Hydrobiologia (2005) 539:157–161
DOI 10.1007/s10750-004-3080-7

Short Research Note

Recovery of the seagrass *Zostera marina* in a disturbed Mediterranean lagoon (Etang de Berre, Bouches-du-Rhône, Southern France)

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Received 13 February 2004; in revised form 30 July 2004; accepted 8 September 2004

Key words: *Zostera marina* recovery, brackish lagoon, disturbance

Abstract

Until 1966, Berre lagoon (Provence, southern France) was a salty lagoon with a highly diversified marine fauna and flora. Increased inputs of freshwater from a hydroelectric plant led to the desalination and stratification of the lagoon. Following these changes, a wide diversity of species disappeared, including the eelgrass *Zostera marina*, a keystone species which previously constituted extensive meadows in the lagoon. After almost three decades of absence, patches of eelgrass were observed in 2001 and 2002 but the success of future recolonization by this community is uncertain.

Introduction

Until the late 1960s, meadows of the eelgrass *Zostera marina* Linnaeus were widespread in the Berre and Vaïne brackish lagoons (Bouches-du-Rhône, southern France, Mediterranean; Fig. 1a) from 1 to 6–7 m depth. At that time, the hydrological conditions of the lagoon were similar to those of the adjacent shallow coastal water: mean salinity was stable and close to 30 psu, except for the areas next to natural freshwater inputs (rivers). Water temperatures showed wide seasonal variations, from 2.5 to 25.0 °C (Gourret, 1907; Decrock, 1914; Huvé & Huvé, 1954; Huvé, 1960; Mars, 1966). From 1966, the diversion of the Durance river towards the Saint-Chamas hydroelectric power plant and into the Berre lagoon, resulted in (i) heavy input of freshwater; (ii) the decline of surface water salinity; (iii) stratification with freshwater at the surface and more salty water at depth (under calm conditions); (iv) entrophication and unstable ecological conditions (Minas, 1974, 1976; Stora, 1976; Stora et al., 1995; Nérini, 2000; Nérini et al., 2000). In the early 1970s, the *Zostera marina* stands underwent a dramatic decline; they were first reduced to a narrow belt of 10–300 m width, limited to 3 m depth (Riouall, 1971, 1972a, b; Huvé et al., 1973) and progressively disappeared from the Berre and Vaïne lagoons. The last sighting of this species was in 1973 (Riouall, 1973, 1977).

The Salinity tolerance of *Z. marina* is quite exceptional for a seagrass: the species can occur from fully marine water and more or less stable brackish water down to a salinity of 5 psu (Hartog, 1970; Kamermans et al., 1999; Katwijk et al., 1999). Vegetative growth occurs between 10 and 15 °C and generative shoots are produced between 15 and 20 °C (Hartog, 1970), which fits well with Mediterranean populations, though other populations may thrive in different temperature ranges (Silberhorn et al., 1983). Other factors known to affect the occurrence of *Z. marina* are: turbidity (Ibarra-Obando et al., 1997; Katwijk et al.,

