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Trace elements, rare earth elements and inorganic arsenic in seaweeds from Giglio Island (Thyrrenian Sea) after the Costa Concordia shipwreck and removal

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ABSTRACT

The occurrence of trace elements, REE and iAs was investigated in macroalgae collected from Giglio Island (Grosseto, Italy), 3 years after the Costa Concordia shipwreck recovery operations.

There was a high variability of metals and REE between species, even those belonging to the same phylum. Arsenic level was found within the range of the Tuscany marine environment; the inorganic fraction was from 9% to 31%. Al, Be, Pb and Zn levels in seaweeds from Giglio Island were found to be significantly higher than in macroalgae from other islands of the Tuscany archipelago. REE were double the values found in the Tuscan islands of Elba and Capraia. We suggest that concentrations of metals and REE were influenced by the 3-year-long naval operations carried out for the Costa Concordia shipwreck rescue, and that macroalgae could be suitable bioindicators of perturbations in metal concentrations in the marine environment.

Capsule: Inorganic contaminants in seaweeds for Giglio Island.

1. Introduction

In January 2012, the Costa Concordia cruise ship collided with coastal underwater rocks in front of Giglio Island (Tuscany, Italy), causing 32 deaths. A complex recovery operation of the partially submerged shipwreck was carried out, after removing the fuels, lasting about 2 years, and ending in September 2014 with the final transport of the shipwreck to Genoa harbor, where it was scrapped.

Investigations were conducted to study the environmental impact of the shipwreck on this coastal ecosystem, and in particular, the potential influence of the removal operations, which required the use of many vessels and crafts, and the use of a significant amount of steel.

Some investigations have already been performed in Giglio Island. In particular, Regoli et al. (2014) investigated the possible presence and effect of several contaminants such as trace metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead, vanadium and zinc), polycyclic aromatic hydrocarbons, volatile and aliphatic hydrocarbons, polychlorinated biphenyls, halogenated pesticides, organotin compounds, brominated flame retardants and anionic surfactants, utilizing *Mytilus galloprovincialis* as the bioindicator organism ("mussel watch"). They concluded that there was no significant increase in environmental pollution, even if the use of transplanted mussels allowed very sensitive detection of early biological disturbances (Regoli et al., 2014). Bacci et al. (2016) studied the *Posidonia oceanica* canopy in the area affected by the Costa Concordia shipwreck; they found changes in epiphytic assemblages, temporary decrease of encrusting macroalgae, an increase of erected macroalgae and foraminifers, and a temporary increase of tip erosion of the canopy in the studied area. Casoli et al. (2017) assessed the impact on coralligenous habitats of activities associated with salvaging the wreck of the ship and demonstrated a reduction in quality of coralligenous habitats. Moreover, Avio et al. (2017) characterized micro plastics in different benthic fish, finding that samples collected close to the Costa Concordia shipwreck had a high ingestion of microplastics compared to values reported worldwide.

To our knowledge, there are no previous studies that have investigated the distribution of metals, rare earth elements (REE) and inorganic arsenic (iAs) in seaweeds from Giglio Island. In fact, the levels of inorganic contaminants in macroalgae from Italian Mediterranean coasts have been scarcely investigated. Nevertheless, these marine organisms constitute a reliable bioindicator, due to their ability to

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concentrate metals at orders of magnitude higher than in the surrounding seawater. Moreover, being widespread and sessile, macroalgae can easily indicate any modifications of anthropogenic impacts on coastal ecosystems.

We recently performed a study (Squadrone et al., 2017; Squadrone et al., 2018) regarding the content of trace elements and REE in seaweeds from two other islands of the Tuscan Archipelago, Elba and Capraia (LI).

Since previous studies registered the impact on the marine ecosystem (Regoli et al., 2014; Bacci et al., 2016; Casoli et al., 2017; Avio et al., 2017) mainly related to the rescue operations of the shipwreck, our aim was to use seaweeds from Giglio Island as bioindicators of metal concentrations to assess the contamination status of this area.

This study will improve the knowledge of the presence of inorganic contaminants after the catastrophic event of 2012 and could constitute a baseline study for future monitoring of Giglio Island and Tuscan Archipelago coastal ecosystems.

2. Materials and methods

2.1. Sampling

The study was carried out at Giglio Island (surface 21.2 km^2, Grosseto, Tuscany region), which is the second largest in the Tuscan Archipelago National Park (PNAT) after Elba Island (North-western Mediterranean Sea, Italy), located 8.63 nautical miles west of the promontory of Mt. Argentario between 42°23′18″N and 10°52′42″E of Punta del Fenaio and 42°18′58″N and 10°56′44″E of Punta del Capel Rosso (Fig. 1). Since 1960, the island has experienced a gradual increase in tourism, which is the only economic resource (Ciocchini et al., 2017). Located between the Ligurian Sea and the Northern Tyrrhenian Sea, the Tuscan Archipelago is in the Natura 2000 network that comprises the largest protected area in European seas, and which is home to the Pelagos International Sanctuary, the most important area for the protection of sea mammals in the Mediterranean Sea. Furthermore, the Central Tyrrhenian Sea is an area for which there is a lack of bibliographic data related to marine quality assessment (Renzi et al., 2010; Janeiro et al., 2014; Squadrone et al., 2017).

The sampling site (Fig. 1), Punta Radice (42°22′82″N and 10°54′43″E), was located 1 nautical mile from the rock Le Scole, where the cruise ship Costa Concordia collided in January 2012. After its partial foundering, the Costa Concordia remained adjacent to the eastern coast of Giglio Island for over 2 years. Its salvage required high-impact engineering works, during the course of which monitoring of benthic and zooplanktonic communities was undertaken (Regoli et al., 2014; Casoli et al., 2017).

Seaweed samples (n = 5 for each species) were collected by scuba diving in summer 2017 along a bathymetric transect from the surface to − 46 m. The sampled seaweeds, easily available and abundant in the studied site, were representative of the phylum Chlorophyta (*Codium bursa*, *Flabellia petiolata*, *Acetabularia acetabulum*, *Caulerpa cylindracea*), Ochrophyta (*Padina pavonica*, *Dictyota dichotoma*, *Halopteris scoparia*) and Rhodophyta (*Peyssonnelia squamaria*, *Phyllophora crispa*).

After collection, the macroalgae were extensively washed on board with seawater and then stored in refrigerated conditions (− 20 °C). Specimens were transported to the laboratory and examined under the microscope, after being cut into thin sections, in order to identify the species. Samples were rinsed with tap water, then with distilled water, freeze-dried and homogenized to obtain a fine powder. Approximately 1–1.5 g of each sample was employed for analytical detection.

We investigated the occurrence of inorganic contaminants including the following metals: aluminum (Al), arsenic (As), beryllium (Be),

Fig. 1. Giglio Island, Tuscany; sampling site.