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Testing the saprobity hypothesis in a Mediterranean lagoon: Effects of confinement and organic enrichment on benthic communities

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This study is dedicated to the memory of Prof. Patrizia B. Albertano (1952–2012).

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ABSTRACT

The macrobenthic community was compared at four sites characterized by varying degrees of freshwater input, organic enrichment and confinement in the Cabras lagoon (Sardinia, Italy). Three sites, riverine (C1), confined (C2) and seaward (C3), were studied on two dates of summer 2010 and on two dates of winter 2011. A fourth site (C12), representative of the central sector of the Cabras lagoon, was included in this study using the extensive historical datasets at our disposal from previously published work. We aimed to test the hypothesis that (1) the benthos is distributed according to the recently proposed concept of habitat saprobity for coastal lagoons that unifies the Pearson–Rosenberg (*sensu* organic enrichment) and Guélorget–Perthuisot (*sensu* confinement) models, and (2) indicator species of different saprobic levels can be identified among dominant species occurring along the saprobity gradient. Salinity was also considered as an additional agent of selection in brackish environments. Irrespective of significant seasonal changes within each site, our results highlighted major environmental and biotic differences between sites. At the northward riverine site (C1), most affected by freshwater input and with limited organic matter (OM) enrichment, *Corophium orientale* was the single dominant species. The most confined site (C2) was characterized by the highest levels of sedimentary OM and benthic Chlorophyll-*a* and by mesohaline conditions; the site was inhabited mainly by the halolimnobic *Hediste diversicolor* and *Hydrobia* spp. Site C12, characterized by a high OM load and high residence time, was dominated by the opportunistic detritivorous *Alitta succinea* and *Polydora ciliata*. At the southernmost seaward site (C3) the considerable seawater renewal, resulting in high salinity (only in summer) and limited OM load, favored a much more diverse macrobenthic assemblage, essentially composed of both marine species, such as *Corophium insidiosum*, *Gammarus aequicauda*, and brackish-water species, such as *Lekanesphaera hookeri* and *Idotea chelipes*. We conclude that the biotic and abiotic characteristics of the Cabras lagoon can be represented by a succession of spatial zones along two main gradients determined by salinity and saprobity. The salinity gradient proved to be the main structural feature in the oligohaline pole, while in the range of variable salinity, saprobity appeared to be the main selection factor. To illustrate our findings, we provide a graphical representation summarizing the changes in environmental parameters and indicator species along the salinity and saprobity gradients.

1. Introduction

Ecological aspects of brackish-water environments, such as coastal lagoons, have been investigated for some time because of their multifunctional uses and potential for exploitation. The large geomorphological, hydrological and biological heterogeneity of such environments has prompted numerous conceptual models and synthetic patterns aimed at explaining the main processes and

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mechanisms of lagoon biological functioning (Ardizzone et al., 1988; Basset et al., 2006; Tagliapietra and Ghirardini, 2006).

The main impact of salinity has been stressed since the earliest studies (Remane, 1934; Venice System, 1959). D'Ancona et al. (1954) and Sacchi (1961) went on to note the role of "vivification" (i.e. water renewal) from the adjacent marine ecosystem. Subsequently, the importance of sea water renewal in lagoonal systems was taken in account in the drawing up of the Guélorget–Perthuisot [P–R] model for so-called "paralic" (i.e. confined) environments (Guélorget and Perthuisot, 1992). Some authors discussed the ecological factors linked to the confinement of paralic environments (Sacchi and Occhipinti Ambrogi, 1992; Barnes, 1994; Koutsoubas et al., 2000). Such environments' intra- and inter-heterogeneity has also been discussed in the light of the mechanical energetic gradient, according to the "ergocline theory" (Legendre and Demers, 1985; Galuppo et al., 2007). Moreover, because of lagoons' hydrological regime and morphology with restricted outflows, a large amount of organic matter (OM) settles and decomposes in the sediment; such OM includes continental and marine detritus, and the majority of the biomass produced inside the lagoon (Barnes, 1980; Magni et al., 2005). Thus, trophic loading inside the lagoon is increased by the substantial accumulation of decaying organic material which remains trapped (De Falco et al., 2004; Magni et al., 2004; Como et al., 2007).

The selective role of trophic loading on benthic communities' structure and distribution in some Italian coastal lagoons has been highlighted by Fresi et al. (1985) and Gravina et al. (1988). The latter introduced the idea that, within a defined range of confinement, the brackish-water communities are re-arranged depending principally on the trophic pattern. More recently, Pusceddu et al. (2007) showed that the trophic state of brackish-water ecosystems is closely linked to ecosystem efficiency and biodiversity. Furthermore, Magni et al. (2009) demonstrated the applicability of the Pearson–Rosenberg [P–R] model (Pearson and Rosenberg, 1978), describing a generalized pattern of response of marine benthic communities in relation to organic enrichment, to coastal lagoons.