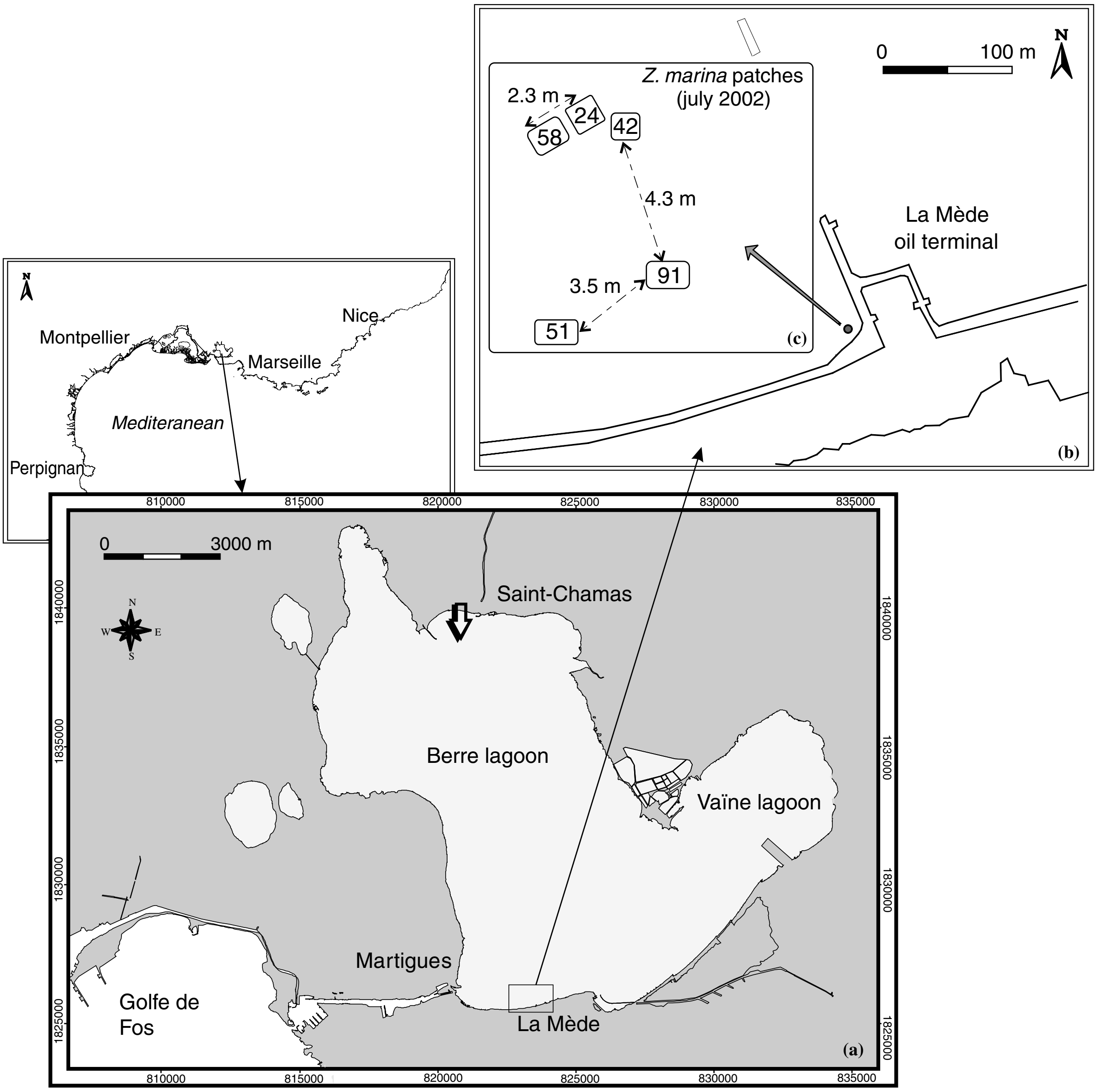

Figure 1. (a) Localisation of Berre and Vaïne lagoons, Bouches-du-Rhône, Southern France, Mediterranean and the input of freshwater from hydroelectric plant (arrow). (b) Localisation of Z*ostera marina* patches in the Berre lagoon. (c) Patches of *Z. marina* near La Mède, in July 2002. Boxes: number of shoots per patch.

1998), light availability (Duarte, 1991; Cabello-Pasini et al., 2003), sediment dynamics (Frederiksen et al., 2004a, b) and nutrient load (Hemminga et al., 1991; Pedersen & Borum, 1992; Short & Wyllie-Echeveria, 1996; Fonseca & Bell, 1998).

The turbidity and the nutrient load, due to the heavy freshwater inflow into the Berre lagoon, the resulting wide variability of salinity and water stratification, with under calm conditions a superficial fresh water layer, are the likely causes of the decline of *Z. marina* in the Berre lagoon. In the Wadden sea (Netherlands), the replacement of an estuarine gradient by a variable salinity regime, with the input of freshwater regulated by sluice, also had negative consequences on *Z. marina* populations, making them more vulnerable to other forms of stress (Katwijk et al., 2000).

Observation

Since 1990, the benthic macrophytes of Berre and Vaïne lagoons have been extensively monitored every year (Pergent-Martini et al., 1995; Soltan & Francour, 2000; this work). Monitoring methods consisted in the exploration of 46 sites by diving, perpendicular to the shore, down to the lower limit of macrophytes (less than 2 m depth) and snorkelling between these sites, parallel to the shore along the narrow strip prone to harbouring eelgrass. Through 2000, *Z. marina* was never sighted, confirming its disappearance. The possibility that isolated shoots of *Z. marina* had escaped observation cannot be excluded though this is unlikely, considering the close monitoring network over a 10-year period. In July 2001, *Zostera marina* was observed, along the La Mede oil terminal harbour pier (Fig. 1b), in a sector where an extensive belt of *Z. marina* was formerly present (Riouall, 1973). Depth (2 m), size and number of *Z. marina* patches and the number of shoots per patch were recorded: 6 patches (encompassing a total of 124 shoots) were scattered within a 4 m^2 surface area. In July 2002 some of these patches had coalesced while new patches had appeared (encompassing a total of 266 shoots, Fig. 1c). It is to be noted that the observed patches were composed of isolated rhizomes, without flowers or seeds, and that shoot density remained low compared to other *Z. marina* meadows, such as those in the Thau lagoon (Languedoc-Roussillon, Southern France) (Laugier et al., 1999; Plus et al., 2003). The substrate was mainly composed of calcareous annelid and shell debris.

Discussion and conclusion

The recolonization by *Zostera marina*, after almost three decades of absence, may be due to an improvement in environmental conditions within the Berre lagoon. The power plant freshwater discharge steadily decreased from more than 6 Gm^3/a in 1977 to less than 2 Gm^3/a since 1994 onwards, together with a dramatic reduction in the silt load (from 1.6 Mt/a in 1977 to 0.1 Mt/a) (Electricité de France, unpublished data). There is however no evidence of such a trend for nutrients (Kim & Travers, 1997a; b), despite a significant reduction in industrial wastewater and domestic sewage input since the 1980s. The lag time between improvement in environmental conditions and the first sighting of *Z. marina* raises the question of their actual role. A possible hypothesis for this delayed colonization could be the poor availability of propagules (seeds and/or cuttings); the nearest *Z. marina* stand lies in the open sea (Golfe de Fos; pers. obs.). In Thau lagoon, the complete recolonization of the *Z. marina* meadow, totally destroyed by an anoxic crisis, took place in less than 1 year, because of seeds and rhizomes surviving the crisis within the sediment (Plus et al., 2003). Another hypothesis for the delayed recolonization could be the opening of a window of opportunity within the range of environmental fluctuation.

To date, we cannot forecast whether the observed *Z. marina* patches in the Berre lagoon are the harbinger of extensive recolonization of the lagoon, which would support the hypothesis of a durable improvement in environmental conditions or whether they will be eliminated by subsequent chance climatic events or by a new anthropogenic disturbance.

Acknowledgements

The authors are indebted to Philippe Picon (GIPREB) for field assistance, to Michael Paul for improving the English text and to the reviewers for their critical comments on the manuscript. This study is a part of a global monitoring program of Berre and Vaïne lagoons funded by GIPREB (Berre l'Etang, France).

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