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Seasonal dynamics of upper sublittoral assemblages on Mediterranean rocky shores along a eutrophication gradient

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ABSTRACT

Changes in the seasonal dynamics of Mediterranean macroalgal-dominated assemblages from the upper sublittoral zone are described along a gradient of sewage pollution. Algal coverage and composition were measured for more than one year at approximately monthly intervals. Nutrients concentrations (nitrites, nitrates, ammonia and phosphates) showed different seasonal patterns depending on the distance to the pollution focus. *Ulva*-dominated assemblages appearing close to the sewage outfall showed maximal coverage during early spring and started to decrease in May. *Corallina*-dominated assemblages - replacing ulvacean algae at intermediate levels of pollution - followed the same pattern, peaking in March and decreasing in May. In contrast, *Cystoseira*-dominated assemblages, present at sites with low or no influence of sewage, increased coverage in May and continued with high coverage until the end of summer. Neither ephemeral algae (*Ulva* spp.), nor stress-tolerant algae (*Corallina elongata*), nor canopy-forming algae (*Cystoseira* spp.) have a seasonal growth cycle governed by eutrophication. Results demonstrate also that the period from May to July is the best time of the year for Water Framework Directive (WFD) monitoring purposes as less variability is observed within the assemblages.

1. Introduction

In several coastal areas, human activities have led to eutrophication processes implying increased nutrient availability and primary production (Kautsky et al., 1986; Rönnberg and Bonsdorff, 2004). Wastewater discharges close to the coastline deteriorate water quality and spoil macroalgal communities thriving in rocky-shores (e.g. Bellan-Santini, 1968; Borowitzka, 1972; Munda, 1974; Littler and Murray, 1975; Arévalo et al., 2007; Pinedo et al., 2007, 2013). This deterioration consists of changes both at the population, community or, even, at the ecosystem level (Soltan et al., 2001; Lotze et al., 2001; Arévalo et al., 2007). Sensitive species are replaced both by stress-tolerant and opportunistic species when pollution levels increase (e.g. Munda, 1974; Murray and Littler, 1978; Tewari and Joshi, 1988; Díez et al., 1999; Arévalo et al., 2007) entailing a simplification of the architectural complexity of the communities (Borowitzka, 1972; Belsher, 1974, 1979; Gorostiaga and Díez, 1996; Middelboe and Sand-Jensen, 2000; Arévalo et al., 2007).

Seasonal patterns on rocky shore communities are strongly determined by physical factors, being initiated by light, temperature and desiccation (Underwood and Jernakoff, 1984; Gunnarsson and Ingólfsson, 1995) and subsequently curtailed by nutrients (Ballesteros, 1989; Gunnarsson and Ingólfsson, 1995). Low nutrient availability is one of the major environmental factors limiting macroalgal growth and determining species composition in temperate shores (Lotze et al., 2000; Worm and Lotze, 2006). Macroalgae experience periods of very low N and P concentrations in the surrounding waters (Ballesteros, 1989; Delgado et al., 1994) and some slow-growing perennials rely on nutrient storage for growing when day length and temperature increase. In contrast, growth of opportunistic macroalgae completely rely on dissolved nutrient concentrations in seawater. Thus, sites of high nutrient loading, such as near wastewater outfalls, are suitable environments for opportunistic algae to proliferate (Pedersen et al., 2010).

Although the effects of eutrophication on rocky shore assemblages are well known (Middelboe and Sand-Jensen, 2000; Eriksson et al., 2002; Díaz et al., 2002; Díez et al., 2003; Worm and Lotze, 2006; Arévalo et al., 2007; Pinedo et al., 2013) and modifications in macroalgal composition following water quality improvements have been described (Hardy et al., 1993; Bokn et al., 1996; Gorostiaga and Díez, 1996; Soltan et al., 2001; Archambault et al.,

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2001; Díez et al., 2009; Tsiamis et al., 2013; Pinedo et al., 2013), the seasonal patterns in assemblages located along a gradient of nutrient enrichment have been far less studied (López Gappa et al., 1993; Abou-Aisha et al., 1995; Rodríguez-Prieto and Polo, 1996; Archambault et al., 2001).

Here we describe the seasonal variability in the structure and coverage of upper sublittoral assemblages located along a nutrient gradient caused by the discharge of a domestic sewage outfall in order to test whether: (1) differences on species richness and total coverage among assemblages are maintained over the whole seasonal cycle; (2) the abundance of the species defining the assemblages change over the year and if nutrient uploads can modify the seasonal growth cycle of canopy-forming of the genus *Cystoseira*, even at moments that growth could be limited by nutrient availability (summer); (3) differences on the assemblages are maintained over the year, spring being the season with a highest distinctness of the assemblages, and (4) the coverage of species showing seasonality responds to nutrient concentrations in sea water.

