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Eco-physiological responses of cold-water soft corals to anthropogenic sedimentation and particle shape

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ABSTRACT

Anthropogenic disturbances in the marine environment, such as excessive sedimentation produced by mine tailing deposition, can affect the physiology and behavior of benthic fauna. Mine tailing particles are sharper than natural occurring sediments and could therefore cause more harmful effects. Cold-water coral ecosystems are among the habitats in danger of being affected by dumping of mine tailings. Cold-water corals have very slow growth rates but the habitats they provide support high levels of species richness and functional diversity. Two soft corals, cauliflower coral (*Duva florida*) and red tree coral (*Primnoa resedaeformis*), were chosen as model organisms to study the effects of excessive mine tailing sedimentation and the effect of particle shape in a three-month long experiment. The corals were exposed to a concentration of 8 mg l^{-1} of two types of sediment, rough edged mine tailings (MT) and smooth edged spherical glass beads (GB). Glass beads were mimicking natural, smooth sediment, and both sediment types had a particle size distribution of 0–63 µm. Sedimentation effects were investigated using $^{13}C/^{12}C$ isotope ratio to assess food intake, time-lapse images to determine the effects on tissue and behavior, and histological samples to identify and quantify particles inside the polyps. When exposed to MT, food intake decreased significantly in *D. florida* and increased significantly in *P. resedaeformis*. *Duva florida* exhibited a behavioral response under MT treatment, being contracted for prolonged periods. *Primnoa resedaeformis* lost a significant proportion of polyps under both treatments. Histology showed mine tailing particles of sizes < 10 µm embedded in the tissue of both species. The results suggest that sharp particles are more harmful than smooth edged particles to both species, in the size range studied. This should be considered when assessing the impacts of anthropogenic activities that increase sedimentation in benthic habitats.

1. Introduction

Anthropogenic sedimentation to the deep ocean can be caused by several types of activities, including: deposition of mine tailings, drilling muds from oil and gas exploration, trawling or deep-sea mining (Ramirez-Llodra et al., 2011). Mine tailings are defined as the waste remaining after the extraction of the mineral of interest from the ore by means of crushing and milling, this process renders the particles sharp. Mine tailings can represent up to 99% of the extracted ore (Mining and Project, 2002) and waste specific contents depend on the extracted mineral (Ramirez-Llodra et al., 2015).

Disposing of the mine tailings on land can be challenging since it may compete with other land uses, and is dependent on adequate geological conditions (Vogt, 2013). To avoid possible complications relating to tailing disposal on land (Arnesen et al., 1997; Koski, 2012; Martin and Davies, 2000; Sammarco, 1999), discharge at sea is seen as a viable option. Three forms of deposition normally occur: 1) Coastal/shallow water Tailing Disposal (CTD) in the euphotic zone in coastal areas (Franks et al., 2011); 2) Submarine Tailing Disposal (STD): < 100 m depth; and 3) Deep Submarine Tailing Disposal (DSTD), released > 100 m depth with final deposition below 1000 m (Ellis and Ellis, 1994; Skei, 2014; Vogt, 2013). In DSTD and STD, to prevent the slurry (tailings and water mix) from mixing with the surface water and to avoid plumes, coagulating and flocculating agents are used in all three techniques. The accepted consequence of using these techniques is that all the biota under the dumping site will be lost. The adjacent

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benthic environment will also be affected as sediment spreads outside the deposition area and the creation of plumes could affect the benthic, and pelagic environment (Vogt, 2013) causing system clogging. Little information is available on deep-sea ecosystems regarding the biology and dynamics (e.g.: interactions between species, recovery rates (Armstrong et al., 2012) making it difficult to assess the full impact of mine tailings deposition. Furthermore, resuspension of particles by upwelling events and/or current systems can also spread the tailings to wider areas (Vogt, 2013). Particles smaller than 10 μm remain in suspension for longer periods of time than larger particles (Syvitski et al., 1985) and can disperse away from the designate dumping site, potentially impacting nearby biodiversity.

Norway is one of the few countries where STD is permitted (Kvassnes and Iversen, 2013). Active mines in Norway (seven as of 2013) deposit between 0.03 and 3 million metric tonnes of tailings a year. In 2013 none of the tailings contained any significant concentration of potentially toxic metals such as copper or lead (Kvassnes and Iversen, 2013). Thus, only the physical consequences of the tailings on the nearby biota are expected (Kvassnes and Iversen, 2013). The morphology of the tailing particles (smooth vs rough edged particles of different densities) may affect the physiology of organisms, as particles from mine tailings have rougher edges than natural occurring sediments (Gray, 1974). Biota exposed to plumes of tailings outside the deposition area may be vulnerable to harmful effects such as system clogging of tissue as documented for deep-sea sponges (Tjensvoll et al. (2013), tissue abrasion (Riegl, 1995) and higher metabolism due to stress and supplementary mucus production as demonstrated for scleractinian and alcyonacean tropical corals (Riegl and Branch, 1995).

