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Assessing the potential impact of water-based drill cuttings on deep-water calcareous red algae using species specific impact categories and measured oceanographic and discharge data

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ABSTRACT

The potential impact of drill cuttings on the two deep water calcareous red algae *Mesophyllum engelhartii* and *Lithothamnion* sp. from the Peregrino oil field was assessed. Dispersion modelling of drill cuttings was performed for a two year period using measured oceanographic and discharge data with 24 h resolution. The model was also used to assess the impact on the two algae species using four species specific impact categories: No, minor, medium and severe impact. The corresponding intervals for photosynthetic efficiency ($\Phi_{PSIImax}$) and sediment coverage were obtained from exposure–response relationship for photosynthetic efficiency as function of sediment coverage for the two algae species. The temporal resolution enabled more accurate model predictions as short-term changes in discharges and environmental conditions could be detected. The assessment shows that there is a patchy risk for severe impact on the calcareous algae stretching across the transitional zone and into the calcareous algae bed at Peregrino.

1. Introduction

The calcareous red algae, *Mesophyllum engelhartii* (Foslie) Adey and *Lithothamnion* sp. are encrusting species growing on different hard substrates such as rhodoliths. Rhodoliths are calcified multi-spherical structures of different sizes made of dead calcareous algae and other calcifying organisms such as bryozoans and different species of polychaetes (Tâmega et al., 2013) (Fig. 1). These multi-spherical structures are regarded as important for the ecosystem, creating a habitat for other taxa living between, on and in the rhodolith structures (Basso, 1998). Rhodoliths are found down to 250 m (Henriques et al., 2014; Littler et al., 1991, 1986), and the largest occurrence is discovered along the Brazilian Continental Shelf (Amado-Filho et al., 2012; Foster, 2001; Kempf, 1970). The knowledge about growth, sensitivity to environmental stressors and ecological importance of the deep water rhodolith communities is rather sparse (Henriques et al., 2014; Steller et al., 2009, 2007). However, these communities may be disturbed and buried due to natural sedimentation and anthropogenic activities such as fish–trawling and mining (Nelson, 2009). Burial may result in reduced photosynthetic activity due to reduced gas exchange (Figueiredo et al., 2015; Harrington et al., 2005; Wilson et al., 2004). It is also demonstrated that fine particles (<63 μm grain size) may reduce the photosynthetic efficiency of coralline algae to a larger extent than coarse calcareous and nutrient-rich shallow estuarine sediments (Figueiredo et al., 2015; Harrington et al., 2005; Riul et al., 2008; Wilson et al., 2004).

Furthermore, rhodolith beds are increasingly exposed to discharges of drill cuttings from oil and gas activities, for instance in

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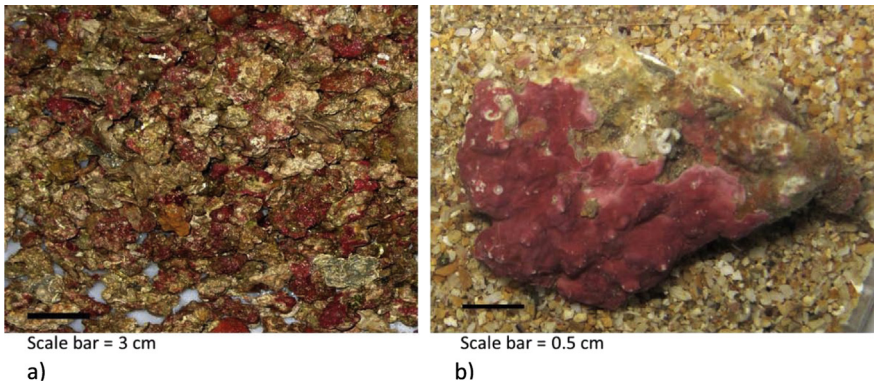

Fig. 1. a) Rhodolith bed, b) Rhodolith with healthy calcareous red algae (reddish colour).

