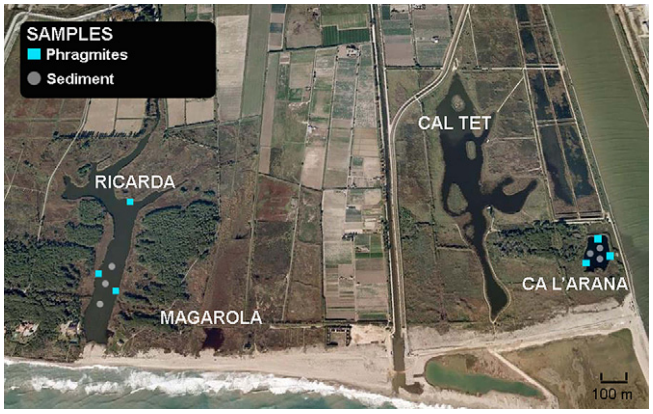

Fig. 1. Aerial picture of the study site. Lagoons' names are in white capital letters, and the places where epiphytic macroinvertebrates (white squares) and sediment-associated macroinvertebrates (white circles) were sampled are marked. (Source: Institut Cartogràfic de Catalunya).

The two neighboring lagoons were sampled for *Chironomidae exuviae* as the most probable sources of colonizing individuals after disturbance. Cal Tet is a brackish man-made shallow lake (mean conductivity = 7.23 ± 0.96 mS cm^{-1}), created in 2003. It has an area of 13 ha and a maximum depth of 1.2 m. Magarola is a small (area = 0.42 ha) and shallow (maximum depth = 1.5 m) natural lagoon with meta-haline waters (mean conductivity = 47.34 ± 3.31 mS cm^{-1}), and it is exclusively fed by groundwater (Cañedo-Argüelles et al., pers.comm.).

3. Material and methods

3.1. Sampling design

All of the samples (physico-chemical and biological) were collected monthly from May 2004 to July 2005 in the Ca l'Arana and from June 2004 to July 2005 in the Ricarda.

Water transparency (Secchi disk) and depth profiles of salinity, pH, water temperature and dissolved oxygen profiles were measured *in situ* using a multi-parametric sensor (WTW multi-parameter model 197i). All the variables were recorded from the surface to the bottom every 50 cm in the deepest point of each lagoon. Surface water was collected for dissolved inorganic nutrient analysis (NH_4^+, NO_3^-, NO_2^-, DIN, SRP, Si^{2+}), as well as analyses of total organic carbon (TOC), major ions (Cl^-, SO_4^{2-}, Ca^{2+}, K^+, Mg^{2+}, Mn^{2+}, Na^+), phytoplanktonic chlorophyll-*a*, and suspended solids. All of the analyses were performed following standard methods (Greenberg et al., 1999). Accumulated rainfall data for each month were obtained from the nearest meteorological station (information available at: http://www.meteocat.com).

Aquatic macroinvertebrates were sampled in two habitats: the reed belt (epiphytic macroinvertebrates) and the deep zone (sediment-associated macroinvertebrates). Three samples were collected for each habitat in each site and sampling occasion (Fig. 1). The epiphytic macroinvertebrates were quantitatively collected following Kornijów and Kairesalo, 1994. A plastic tube of 6 cm wide and 50 cm long was lowered over stems, and they were cut so that they floated up into the tube. Then, water was drained out through a 250-μm mesh and macroinvertebrates were removed from the stems by hand and fixed for their conservation in four percent formaldehyde. Three to ten stems were collected in each sample and measured for density calculation (diameter × height × 3.14). The sediment-associated macroinvertebrates were collected using a Van Veen grab sampler (grab sampling area = 299 cm^2). Once collected, sediment was rinsed in the field through a 250-μm mesh and preserved in four percent formaldehyde. Once in the laboratory, the macroinvertebrates were sorted and identified on the species level, except in the case of oligochaetes and non-chironomidae diptera (family level).

In order to detect any possible influence of disturbance over chironomids' emergence and to test the importance of surrounding sources of colonizing individuals, chironomidae pupal exuviae were collected in the two studied lagoons (Ca l'Arana and Ricarda) and their neighbors (Cal Tet and Magarola) by using a 250-μm mesh size hand-net. The areas of organic matter accumulation on the shore of the water masses were selected and all of the collected material was integrated into one single sample. The collected *exuviae* corresponded to those individuals that had emerged within the past 48 h (Coffman, 1973). Samples were preserved in seventy percent ethanol, and the specimens were sorted under a binocular stereoscope. When samples contained too many individuals, a minimum of 200 were randomly selected for their identification, as recommended by Wilson and Ruse (2005).