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Freshwater inflows and seasonal forcing strongly influence macrofaunal assemblages in Mediterranean coastal lagoons

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ABSTRACT

Coastal lagoons of the Ebro Delta (Catalonia, Spain) are part of the Ebro Delta Natural Park managed by regional government authorities. Coastal lagoons have persistently received freshwater inputs from the Ebro River from May to November that have altered their natural ecology and hydrological cycle. In this study, we evaluate the seasonal effect of contrasting salinity regimes (polyhaline in the Tancada lagoon, mesohaline in the Encanyissada and oligohaline in the Clot lagoon) on the composition, abundance, species richness, alpha diversity and biomass of benthic macrofauna communities, and we assess the relative contribution of local environmental variables to the observed patterns. Additional sampling was conducted in the largest lagoon (Encanyissada) in order to assess variability at lower spatial scale. At both spatial scales (i.e., among-lagoon and within-lagoon), species richness and diversity tended to increase at higher salinities, particularly in summer. At the assemblage level, significantly different groupings were also found among lagoons and among zones of the Encanyissada lagoon, with more distinctive differences also in summer. Environmental factors accounted for up to 56–60% of the variation in macrofaunal assemblages at both spatial scales, with salinity and temperature accounting for the largest contributions (approx. 14% and 10%, respectively), whereas biomass was mostly controlled by temperature and nutrients. Distinctive oxygen and organic matter levels across the lagoons were also associated with the freshwater influx and displayed significant contributions to observed patterns. Our study shows that the low salinity regime and/or other factors related to long-term inputs of freshwater shape the community of macrofauna within the lagoons, a central trophic resource for most of the local species of fish and aquatic birds. Restoration of these systems to their natural hydrological functioning without further inputs of freshwater and higher marine connectivity is suggested as the more appropriate management.

1. Introduction

Coastal areas worldwide are subject to many and varied changes resulting from human activities and natural processes (Aubry and Elliott, 2006), which can impair the health and fitness of resident biota (Adams, 2005) as well as the ability of the coastal zone to deliver ecosystem functions and the goods and services for human well-being (Costanza et al., 1997). In recent times, many estuarine and coastal marine ecosystems have experienced increasing rates of degradation (Halpern et al., 2008) that interact with natural processes and the inherent seasonality of the system in terms of growth, reproduction and abundance of organisms, particularly in temperate regions (Coma et al., 2000). This degradation can be caused by multiple stressors, including altered hydrological conditions, nutrients and suspended matter, hypoxia, toxic chemical pollutants, and other ecosystem alterations, which can impact local organisms through single, cumulative or synergistic processes (Adams, 2005). In particular, freshwater inputs from human sources may cause major modifications in the trophic functioning of coastal areas because they can induce both physiological stress to low salinities in plant and animal communities (Williams et al., 1990; Adams et al., 1992), and modify other central features of ecosystem such as light availability and nutritional conditions as well as other possible effects (see review by Smith et al., 2006).

In the Ebro Delta (Southern Catalonia, NW Mediterranean) approx. 70% of the total surface has been devoted to rice cultivation over the last 150 years, which has undermined the marine connections of coastal lagoons and introduced variable amounts of agricultural wastewater into the system through a growing network of irrigation and drainage canals. From the 1960s to late 1980s, the lagoons received large amounts of agricultural water from the rice fields with high contents of pesticides and fertilizers;

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consequently, submerged macrophytes habitats declined by over 80% and the system shifted to phytoplankton-dominated primary production (Ferrer and Comín, 1982; Comín et al., 1990). The populations of fish and waterfowl severely declined and local fisheries and hunting activities were also impacted (Forés, 1992; Ibáñez et al., 2001). From 1990 to the present, the regional government and Natural Park authorities developed a new water management strategy consisting of replacing wastewater inputs from rice fields (without completely eradicating them) with freshwater inputs from the Ebro River in order to maintain reduced levels of salinity from May to November and decrease the levels of organic matter, nutrients and pesticides (Comín et al., 1991). The connectivity between the lagoons and the sea (both natural and artificially constructed) allows the drainage of excess water inputs into the bay as well as the entrance of saltwater at high tide and during storm events. As a result of these management practices, the extension cover by submerged angiosperms was increased, although peak annual biomasses are still 88–95% lower than maximum values reported elsewhere at similar salinities (Prado et al. 2013a). For fish, the catches of commercial species have not recovered (Rodríguez-Climent et al., 2012) and low salinities have favored the presence of non-native fish species (Caiola and Sostoa, 2002; Franch et al., 2008), that might cause cascading effects on the local food-web. In contrast, the populations of aquatic birds have become increasingly abundant (Ibáñez et al., 2001), thus favoring local hunting and bird-watching activities that have an important role in the local economy.

