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Biodegradable plastic bags on the seafloor: A future threat for seagrass meadows?

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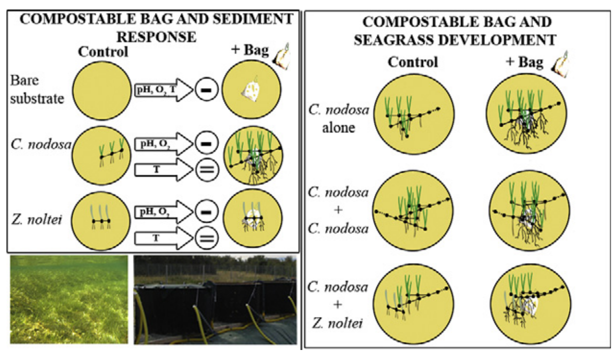
HIGHLIGHTS

- Biodegradable bag effects on marine sediments and plants are not understood.
- Bags slowly degrade in marine sediments and affected pore-water parameters.
- Bags altered above/below seagrass compartments and plant/species relationship.
- Biodegradable plastic effect on seagrass ecosystems needs further attention.

GRAPHICAL ABSTRACT



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ABSTRACT

Marine plastic litter is a global concern. Carrier bags manufactured from non-biodegradable polymers constitute a large component of this litter. Because of their adverse impact on marine life, non-biodegradable bags have recently been replaced by biodegradable ones. However, growing evidence shows that these latter are not readily degradable in marine sediments and can alter benthic assemblages. The potential impact of biodegradable bags on seagrasses inhabiting sandy bottoms, which are the most widespread and productive ecosystems of the coastal zones, has been ignored. Mesocosm experiments were conducted to assess the effect of a commercialized biodegradable bag on a common seagrass species of the Mediterranean, *Cymodocea nodosa*, both at the level of individual plant (clonal growth) and of plant community (plant-plant relationships), under three culture regimes (plant alone, in combination with a neighbour of the same species or of the co-existing seagrass *Zostera noltei*) simulating different natural conditions (bare substrate, monospecific meadows or mixed meadows). The bag behaviour in marine sediment and sediment physical/chemical variables were also examined. After six months of sediment exposure, the bag retained considerable mass (85% initial weight) and reduced sediment pore-water oxygen concentration and pH. In the presence of bag, *C. nodosa* root spread and vegetative recruitment increased compared to controls, both intra- and interspecific interactions shifted from neutral to competitive, and the growth form changed from guerrilla (loosely arranged group of widely spaced ramets) to phalanx form (compact structure of closed spaced ramets) but only with *Z. noltei*. These findings suggest that biodegradable bags altering sediment geochemistry could promote the spatial segregation of seagrass clones and influence species coexistence.

1. Introduction

Plastic pollution in the marine habitat is a growing environmental problem at global scale (Derraik, 2002; Gross, 2013). Plastic carrier

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bags composed of polyethylene or polypropylene are a major component of the plastics accumulated in the marine environment (seawater and seafloor, Galgani et al., 1995; Thompson et al., 2004; Carson et al., 2011). Due to their extreme durability and adverse impact on marine organisms, these bags have been banned in many countries and replaced by biodegradable bags typically made from renewable raw materials such as starch or cellulose or bio-synthesized materials (Convery et al., 2007; UNEP, 2015). These materials are generally hygroscopic and/or have higher density than seawater thus the bags tend to settle onto the seafloor (Andrady, 2011) where they may be eventually entangled in marine vegetation and/or buried by sand. However, the expected benefits conferred by the increased use of biodegradable bags to marine organisms and ecosystems have been recently questioned (Accinelli et al., 2012; Tosin et al., 2012; Green et al., 2015). In fact, most polymers presently used for manufacturing biodegradable carrier bags (Accinelli and Abbas, 2011) are designed to breakdown into water, carbon dioxide/methane and biomass in a short time via microbial assimilation under standard conditions (i.e. soil, home or industrial compost facilities) that are generally not encountered in marine habitats. Very few companies worldwide claim to produce polymers designed to be biodegradable under marine environments (ASTM D7081-05), but the pass/fail criteria adopted for establishing the degradability are based on standard laboratory tests and their results cannot be extrapolated to real marine conditions. Indeed, the rate of degradation of bioplastics in marine environments strongly depends on local characteristics (including type of bacteria and organisms present, light, temperature and oxygen) and the compartment to which they are disposed, i.e. floating in seawater (pelagic zone) or in the seabed (Andrady, 2015). Studies have shown that some starch-based plastic bags degrade only partially after 236 days under sublittoral conditions (Tosin et al., 2012) remaining accessible for a given time to a suite of organisms living at or in the sediments. The persistence of this material also inhibits gas changes between the overlying water and pore waters, and the resulting hypoxia or anoxia may alter macrobenthic community structure and interferes with the normal functioning of associated ecosystems (Green et al., 2015).