Cold-water coral habitats have been known for centuries (Rogers, 2004), but it is not until recent years (last 20 to 30 years) that technological developments have allowed scientists to investigate them (Roberts et al. 2006). Few studies, therefore, have been done (relative to shallow water species) on their ecology and physiology, and most published papers have focused on the stony coral *Lophelia pertusa* and other reef building species (Rogers, 1999). Soft corals (Alcyonacea), living in cold-water ecosystems have been given very little attention but the presence of soft corals is important for the benthic community because they act as ecosystem engineers (Scinto et al., 2009) and harbor a number of associated fauna (Krieger and Wing, 2002; Mortensen and Mortensen, 2005). Due to their longevity, slow growth rates and long generation times these species are vulnerable to human impacts, such as trawling, hydrocarbon exploitation, mine tailing disposal and deep sea mining (Althaus et al., 2009; Clark and Rowden, 2009; Fisher et al., 2014; Ramirez-Llodra et al., 2011; Williams et al., 2010). Changing environmental conditions related to climate change are also a major threat (Fabricius and De'ath, 2001). The impacts of damaged cold-water coral habitats are numerous and can affect human kind in a large scale by compromising food security (see below), limiting thepossibilities for bioprospecting and reducing nutrient and element cycling; (Rocha et al., 2011; Soetaert et al., 2016; van Oevelen et al., 2009). Cold-water benthic habitats are found worldwide and are associated with fish communities. In Norwegian waters, typical associations of red rock fish (*Sebastes viviparus*), tusk (*Brosme brosme*) and saithe (*Pollachius virens*) with cold-water coral reefs and gardens are observed (Edinger et al., 2007; Husebø et al., 2002; Jakobsen, 2016; Kutti et al., 2014; Mortensen et al., 2010, 2015). Damaging these habitats can have serious repercussion for fish populations. Fishermen in Norway noticed that fish landings diminished where coral habitats had been damaged (Fosså et al., 2002). Stronger evidence for the importance of cold-water corals for fish was reported by Baillon et al. (2012), who classified them as fish larvae nurseries. Other associated fauna might be adversely affected by loss of coral surface (Krieger and Wing, 2002) Paradoxically, the eco-physiological responses of soft corals to environmental key variables (e.g. temperature, light regime, salinity), and anthropogenic stressors such as increased sedimentation (clogging of tissue, increased metabolism) and climate change or ocean acidification have not been documented in detail.

This study aims to determine the effects of mine tailing sedimentation and particle shape on metabolism, behavior and tissue abrasion of cold-water soft corals, and to answer the following questions: Do cold-water soft corals and Gorgonians react differently to two differently shaped sediments? In regard to tissue abrasion, and metabolism? Two species present in Norwegian waters, the cauliflower coral (*Duva Florida*) and red tree coral (*Primnoa resedaeformis*) were chosen as model organisms. *Duva florida* (Rathké, 1806) is found in the North Atlantic and the Mediterranean from 40 to below 300 m depth (Utinomi, 1961; Van Ofwegen, 2011). It typically lives on rocky substrate, often attached to *Lophelia pertusa* rubble. *Primnoa resedaeformis* (Gunnerus, 1763) is typically found in the North Atlantic at depths between 90 and 1000 m (Cairns and Bayer, 2005). Colonies can grow more to than 1 m in height and often found close to *L. pertusa* aggregations. Soft corals were chosen as they constitute an important, yet often overlooked, component of many cold-water coral ecosystems. *Duvaflorida* and *P. resedeaformis* where chosen as they represent two different morphological structures of soft corals (one with internal axis and one without).

2. Materials and methods

2.1. Specimen collection

During collection, 27 colonies of *D. florida* were randomly selected in May 2015 at Nord-Leksa (63°36′402″ N, 9°23′145″ E) outside Trondheim fjord (Fig. 1), using a remotely operated vehicle (ROV) Sperre K30 equipped with a manipulator arm and collection net detailed in Ludvigsen et al. (2015). All individuals were collected from 174 to 188 m depth. The living corals were placed in temperature insulated containers filled with 10 °C deep-water for transportation to the laboratory. The corals remained in the containers for 8 h. At the lab, they were transferred to three 108 l containers with flow-through deep-water (100 m depth, sand-filtered, holding a temperature of 8 °C) with exchange rate of 10 times daily. The specimens were then left to acclimate for two weeks.

Three *Primnoa resedaeformis* colonies were randomly sampled in June 2015 from Tautra, inside Trondheim fjord (63°34′205″ N, 10°25′512″ E) (Fig. 1), from 94 to 113 m of depth. Colonies were collected, cut close to the base using the ROV manipulator arm and placed in a collection net. Upon arrival to the lab the colonies where placed in a 1764 l saltwater tank hanging from the basal end to avoid tissue damage. The tank was equipped with deep-water flow through system of 100 ml s^{-1} (water was exchange 4 times daily). Colonies were left to acclimate for 3 days before fragmentation.

2.2. Maintenance of corals in the lab

Individuals of *D. florida* were detached from the dead *L. pertusa* fragments and the epifauna were removed. Each individual was placed in a glass/plastic support to mimic the support provided by the coral rubble in situ and then transferred to nine different 46 l aquaria, each aquarium had 3 *D.florida* specimens. *Primnoa resedaeformis* were fragmented from the colonies (3 fragments from each colony) and put in supporting holdfasts made of Reef construct epoxy cement (Aqua Medic). It was ensured that the fragments in each aquarium came from different colonies. Three fragments were added to the nine different aquaria were *D.florida* was previously added. The aquaria, that were maintained as a flow through system provided with fjord water from 100 m depth. Flow was maintained at 4 ml s^{-1}, resulting in a water exchange of 7.5 times daily. Each tank was equipped with a MICRO-JET MC 450 pump to further enhance water movements. The aquaria were maintained in a dark temperature controlled room at 4-6 °C. Water temperature was recorded and corals were fed *Artemia* nauplii twice per week. The final *Artemia* nauplii concentration in aquaria was