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The influence of demersal trawl fishing gears on the resuspension of dinoflagellate cysts

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ABSTRACT

To investigate the influence of towed demersal fishing gears on dinoflagellate cyst resuspension, towing trials with four gear components were carried out at three sites of differing sediment type in the Moray Firth, Scotland. Samples of sediment plumes were collected using plankton nets mounted on a towed sledge. Diversity of resuspended dinoflagellate cysts was similar at all sites and included *Protoperidinium* and *Gonyaulax* spp., *Proroceratium reticulatum* and unidentified 'round brown' cysts. Cyst concentrations per gram of resuspended sediment varied by gear component and sediment particle size distribution. Gear components with lower hydrodynamic drag generated wakes with smaller shear stresses, mobilising fewer larger sand particles, giving larger concentrations of cysts. Muddy sediments contained higher cyst concentrations which declined with increasing grain size. This study has shown that fishing gear and sediment type can influence the redistribution of dinoflagellate cysts and highlights the importance this may have in relation to dinoflagellate blooms.

1. Introduction

Many species of marine phytoplankton have a dormant resting or cyst stage within their life cycle which sinks out of the water column and rests on the sea bed. These cyst stages serve as survival strategies during periods of unfavourable growth conditions such as nutrient depletion and low light and temperature levels (Anderson et al., 2003; Dale, 1983; Godhe et al., 2001; Kremp, 2001; Wang et al., 2004) or can be an obligate part of their sexual reproductive cycle (Anderson et al., 2003; Garcés et al., 2004; Matsuoka and Fukuyo, 2000). Various species belonging to the Dinophyceae (dinoflagellates), Bacillariophyceae (diatoms) and Raphidophyceae (raphidophytes) are known to produce these cyst stages (Anderson et al., 2003; Dale, 1983; Edvardsen and Imai, 2006; Hallegraeff and Hara, 2003; McQuoid and Hobson, 1996; Round et al., 1990) and several types have been identified. Many species of dinoflagellate can produce a highly resistant resting cyst (termed hypnozygote) which can be used as an overwintering strategy as well as a temporary cyst which can survive short term environmental changes (Anderson et al., 2003). Within the diatoms, three types of resting stage are recognised; the spore, or hypnospore, which are most common among centric diatom species; the resting cell, vegetative cells that become dormant and remain similar in form but with thicker cell walls and the winter stage, which is morphologically similar to the spore but lacks the large energy stores of the spore and resting cell (McQuoid and Hobson, 1996; Round et al., 1990). Cysts of raphidophytes are generally small, spherical in shape and lack any particular ornamentation (Edvardsen and Imai, 2006; Hallegraeff and Hara, 2003; Matsuoka and Fukuyo, 2003).

Historically the majority of research has focussed on dinoflagellates cysts and throughout this paper the term 'cyst' will refer to a dinoflagellate resting cyst. It is widely acknowledged that the presence of cysts within the sediment play a fundamental role in bloom dynamics by creating 'seed banks'. These seed banks can contribute to vegetative phytoplankton communities by providing an inoculum for future blooms (Anderson et al., 2003; Godhe and McQuoid, 2003; Kremp, 2000; Matsuoka and Fukuyo, 2000; Nehring, 1996). Cysts hatch to form vegetative cells and the planktonic phase of the bloom continues. Towards the end of the bloom gametes fuse to form resting cysts which sink to the sediment. Thus cysts are involved with the initiation and termination phases of a dinoflagellate bloom event. In addition, these robust cyst resting stages may also serve as a mechanism for geographic expansion of species into new areas through transport in the ballast tanks of ships (Anderson et al., 2003; Garcés et al., 2004; Ishikawa and Taniguchi, 1996).

Resting dinoflagellate cysts go through a mandatory period of dormancy during which time they are incapable of germination, even upon favourable conditions. This dormancy period is highly variable, being species-specific and can range from 12 h to 12 months (Kremp and Anderson, 2000; Matrai et al., 2005; et al., 2000). It is only after this dormancy and under appropriate

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conditions that cysts may hatch into motile vegetative cells. Oxygen is essential for the hatching of all dinoflagellate cysts. Cysts buried within deep anoxic sediment layers are likely to remain as such unless disturbance of the seabed causes them to be redistributed into surface layers or resuspended into the water column, where a supply of oxygen can allow germination to take place (Kirn et al., 2005; Kremp, 2001; Nehring, 1996). In laboratory experiments temperature, and to a lesser extent, light, have been found to influence cyst germination and for different species these factors can vary significantly (Anderson et al., 2003; Kirn et al., 2005). A wide range of optimum temperature 'windows' has been observed for dinoflagellate species including *Alexandrium minutum* (8–24 °C) (Blanco et al., 2009); *Alexandrium tamarense* (14–26 °C) (Genovesi et al., 2009) and *Scripsiella hangoei* (0–9 °C) (Kremp and Anderson, 2000). However Perez et al. (1998) demonstrated no effect of temperature on germination success of *A. tamarense*. It has also been reported that some species can germinate in darkness (Anderson et al., 2003; Nehring, 1996) and for the dinoflagellate *Peridiniella catenata*, darkness and different light levels do not appear to affect its germination success (Kremp, 2001).

