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The MIRACLE Project: An integrated approach to understanding biogeochemical cycling of mercury and its relationship with lagoon clam farming

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ABSTRACT

The "MIRACLE" Project was aimed at two specific issues: understanding Hg biogeochemical cycling in the Marano and Grado Lagoon and testing the coexistence of clam farming with Hg contamination in the sediments. Mercury contamination was measured in several matrices (water, sediment, biota) and its mobility was tested along with its speciation in relation to biogeochemical processes occurring in the lagoon environment, where bacterial communities have a primary role in converting Hg to its more toxic form, methylmercury (MeHg). Bioaccumulation of the Hg species was investigated on natural and seeded clams (*Ruditapes philippinarum*), the most important commercial bivalves in the Lagoon. The Editorial summarizes the main results obtained from this multidisciplinary study and reported in the Special Issue.

1. Introduction and aim of the research

Coastal lagoon ecosystems are among the most ephemeral features on a geological time scale but they are also among the most productive ecosystems in the biosphere. These transitional environments experience significant short-term variations in physical and chemical properties and processes that control the biological community and its habitat. However, intense human development along the inland shorelines has often altered both fresh and saltwater inputs to many lagoons, as well as nutrient loading, sedimentation, and the input of anthropogenic contaminants. Due to their shallowness and, the limited water exchange with the open sea, lagoons tend to be efficient traps for sediments and, consequently, contaminants, from marine and fluvial origin. Contaminants accumulated in sediments may be undergo burial and/or biogeochemical processes, which affect their distribution, speciation and bioavailability to the lagoon biota. The high potential risk of contaminant remobilization from sediments into the water column and its subsequent bioaccumulation in the trophic chain are also enhanced by the abundance of animal and plant species in this ecosystem. The ultimate risk is the potential uptake of contaminants by human residents since fishing and clam and mussel collection are usually common in coastal lagoons.

In the Mediterranean Sea, some of the major coastal lagoons are located along the northern Adriatic coastline. The Marano and Grado Lagoon is the second largest wetland in the area while the Lagoon of Venice is the most relevant and well known example of these ecosystems, where natural and human induced modifications coexist. The lagoon includes some historical sites designed to protect wildlife migration submitted to the Ramsar Convention in 1971. Following the implementation of the Habitats Directive (92/43/EEC), concerning the protection of biodiversity, the entire basin has been identified in the "Natura 2000" state-sponsored survey as a site to be included among the sites of Community importance (SCIs – IT3320037). In addition, fishing, collection of clams and mussels, and fish and clam farming in the lagoon are important economically for the inhabitants.

Due to human activities, this natural environment has suffered apparent transformations from the morphological point of view, which are coupled with the negative sediment budget presently occurring in this ecosystem (Fontolan et al., 2012). In addition, the Marano and Grado Lagoon has experienced significant contamination by heavy metals, polychlorinated dibenzodioxins (PCDDs) and furans (PCDFs), polycyclic aromatic hydrocarbons (PAHs) and aromatic hydrocarbons related to the Torviscosa chemical complex, the most important industrial site in the region (Ramieri et al., 2011). Contamination affected soils, groundwaters as well as fluvial and lagoon sediments. Among contaminants, mercury (Hg) was deliberately discharged in effluents from the chloralkali plant (CAP) operative since 1949. This source contributes to increased

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metal concentrations in the Aussa-Corno river system and lagoon sediments (Piani et al., 2005) already extensively altered by Idrija mercury mine activities during the last centuries (Covelli et al., 2001). Although direct discharge of Hg from the CAP no longer exists, the metal is still released from the source area into freshwaters flowing into the lagoon (Covelli et al., 2009). The ecosystem has been severely impacted as evidenced by elevated Hg contents in aquatic plants and organisms (Brambati, 2001). This evidence also increased the concern about human health risk linked to Hg exposure through fish and mussel consumption. Fish farms located in embankment areas enclosed by sluice gates cover about 1800 ha of the whole lagoon, with 1400 ha in the eastern (Grado) sector alone (Fontolan et al., 2012). Fish farms are devoted to gilt-head bream (*Sparus auratus*), bass (*Dicentrarchus labrax*) and grey mullet (*Mugil cephalus*).

Due to the environmental and socio-economic problems caused by contamination, in May 2002 the Italian Prime Minister declared a state of emergency for the Marano and Grado Lagoon (Decree of President 3rd May 2002). Part of the lagoon and of the nearby mainland has been included in the Contaminated Sites of National Relevance (SIN) list since 2003 (Fig. 1). A special Deputy Commissioner – *Commissario Delegato* of the lagoon was appointed by the national government in order to deal with and to solve the following main issues: environmental remediation of contaminated soil and groundwaters; re-establishment of safe navigation conditions in the lagoon channels, involving sediment dredging and management of dredged material; improvement of the lagoon ecosystem, especially with respect to water and sediment quality; protection of high-value lagoon habitats; morphological restoration of the lagoon; reduction of contaminant loading from the catchment area; environmental monitoring.