Surprisingly, no attention has been paid to assess the fate of plastics deposited on sandy bottoms colonized by marine vegetation (seagrasses) and their potential effect on plant growth. Seagrasses are clonal plants that colonize shallow coastal waters and estuaries in all continents except Antarctica (Short et al., 2007) and form both monospecific meadows dominated by a single foundation species and mixed meadows composed of species with different structural characteristics and functional traits (Duarte, 2000). Seagrasses depend on resources and conditions both above and within the sediments and are sensible to deterioration of sediment quality, although some species are able to cope with sediment alterations modifying biogeochemical conditions in their rhizosphere (Marbà and Duarte, 2001; Gacia et al., 2002; Borum et al., 2006). Seagrass meadows are vital to coastal ecosystems, provide numerous ecological services to human society (maintenance of marine biodiversity, regulation of the quality of coastal waters, protection of the coastline) and play a fundamental role in structuring communities (Costanza et al., 1997; Cullen-Unsworth and Unsworth, 2013). However, many species are presently under threat worldwide from localized (e.g., water pollution, eutrophication) and global stressors (e.g., climate change), necessitating strategies to prevent further vegetation losses (Orth et al., 2000; Short et al., 2011). Available data on the distribution of marine litter on the seafloor (0–100 m depth) have shown that in some areas the density of conventional plastic bags is relatively high (about 4.4 bags/ha, (Galgani et al., 1995; Galgani et al., 2000). The presence of conventional plastic bags has also been recorded at the edge of shallow seagrass beds (14 bag fragments/ha) along the Italian coast (our unpublished data). Currently, the amount of biodegradable plastics improperly discharged entering into the ocean it is unknown as the mandatory use of biodegradable bags is very recent (UNEP, 2015), but the input of biodegradable bags is expected to become similar (or higher) to the conventional plastic input in future (UNEP, 2015). Therefore, understanding whether, and if so how, discarded biodegradable bags will influence the establishment, expansion and functioning of seagrass meadows in future may help to minimize their potential impact.

In this study, we assessed in mesocosm the effect of a common type of bag manufactured with a starch derived polymer (Mater-Bi), which is available in the European market and certified as compostable and biodegradable, on the development of clones of a widely-distributed seagrass of the Mediterranean Sea, *Cymodocea nodosa* (Ucria) Ascherson. Specifically, we investigated the response of the species to the bag, both at the level of individual plant (architecture and growth potential) and at plant community level (plant-plant interactions), over the first growing season (six months) and under three culture regimes mimicking different naturally occurring situations: in isolation (i.e. when a clone colonizes novel substrate areas), in the presence of a neighbour of the same species (i.e., when a clone establishes into a monospecific stand) or of another seagrass, *Zostera noltei* Hornemann (i.e., when a clone establishes in a mixed stand). The behaviour of the bag in the marine sediment and its effect on sediment physical-chemical parameters, both in the absence of established vegetation and in the presence of *C. nodosa* or *Z. noltei*, were also examined in a parallel mesocosm experiment. The two species may coexist intermixed forming mixed beds (Kraemer and Mazzella, 1999) and have contrasting clonal growth forms: *C. nodosa* produces long internodes that ensure rapid and great occupation of new areas, and forms highly intermingled clumps of genets across the bed according to the guerilla-like growth form (Duarte et al., 2006). In contrast, *Z. noltei* produces short internodes, characteristics of the phalanx-like growth form (Ruggiero et al., 2005), and has a more compact structure that leads to uniform distribution of genets within the bed. Plant-plant interactions and environmental stresses play a fundamental role in structuring plant communities and associated ecosystems (Tilman et al., 1981; Connell, 1983; Goldberg and Barton, 1992; Rose and Dawes, 1999). There is evidence that at sites characterized by anthropogenic input of nutrients and reduced water column transparency *Z. noltei* may have a competitive advantage on *C. nodosa* and may over time replace *C. nodosa* (Kraemer and Mazzella, 1999). Here, we tested the hypothesis that the presence of bags within seagrass meadows would affect the ability of *C. nodosa* clones to compete with clones of the some species or with clones of *Z. noltei* by altering sediment characteristics.

2. Materials and methods

2.1. Experimental set-up and plant material

All the experiments were carried out in an aquaculture system (INVE Aquaculture Research Centre) located at Rosignano Solvay (Italy) that consisted of separate outdoor tanks (7000 L) with continuous flow of natural seawater equipped following a protocol previously established for successfully growing seagrasses (Balestri and Lardicci, 2012). The seawater level in the tanks was maintained at 0.5 m. Seawater temperature ranged from 16 to 25.8 °C, pH was 8–8.2, and salinity varied between 37.6 and 38.4 over the experimental period.

The type of biobag used in this study ("MB" hereafter) consists of Mater-Bi obtained from vegetable oils and corn starch (Novamont, http://www.novamont.com/) and it is certified as compostable under EN 13432 conditions and can be processed in home composting systems (Vincotte certification). Before the start of the experiment, MB bags were cut into equal pieces (14 cm × 14 cm, 0.48 ± 0.04 g dry weight, 20 μm of thicknesses). These pieces were placed in a tank at seawater-air surface and left to settle onto the bottom to simulate the natural entering in the marine environment from land sources. To establish plant culture, plagiotropic rhizomes of *C. nodosa* and *Z. noltei* were collected in April 2016 in a shallow meadow (0.5 m depth) where the two species coexist (North western Mediterranean, Livorno, Italy). Collected plants