Building upon an extensive body of literature, Tagliapietra et al. (2012) reviewed classic conceptual models describing the succession of benthic communities along a gradient of OM enrichment for freshwater (e.g. the Saprobiensystem; Kolkwitz and Marsson, 1908, 1909), coastal marine (the P–R model) and lagoonal (the G–P model) ecosystems. The authors combined the above models under a single conceptual framework of habitat saprobity for coastal lagoons. They referred to saprobity as the "*state descriptor*" of an aquatic ecosystem resulting from the (exogenous and endogenous) input of OM, its biodegradation and the clearance of catabolites. The microbial decomposition of OM involves physico-chemical modifications to the medium which are selective for the biota. The main selection factors are low dissolved oxygen (DO) concentrations, leading to reducing conditions and lower pH, and the accumulation of the toxic by-products of anaerobic metabolism. Clearance depends mainly on the reuse of OM catabolites by microorganisms (often referred to as re-mineralization or self-depuration), on burial and on export from the system by means of water exchange and the release of gases into the atmosphere. These aspects imply that saprobity cannot simply be equated with the OM standing stock or budget of the system, or with single metabolic processes such as respiration, but involves ecosystemic processes (Tagliapietra et al., 2012). The saprobity level of a water body can be ascertained both by metabolic-dynamic measurements and by the analysis of its living communities (Caspers and Karbe, 1966; Sládeček, 1967). The higher the saprobity, the more impaired the system, with progressively poorer benthic communities characterized by species that are increasingly tolerant of reduced conditions and toxicity. In coastal lagoons, these processes are strongly driven by hydrodynamics, which govern the land-sea gradient. This is marked contrast to estuaries where the environmental gradient is mainly structured by the flow of fresh water, which generates a salinity gradient. Within this framework, saprobity was suggested to be a suitable "*state descriptor*" for characterizing the natural conditions of coastal lagoons and assessing their environmental quality (Tagliapietra et al., 2012).

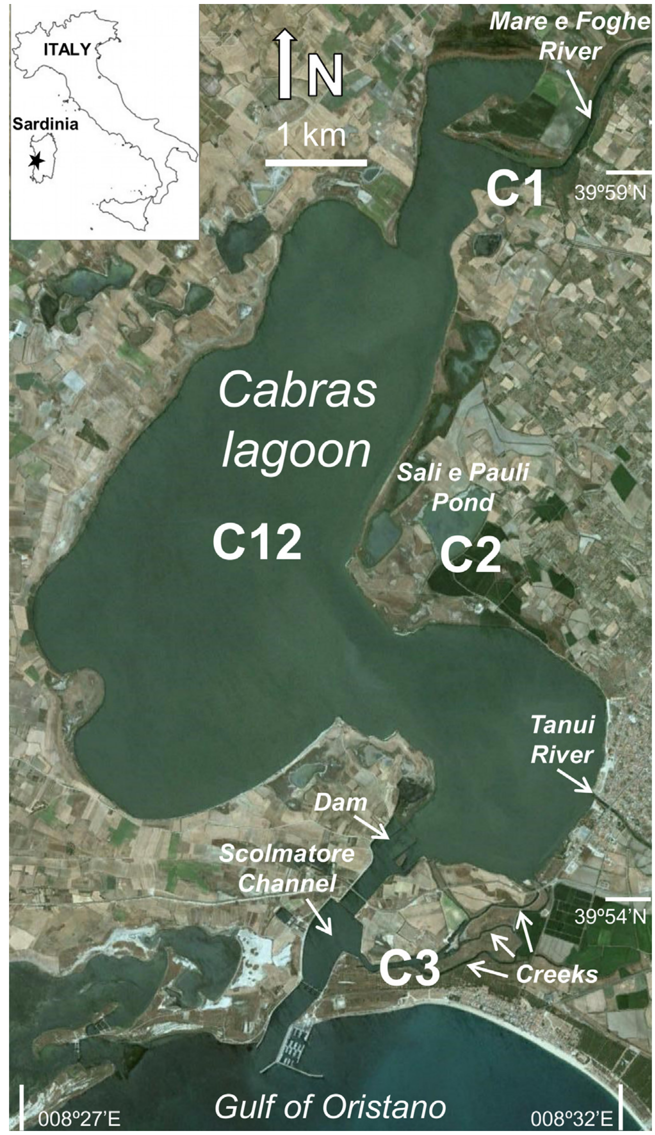

Fig. 1. Location of sampling sites (C1, C2, C12 and C3) in the Cabras lagoon (Gulf of Oristano, western Sardinia, Italy). Image source: Google Earth.

The concept of saprobity was developed for rivers and lakes more than a century ago in relation to the discharge of organic waste (Kolkwitz and Marsson, 1908, 1909). Saprobity is a selection agent for species in all aquatic environments. It is particularly important, however, in coastal lagoons and enclosed coastal basins, especially under microtidal and nanotidal conditions (Tagliapietra and Ghirardini, 2006), where reduced hydrodynamics allows OM to be trapped within the basin and to accumulate on the sediment surface (De Falco et al., 2004), and where most degradation processes occur (Viaroli et al., 2004). Although the application of the saprobity concept to lagoons dates back to the first half of the twentieth century (Potereaev, 1936, cited by Milovidova, 1975; Vatova, 1940a,b), it was little developed and mostly ignored in