Within these activities, the MIRACLE Project (*Mercury Interdisciplinary Research project for Appropriate Clam farming in Lagoon Environment*) was carried out in the period 2008–2009. The main aim was to test the coexistence of clam farming with Hg contaminated sediments and to evaluate the possible extension of the existing commercial rearing activities in those areas of the Lagoon where the risk of Hg bioaccumulation in clams would appear minimal. The MIRACLE project was set up as an interdisciplinary study bringing together researchers involved in several fields such as geochemistry, chemistry, sedimentology, microbiology and marine biology. Mercury occurrence was investigated in several compartments (water, sediment, bacteria, and bivalves) and its mobility was explored along with its speciation in relation to biogeochemical processes occurring at the sediment-water interface in this coastal environment, where bacterial communities have a primary role in converting inorganic Hg to its more toxic form, methylmercury (MeHg). Bioaccumulation of the Hg species was investigated on natural and seeded clams of the *Ruditapes philippinarum* species, the most important commercial bivalve of this Lagoon. After its introduction in the lagoon 25 years ago, the total area devoted to clam farming, which is located in the western sector (Marano), amounts to about 800 ha of which 130 are in full regime of production (Sladonja et al., 2011).

2. Study area and sampling strategy

The Marano and Grado Lagoon covers a total area of 160 km^2, between the Tagliamento and Isonzo River deltas, in the northernmost sector of the Adriatic Sea. The lagoon basin is characterized by semi-diurnal tidal fluxes (65 cm and 105 cm mean and spring tidal range, respectively). Small rivers flow into the lagoon, which drain waters coming from the spring line. Particulate matter from these streams is of secondary importance, restricted to areas surrounding the spring river mouths. Conversely, the primary source of suspended sediments enters from the sea through the six tidal inlets, as contributions from river deltas and from erosion of the barrier islands. Dispersion of sediments into the lagoon is controlled by tidal fluxes. The same fluxes control salinity, which ranges from very low values (2–7 PSU) near the mouths of the

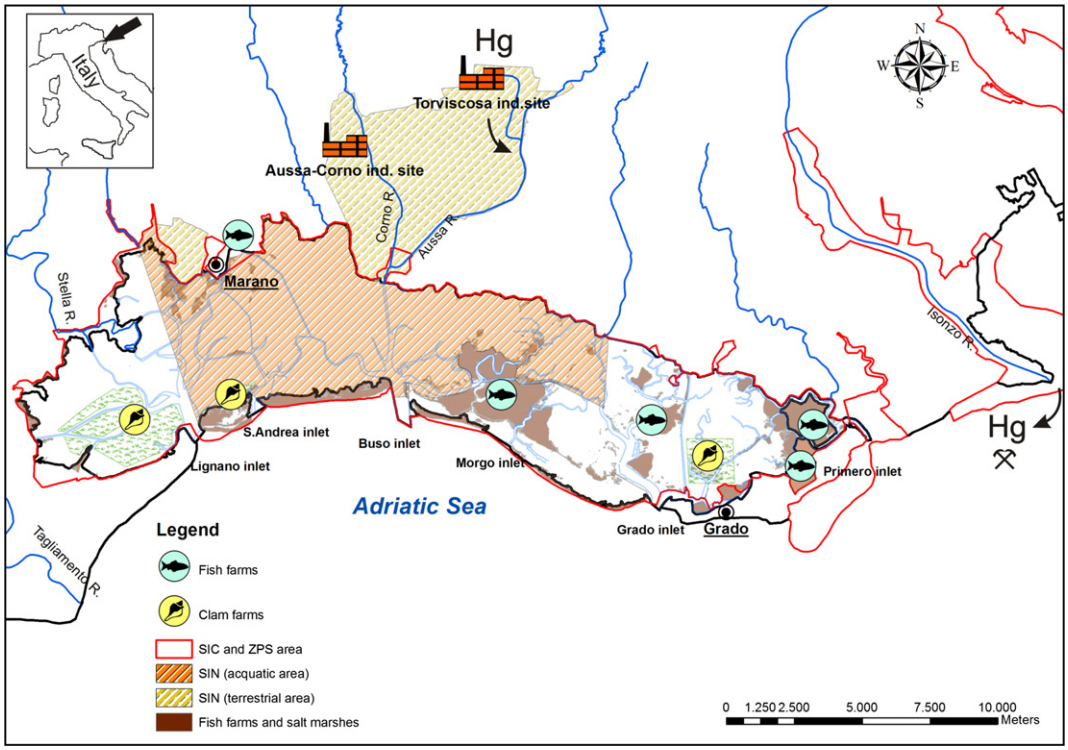

Fig. 1. Main geographical features of the Marano and Grado Lagoon. The two sources of mercury are indicated.