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Metabolic responses of the deep-water sponge *Geodia barretti* to suspended bottom sediment, simulated mine tailings and drill cuttings

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ABSTRACT

Northeast Atlantic sponge beds are recognized as local hotspots for biodiversity and nutrient cycling. Despite their important functional role little is known about their sensitivity to effluents from the expanding hydrocarbon-, mining- and bottom trawling industry. Here, data on physiological and biological responses of the common demosponge *Geodia barretti* to short (4 h) and long-term (50 day) cyclic exposure of suspended particles are presented. The laboratory study showed that 4 hour pulse exposures with crushed rock particles at 500 mg l^{-1} caused a 50% drop in oxygen consumption but with a quick recovery to pre-exposure oxygen consumption once suspended sediment loads returned to background levels. Long-term cyclic exposure (12 h each 24 h) for 29 days caused a permanent drop in oxygen consumption with 60% in sponges exposed to 50 mg l^{-1} of crushed rock but with no apparent effect on the energy content of the sponge. Oxygen consumption and energy content of sponges exposed to natural bottom sediments at the same concentration remained unchanged. In conclusion, *G. barretti* appears to have well developed mechanisms to resist sediment stress, however, the study demonstrated that operations releasing large amounts of suspended crushed rock such as exploration drilling and submarine tailings disposal near sponge beds should be carefully planned to avoid long-term losses of benthic ecosystem functions, such as organic matter re-mineralization.

1. Introduction

Sponges of the family Geodiidae are widely distributed in the northern Atlantic Ocean. They grow abundantly on the vertical faces of the walls in Norwegian fjords and on gravelly substrate on the Norwegian, Icelandic and the Faroe shelves, the Reykjanes Ridge, west of the Shetland Islands and off Newfoundland (Bett, 2001; Klitgaard and Tendal, 2004; Murillo et al., 2012; Cárdenas et al., 2013; Kutti et al., 2013). At depths between 100 and 300 m they can form mass aggregations with biomasses of up to 4–5 kg wet weight (WW) m^{-2}, which can extend several kilometers in length (Kutti et al., 2013; Fig. 1A). Geodiid sponges are sessile filter feeders that function by drawing in oxygenated and food/nutrient rich water through thousands of micron-sized inhalant openings that lead into a branching system of water canals (i.e. aquiferous system) and releasing wastewater through fewer, larger sized exhalent canals and openings (i.e. oscule) (Fig. 1B). The water flow is created by beating flagella of choanocyte cells, lining the choanocyte chambers. This is also where the food uptake from the water takes place. The dominant Geodiid of Norwegian sponge aggregations *Geodia barretti* processes on average 600 l of water kg^{-1} WW day^{-1} (Kutti et al., 2013) removing efficiently bacteria and nutrients from the water column (Bannister et al., unpublished data).

The high filtration capacity of sponges coupled with their sessile nature makes them highly susceptible to pollution. When exposed to sedimentation events and elevated concentrations of suspended sediment sponges can filter fine particles into their aquiferous system and choanocyte chambers (Tompkins-MacDonald and Leys, 2008). This can impede filtration, oxygenation and feeding and induce physiological stress responses such as reduced pumping and increased mucus production (Gerrodette and Flechsig, 1979; Tompkins-MacDonald and Leys, 2008; Bannister et al., 2012; Tjensvoll et al., 2013). Such responses can be accompanied by immediate changes in the respiratory activity of the sponge (Bannister et al., 2012; Tjensvoll et al., 2013). Increased sedimentation and turbidity can cause secondary effects such as reduced growth rates, decreased survival and impeded reproduction of sponge individuals (Roberts et al., 2006; Whalan et al., 2007; Maldonado et al., 2008), with the level of stress responses being dependent on a combination of both the concentration and composition of the suspended particles (Maldonado et al., 2008; Bannister et al., 2012).

Sedimentation and resuspension are natural processes in fjords and on the continental margin regulating the concentration of suspended particles in the benthic boundary layer. Human activities, such as oil

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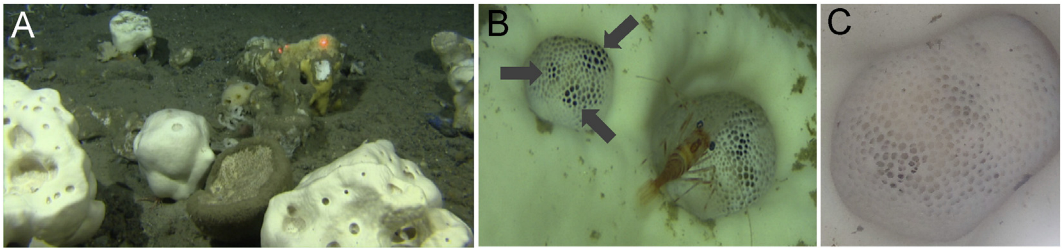

Fig. 1. A) Image from the Træna Deep sponge ground, Norwegian continental shelf, dominated by *Geodia barretti* (white sponge with several large preoscule openings) and with other conspicuous sponges such as *Geodia phlegraei*, *Mycale* sp. and *Phakellia* sp. (distance between laser points is 10 cm. B) Close-up of the preoscules of *G. barretti* covered with a delicate open sarcode (choanosome) network or mesh protecting the true oscules visible underneath (see arrows). C) Close-up of a apparently closed sarcode network of the preoscule of *G. barretti* individual.