the Gulf of Mexico and on the Brazilian shelf (Davies et al., 2007). The Peregrino oil field, located 80 km off the coast of Brazil, south of Cabo Frio, in the Campos Basin area, is located close to a rhodolith bed (Fig. 9). The calcareous algae *Mesophyllum engelhartii* (Foslie) Adey and *Lithothamnion* sp. are among the most abundant algae species present in the area (Figueiredo et al., 2015; Salgado et al., 2010; Tâmega et al., 2013). Drill cuttings with residuals of water-based drilling fluids are discharged from the drilling activities at Peregrino. Drill cuttings are formation rock particulates generated during drilling (Neff, 2008). The water-based drilling fluid discharges only contain residuals of water soluble and none or low toxic components such as barite, clay, salts and calcium carbonate (Bakke et al., 2013; Frost et al., 2006; Neff, 2008). Barite is a weighting agent in drilling fluids and one of the most abundant solid in drilling fluids (Neff, 2008). Laboratory tests verified that the residuals of water-based fluid from the Peregrino oil field are not toxic to *Mesophyllum* and *Lithothamnion* (Reynier et al., 2015). However, as calcareous algae have no individual motion and since the rhodoliths they are living on are expected to have low motion capabilities (Fig. 1), these discharges may have a physical impact on the test organisms through sedimentation of particles. Reduced production of oxygen and reduced *in vivo* photosynthetic efficiency, reported by Reynier et al. (2015) was primarily physical and due to the burial with drill-cuttings. Also sediment mimicking drill cuttings from the Peregrino oil field resulted in reduced *in vivo* photosynthetic efficiency in *Mesophyllum* and *Lithothamnion* (Figueiredo et al., 2015; Villas-Bôas et al., 2014). Photosynthetic efficiency was measured as *in vivo* Chlorophyll *a* fluorescence kinetics of dark acclimated cells (Φ_{PSII_max}). A decrease in photosynthetic efficiency is regarded as a response to stress (Genty et al., 1989).

Modelling is frequently used to assess potential risk or impact of discharges to sea from oil and gas exploration and production. Environmental risk assessment based on the PEC/PNEC approach is commonly used by offshore operators in Europe, and the principle is accepted by the Oslo Paris Commission (OSPAR) as a basis for environmental management of produced water discharges (OSPAR, 2012a, 2012b). One example of such a model is the Dose-related Risk and Effect Assessment Model (DREAM) (Beyer et al., 2012; Durgut et al., in press; Johnsen et al., 2000; Rye et al., 2008; Smit et al., 2008). DREAM predicts dispersion and potential environmental risk based on the PEC/PNEC approach for discharges of produced water and drill cuttings to the marine environment. A major criticism against this approach has been the lack of ecosystem relevance as the PNEC levels derived from the literature may not be representative for local species. This is especially of concern when operating in areas considered as particularly vulnerable or housing species or habitats of particular interest. This situation is indeed valid for the Peregrino field, housing a deep water calcareous algae community. However, DREAM also allows the use of species specific effect data as an option to the more generic PNEC approach, giving a risk or impact assessment targeted at selected species.

The aim of the present study was to assess the potential impact of drill cuttings discharges on the dominating species of calcareous algae at the Peregrino oil field. Furthermore, the purpose was to verify that the assessment of the potential impact as performed by DREAM provides valid and reliable information for environmental management. This was achieved by:

1) establishment of species specific impact categories for the calcareous algae *Mesophyllum engelhartii* (Foslie) Adey and *Lithothamnion* sp. based on exposure studies performed in a flow-through system (Figueiredo et al., 2015) and
2) modelling the potential impact on the two calcareous algae species using the established impact categories together with measured current velocity and direction and actual drill cutting discharges with high temporal resolution.

2. Methods

The methodological approach in this study is based on the principles outlined by Nilssen et al. (2015) for integrated environmental mapping and monitoring, describing a flexible approach for optimised knowledge gathering through combined use of laboratory experiments and measured field and discharge data with modelling. To enable the link between the impact categories obtained from the flow-through exposure studies (Figueiredo et al., 2015) and the dispersion modelling, sedimentation experiments were performed to convert sediment coverage (%) to sediment deposition (kg m^{-2}). A flow chart of the different elements used to perform the assessment of potential impact on the two calcareous algae species is illustrated in Fig. 2.

2.1. The Peregrino area

The Peregrino oil field consists of two fixed well head platforms (WHP) for drilling of production and water injection wells, and one floating production storage and offloading unit (FPSO). The WHPs are located 10 km apart with the FPSO in between. Drilling at the Peregrino field commenced in November 2010 and until May 2013,