2. Materials and methods

2.1. Study site

Tossa de Mar (Spain, Northwestern Mediterranean; Fig. 1) is a highly ranked tourist destination (Sardá et al., 2005), whose sewage is composed only of domestic waste. There is no industrial development in the area and agriculture is extremely reduced. Most of the land (>90%) is covered by extensive Mediterranean forests of cork oak and pines and thus pollution from run-off waters is very low. Domestic waters receive two treatments before they are discharged to the sea: (1) biological treatment from autumn to spring when the total population is low, and (2) primary and biologic treatment during summer when the tourist population is the highest. The sewer outfall discharged an average of 2703 m^3/day during the sampling period (4023 m^3/day in summer and 1485 m^3/day in winter). Wastewater from the outfall usually flows to the south along the coast following the direction of dominant currents.

2.2. Sampling design and analytical procedures

Sampling was conducted from August 2002 to September 2003 along a 1.5 km length of coast near to Tossa de Mar, in the influence area of sewage effluent from the treatment plant. The discharge outfall is located at the coastline in a highly exposed sea-cliff (Fig. 1). Five sampling sites were situated at increasing distances of the outfall (2, 8, 84, 163 and 1350 m), the most distant being used as control site (Fig. 1). Sites were selected to be as similar as possible with respect to orientation, coastal slope and wave exposure in order to decrease assemblage variability due to environmental factors other than nutrient concentrations in the water column.

Sampling was conducted in the upper sublittoral zone (0.1–0.3 m depth). Three samples were taken at each sampling site each 40 days by scraping off all organisms from a 225 cm^2 surface. This surface area is sufficiently large to permit a quantitative description of the upper sublittoral macroalgal assemblages in the Northwestern Mediterranean (Coppejans, 1980; Verlaque, 1987; Ballesteros, 1992). Samples were preserved in formalin: sea-water at 4% and sorted in the laboratory. Algae and invertebrates were identified to species level and quantified in terms of coverage. Species coverage was measured as horizontal surface area (cm^2) covered by spreading specimens over a laboratory tray to form a thin layer (Ballesteros, 1986; Sales et al., 2012).

Three water samples were collected at each sampling site every 20 days with clean plastic bottles and kept frozen until chemical analyses were done. Water samples were analyzed for dissolved nutrients (phosphates, nitrates, nitrites and ammonia) on a Bran-Luebbe® TRAACS 2000 Autoanalyzer.

2.3. Data analysis

Seasonal differences at each site for assemblage data, species coverage, and nutrients analysis were determined by non-parametric tests (Kruskall-Wallis), as normality was never met after different data transformation using Systat (version 9). Spearman correlations between seasonal nutrient concentration and algal

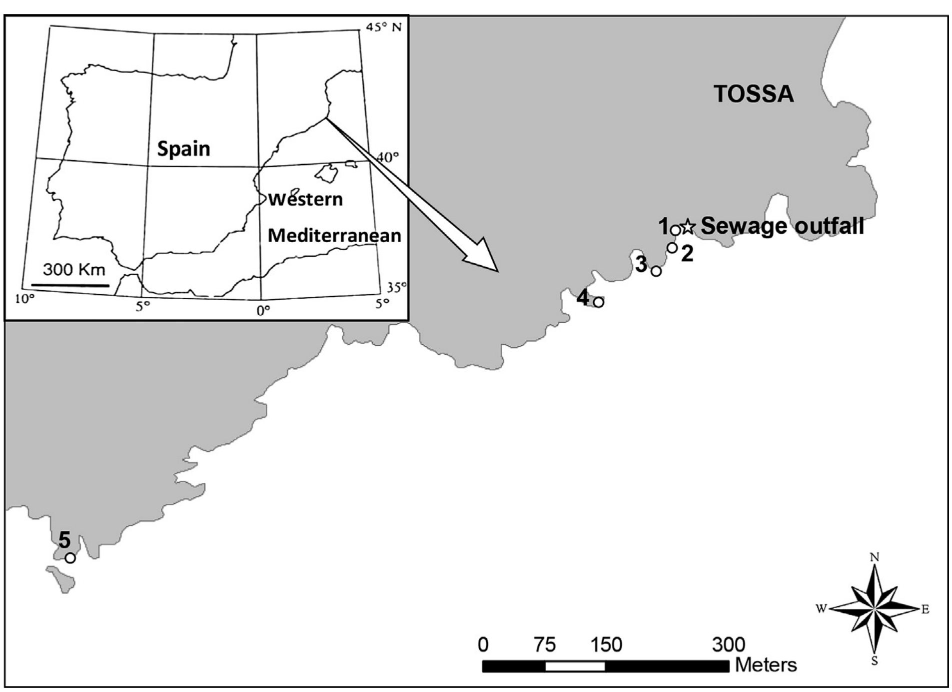

Fig. 1. Location of study area and sampling sites. Sewage effluent indicated with *.