drilling operations, disposal of mine tailings and bottom trawling can cause changes to the quantity and quality of suspended particles encountered by benthic suspension feeders. Benthic releases of sediment from oil drilling operations occur mainly during exploration drilling when large amounts of crushed rock and drill-mud are deposited on the sea floor with a subsequent resuspension of the fine mineral particles into the water around the drilling sites. This release is normally restricted to 1–2 months with temporarily doubled turbidity levels up to 500 m away from the discharge locations (Møskeland et al., 2012). Currently 45–55 exploration wells are drilled on the Norwegian shelf annually (Anon., 2013), with each well discharging approximately 1000 tonnes of drill cuttings (Neff, 2005). Benthic releases of sediments from the mining industry occur in Norwegian fjords through the disposal of mineral waste particles through submarine tailings disposals (Cornwall, 2013). The same sites are often used for decades, with deposition rates varying between 300,000 and 4 million tonnes annually (Berge et al., 2012). The level of suspended sediments in the benthic boundary layer can be elevated up to ten times 1–2 km away from the designated dump site (Berge et al., 2011). Four disposal sites are currently in operation and two applications for new disposal permits are in progress. Bottom trawls that are dragged over the sea-bed will resuspend bottom sediments and create turbidity clouds with 10–100 times higher turbidity than background concentrations depending on the type of bottom sediment (Bradshaw et al., 2012; Martín et al., 2014). Turbidity clouds with slightly elevated levels of small suspended mineral particles (i.e. <10 μm) can remain for days and thereby propagate to areas beyond the fishing grounds by down slope gravity flow or bottom currents (Bradshaw et al., 2012). Recent laboratory experiments have shown that *G. barretti* will arrest its pumping when exposed to short term pulses of fine grained natural sediments with concentrations 10 times higher than background concentrations (Tjensvoll et al., 2013). The effects of long-term exposure to suspended particles from natural bottom sediment and mine tailings and drill cuttings have not been studied despite sponges being important functional components in many areas that are heavily used by the bottom trawling, oil and mining industry.

The objective of this paper was to examine short- and long-term effects of elevated concentrations of small (i.e. <250 μm) suspended particles of natural bottom sediment and crushed rock, i.e. simulated mine tailings and drill cuttings, on the physiology of the dominant deep-water sponge *G. barretti*. This was done by examining 1) the effect of single 4 hour pulse exposures of suspended crushed rock particles of five different concentrations on the respiratory activity of the sponge and 2) the effect of a 50 day cyclic exposure to suspended particles of natural bottom sediment and crushed rock at two different concentrations on the respiratory activity and energetics of the sponges. A secondary objective was to find approximate duration and concentration thresholds for releases of suspended mineral particles of different origin. Such thresholds could be helpful tools to managing the release of particles from anthropogenic activities in or near important sponge aggregations.

2. Methods

2.1. Collection and preparation of particles

Natural bottom sediment for the two exposure studies was collected at 200 m depth in Hardangerfjorden (59°46.4 N, 05°40.4E) with a van Veen grab. Crushed granite rock (i.e. simulated drill cuttings and mine tailings) was collected from a producer of artificial sand near the city of Bergen (Fana Stein A/S). The natural sediment was wet sieved to a size of <250 μm (Table 1, Fig. 2), homogenized and kept frozen until the start of the experiments. The wet weight/dry weight composition was estimated. The crushed rock was dry sieved to a size of <250 μm and stored dry until the start of the experiments. Size composition of the sediments was analyzed using laser diffractometry (Coulter LS Particle Size Analyser at NGU, Norway). The natural bottom sediment had a median grain size of 71 μm (mean 139 μm). The crushed rock had a median grain size of 56 μm (mean 72 μm).

2.2. Short-term sediment exposure experiment

2.2.1. Sponge collection and maintenance

Sponges were collected in October 2010 and in July 2011 at approximately 200 m depth in Langenuen, western Norway (59°49.5 N, 05°33.3E) using the ROV *Aglantha*. On-board the sponges were transferred (submerged in water) from a collection box mounted on the ROV to large fish tanks. Water in these tanks was continuously renewed with unfiltered water from 100 m depth. At the end of the cruise the sponges were transported to the Institute of Marine Research (IMR) in Bergen, Norway where they were kept in flow through tanks, which received unfiltered water from 120 m depth for approximately 2 months before the experiments started. No additional food was added to the tanks.

2.2.2. Short-term exposure to crushed rock

Oxygen consumption of *G. barretti* was measured for individual sponges in sealed recirculating incubation chambers during 5 consecutive 4-hour intervals consisting of one pre-exposure interval, one exposure interval and 3 post-exposure intervals each separated by a 30–60 minute long flushing cycle (using the same chambers and following the methodology of Tjensvoll et al., 2013). At the start of the exposure

Table 1
Size composition of the two sediment particle types added to the concentration stock tanks and used to dose the sponges.

Natural bottom sediment		Crushed rock	
Particle size (μm)	Percentage	Particle size (μm)	Percentage
<3.9	7	<4.9	12
4–62.9	42	5–62.9	42
63–124.9	23	63–124.9	24
125–250	28	125–250	22