



Spatiotemporal dynamics of submerged macrophytes in a Mediterranean coastal lagoon

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ABSTRACT

The seasonal and interannual dynamics of the biomass and spatial distribution of a macrophyte meadow were explored in a Mediterranean coastal lagoon (Albufera des Grau, Balearic Islands) from 2002 to 2007. The dynamics in the main physicochemical variables were also analysed to assess the factors involved in the spatiotemporal variability of the submerged macrophytes.

The meadows were dominated by *Ruppia cirrhosa*, which showed a marked seasonal cycle with winter quiescence and complete annual regrowth. The annual production of *R. cirrhosa* had high interannual variability and was amongst the highest described for this species in the literature, ranging 327–919 gDW m⁻². The spatial distribution of macrophytes was determined by light availability and wave exposure, with the highest abundances found in shallow and gently sloped areas sheltered from the strong northerly winds. The interannual variations in macrophyte descriptors (area of occurrence, average depth of the meadows, and maximum biomass) were mainly related to water turbidity and salinity, but the effect of these variables was constrained to the spring and summer months, respectively. A significant negative correlation between the extent of coverage of *R. cirrhosa* and the water level at the end of the previous annual cycle was observed, suggesting a positive effect of desiccation on the extent of coverage of the macrophytes. After six years of apparent stability, the macrophytes abruptly disappeared from the lagoon. Although the mechanisms are not clear, this shift was likely attributable to a combination of several factors.

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1. Introduction

In coastal ecosystems, submerged macrophytes are key species with important structuring, roles serving as habitat and food resources not only for aquatic organisms but also for many water-bird species (Yáñez-Arancibia et al., 1994; Levin et al., 2001). In these highly productive systems, the primary producers are either dominated by rooted macrophytes, macroalgae or phytoplanktonic communities, usually in relation to nutrient levels (Knoppers, 1994; Duarte, 1995; Taylor et al., 1999; Hauxwell and Valiela, 2004; Sand-Jensen and Nielsen, 2004). During the last century, increased nutrient inputs to coastal environments have favoured the spread of fast-growing macroalgae, replacing the original rooted macrophytes and leading to strong environmental alterations (Valiela et al., 1997; Raffaelli et al., 1998). The characterisation of the submerged aquatic vegetation in coastal ecosystems is thus of prime importance for assessing their ecological

status (Dennison et al., 1993). Moreover, the shifts in the dominance of primary producers in eutrophic coastal lagoons have recently been interpreted as a sequence of alternative stable states (Trobajo et al., 2002; Viaroli et al., 2008) similar to those in freshwater shallow lakes that inspired the regime shifts theory in ecology (Scheffer et al., 1993).

Apart from this, the characterisation of the dynamics of submerged macrophytes in medium to low impacted systems will contribute to a better understanding of the factors controlling their distribution and abundance under natural conditions (Duarte, 2002). Despite the large number of factors that appear to be involved (Hemminga and Duarte, 2000), salinity and light availability have traditionally received most of the attention. However, the need to consider other factors (physical, geological and geochemical) has recently been highlighted (Koch, 2001; Viaroli et al., 2008).

In Mediterranean coastal lagoons in particular, the need for a comprehensive depiction of macrophyte dynamics based on long-term data sets is especially relevant given the inherently high temporal variability of these environments (Quintana et al., 1998; Comín et al., 2004; Viaroli et al., 2005). Nonetheless, long-term

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studies reporting the spatiotemporal dynamics of submerged macrophytes in low impacted systems are scarce in the literature.

This study aims to characterise the spatiotemporal variability of submerged vegetation in a well-preserved Mediterranean coastal lagoon with dense and extensive macrophyte meadows (Albufera des Grau, Menorca, Western Mediterranean). Extremely high biomass of the euryhaline macrophyte *Ruppia cirrhosa* was recently observed in the lagoon (Obrador et al., 2007). This paper is part of a major research program dealing with the properties and stability of the macrophyte-dominated state in the Albufera des Grau. *R. cirrhosa* is an aquatic angiosperm which often forms dense and productive meadows in European transitional waters (Verhoeven, 1979). It is not considered to be a true seagrass species because it does not occur at consistently high salinities (Den Hartog, 1970 in Borum et al., 2004). Previous studies have pointed to salinity, water turbidity or the redox status of surface sediments as factors controlling its distribution and abundance (Verhoeven, 1979, 1980; Menéndez and Comín, 1989; Azzoni et al., 2001; Menéndez et al., 2002).

The main objectives of this study were to characterise the spatial, seasonal and interannual dynamics of the macrophyte meadows and to determine the factors involved in the dynamics of submerged vegetation. We also aimed to quantify the variability in annual production of *Ruppia cirrhosa* to confirm the extremely productive character of the lagoon depicted by Obrador et al. (2007). This includes a brief comparison of four methods described in the literature to calculate macrophytic annual production.