Among animal communities, macrofaunal assemblages constitute a major food resource for a large number of fish species of commercial and natural interest (Hindell et al., 2001; Rodríguez-Climent et al., 2013), as well as for many types of aquatic birds (review by Green et al., 2002) and play a central role on the trophic functioning of ecosystems. In addition, the use of invertebrates for assessing environmental conditions in aquatic ecosystems has thus long been recognized (Jónasson, 2004), and has produced a variety of biological monitoring tools using aquatic invertebrates (Hering et al., 2006; Bonada et al., 2006). Therefore, information on the spatial variability of benthic assemblages and the factors responsible for their distributional abundance can provide valuable and robust information for the formulation of monitoring and multifunctional management strategies (Kendall and Widdicombe, 1999). Fluctuations in salinity have been shown to have a great influence on the abundance, biomass, and diversity of macrofauna (Montagna et al., 2002). Salinity stress (Whiteley et al., 2001) and hypoxia (Ritter and Montagna, 1999) can reduce benthic populations, whereas nutrient loading may increase the abundance and biomass of benthic organisms through enhanced food availability from primary producers (Montagna and Yoon, 1991). Also, suspended sediments in freshwater inflows can alter the distribution of different grades of sediment and modify patterns of benthic fauna associated to sediment grain (Kendall and Widdicombe, 1999), particularly in exposed sites subjected to strong wind forcing and low hydraulic flushing that enhance sediment resuspension (Kjerfve, 1994). Hence, the net effect of freshwater inflow on macrofaunal communities (altered secondary production, and species losses via low-salinity intolerance) is a function of the interaction between physical (e.g., wind exposure, sedimentation, and resuspension) and chemical processes (salinity variations, nutrient enrichment and cycling; Longley, 1994). In addition, because structural complexity may hinder foraging by predators (Farina et al., 2009), the survival of macrofauna is often positively related to the density and biomass of vegetation (Gotceitas et al., 1997; Schmidt and Scheibling, 2007) which, in turn, may be influenced by the combined effects of salinity and nutritional conditions. Although there is considerable knowledge about factors controlling benthic invertebrate communities, so far no studies have evaluated the consequences of altered freshwater inflows from the perspective of the multiple stressors that can be simultaneously interacting with changes in salinity conditions and reported seasonal changes in the structure of the entire assemblages.

In this scenario, the specific objectives of the present study were: 1) to evaluate patterns of variability in species richness, diversity, and biomass and in the overall community structure of macrofaunal assemblages under current salinity regimes (relatively stable since at least 2007; Rodríguez-Climent et al., 2012) at the within-lagoon and among-lagoon spatial scales, and, most importantly, 2) to assess the relative importance of salinity and other environmental factors on former community variables and on the compositional structure of assemblages. In addition, our overall aim was also to update the status of macroinvertebrate populations in the Ebro Delta coastal lagoons and compare it to other studies in similar systems. Given that freshwater inflows can impact the composition and abundance of macrofauna through many factors, this information may help regional authorities to re-evaluate current management practices in order to optimize functional and ecosystem service values and improve the current ecological status.

2. Materials and methods

2.1. Study sites

The study was conducted in three coastal lagoons of the Ebro Delta receiving freshwater inflows from April–May until December as well as marine water through canals connecting with the sea. The lagoons are separated from the Ebro River by approx. 5.5–6.5 km, and did not receive freshwater naturally until human intervention. The Encanyissada lagoon is the largest in size (418 ha) and is connected to the Alfacs Bay through a natural outlet and to the Clot lagoon (56 ha) through an artificial channel. The third investigated lagoon was the Tancada, which is an intermediate size (185 ha) and is connected to the Alfacs bay through one large and two narrow artificial canals (Fig. 1). The three lagoons feature circumvallation canals with multiple lock-gates that allow the entrance of agricultural water at the discretion of the natural park authorities during the rice cultivation season. In addition, the Clot lagoon receives riverine water through a canal located close to the connection with the Encanyissada, which allows its subsequent entrance into the later. For the Tancada, drainage water constitutes the only source of freshwater into the lagoons. Formerly to human intervention approx. 150 years ago, the three lagoons were united in a much larger one, which was highly connected to the Alfacs Bay through an extensive saltmarsh area. The lagoon was isolated from the sea as a result of the transformation of most of the salt marsh area into rice fields, which in addition to new inputs of drainage water, altered the natural dynamics of the system and ultimately caused its breakage into three different water bodies.

In each lagoon, study sites were selected according to areas that that had been seasonally monitored for salinity since 2007, and could provide long-term information on their hydrological regimes. In total, 5 sites of the Encanyissada lagoon (E15, E16, E23, E24 and E25) were compared to with 5 sites in the Clot (C2 to C6) and 5 in the Tancada lagoon (T9 to T13) (see Fig. 1). The distance between all sites was approx. 300 m apart. In the particular case of the Encanyissada (much larger in size than the other two lagoons), the possible variability among distant areas was investigated through a within-lagoon spatial design. Four geographical zones, separated by approx. 550–700 m, and each including 3 monitoring sites were randomly selected for assessing internal variation within the Encanyissada lagoon (North: E9, E10 and E20; Northeast: E23, E24 and E25; Southeast: E21, E22 and E27; and South: E1, E2 and E11).