2. Methods

2.1. Study site

The Albufera des Grau (surface area 78 ha, volume 1.0 hm³) is an enclosed brackish coastal lagoon located in the northeast coast of the island of Menorca (Balearic Islands, Western Mediterranean; Fig. 1). The lagoon was declared a Nature Park in 1995 and currently does not support recreational, commercial or intense fishing industries. Its average depth is 1.37 m with a maximum of 3 m (Pretus, 1989). The lagoon, which is subject to high seasonal and

interannual hydrological variability, is irregularly connected to the sea (Obrador et al., 2008). The freshwater inputs are frequently torrential and are supplied by two streams that drain an area of 56 km². The main land covers in the watershed are comprised of natural vegetation and extensive dry farming land. Currently, the lagoon exhibits dense littoral meadows of *Ruppia cirrhosa*, which attain biomass values of up to 1760 gDW m⁻² (Obrador et al., 2007). Macroalgae (*Polysiphonia* spp., *Gracilaria* sp. and *Chaetomorpha crassa*) are currently sparsely observed, but macroalgae-dominated states without macrophytes were also observed in previous decades (Margalef, 1952; Pretus, 1989).

2.2. Spatial distribution of macrophytes

The spatial distribution of macrophytes was determined from systematic surveys of the lagoon conducted annually during the period of maximum biomass (summer) for the years 2002–2007. Macrophyte cover was determined by visual observation from a boat, and repeated dives were conducted in order to identify macrophyte species when necessary. The surface of the lagoon was divided into a 25 × 25 m grid and the abundance of each macrophyte species was determined for each unit. Macrophyte abundance was recorded using a percent cover scale with five classes (absent, <25%, 25–50%, 50–75%, >75%). The surface area of occurrence of each species was calculated, together with the average depth of the meadows weighted by the area assigned to each level of the cover index. The spatial distribution of macrophytes was compared with the basic morphometrical descriptors of the lagoon. The depth (from 0 to 300 cm), slope (from 0 to 90°) and slope direction (from 0 to 360°) were calculated for each grid unit from the bathymetry of the lagoon. The effect of the environmental variables on macrophyte cover was evaluated with a factorial regression analysis where the cover index was treated as an ordinal multinomial variable (logit transformed). Complementary 3D graphs were used to better visualise the effects on macrophyte cover, applying a weighted least-squares smoothing method. All the statistics were performed using Statistica 8.0 software.

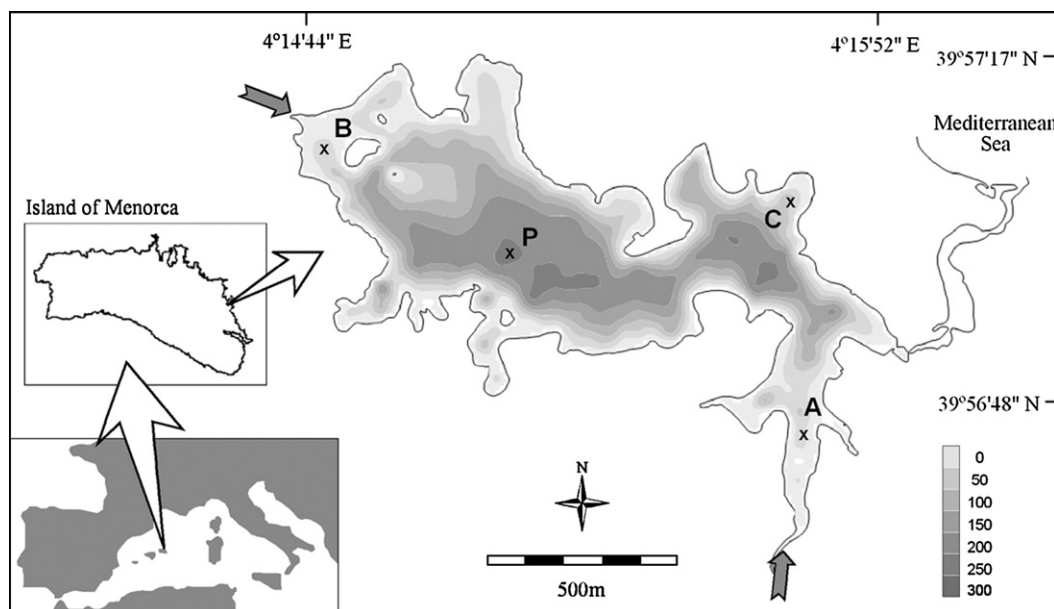


Fig. 1. Location and bathymetric map (50 cm isobaths) of the Albufera des Grau coastal lagoon on the Island of Menorca (western Mediterranean). The sampling sites (crosses) and the freshwater inputs (grey arrows) are shown.

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