Previous literature has addressed the importance of cyst resuspension when investigating phytoplankton bloom dynamics and the environmental conditions through which this can occur (Giannakourou et al., 2005; Kremp, 2001; McQuoid, 2002; Nehring, 1996). Benthic shear stress from strong water currents and wind mixing, turbulence, upwelling and sediment disturbance caused by pelagic or benthic organisms are reported as the main likely causes of sediment mixing and cyst resuspension (Cannon, 1993; Kirn et al., 2005). Little work has been performed to date on how anthropogenic activities can affect resuspension and redistribution of phytoplankton cysts.

The ocean is a natural resource of major socio-economic importance. It is used for fishing, transportation, recreation, mineral extraction, oil drilling and more recently renewable energies. While many of the activities associated with exploiting the ocean resource do not effect the seabed, it has been shown that some, particularly, fishing with towed demersal gears and dredging to extract sand and gravel can significantly impact the benthic ecosystem (Boyd et al., 2005; Desprez, 2000; Dolmer, 2002; Dolmer et al., 2001; Gilkinson et al., 2005; Hall, 1999; Jennings and Kaiser, 1998; Kaiser et al., 2002; Løkkeberg, 2005; Sardá et al., 2000). Such studies have generally focussed on benthic macrofauna including bivalves, polychaetes, echinoderms and amphipods, where changes to species assemblages and sediment compositions are common. Both of these activities also result in the mobilisation of sediment and the possible resuspension of phytoplankton cysts. A study by Giannakourou et al. (2005) has demonstrated that the highest concentrations of viable cysts appear within the subsurface sediment layers during periods of no activity, however during periods of intense trawling activity and sediment mobilisation and mixing, more homogenous cyst profiles are apparent.

In Scotland, demersal towed fishing gears are responsible for over 50% (by value) of the fish landed. A recent study by O'Neill and Summerbell (2011) examined how the interaction of these types of gears, the seabed and the ambient water produced regions of high velocity, high bed shear stress, high turbulence and possibly fluidised bed, and how all of which contributed to the entrainment of sediment around and behind the gear components in contact with the seabed. This study also demonstrated that the mass of sediment entrained in the wake of a specific gear component was related to the hydrodynamic drag of the component and the type of sediment over which it was towed.

Here, in a related series of observations we investigate how towed demersal fishing gears affect the resuspension of phytoplankton cysts within sediments in the Moray Firth, northeast Scotland. We report on studies to quantify the cyst densities within sediment plumes behind four different fishing gear components in contact with the seabed and examine if the impact is consistent between areas with different sediment types.

2. Materials and methods

2.1. Study sites

Experimental trials were carried out by the RV Clupea in three areas within the Moray Firth (Fig. 1) (Dornoch, Nairn and Burghead), on the northeast coast of Scotland during November 2007. Samples of the sediments at the three experimental sites were collected using a modified Day grab and were classified, using the Folk description as being 'muddy sand' at Dornoch and Nairn and 'sandy mud' at Burghead. The percentage silt (<63 μm) in the sediments was 20%, 42% and 69% by volume respectively and the d50 values were 89, 75 and 41 μm (O'Neill and Summerbell, 2011).

2.2. Sample collection

To investigate the benthic impact of towed demersal gears, a benthic sledge (Fig. 2a) was used to tow four different components of a demersal trawl that come into contact with the sea bed. These were: a trawl door which is designed to spread the mouth of a trawl and to ensure that the gear maintains contact with the seabed (Fig. 2b); and three sections of the groundgear (rockhoppers, small rubber discs and a length of chain (Fig. 2c)) which are used to protect the fishing net and again maintain contact with the seabed. To measure sediment volume concentration and particle size distribution of sediment that was redistributed into the water column by these components, a LISST 100X particle size analyser was mounted onto the sledge, recording at second intervals during deployment. The sledge was either towed directly by the research vessel in which case the groundgear sections were held in position in front of it by two aluminium arms or it was towed by chains behind the trawl door. Video cameras were also attached to the sledge and permitted estimation of the width and height of the sediment plume. The mass of sediment remobilised per metre towed was estimated using the sediment concentration measurements from the LISST 100X and these estimates of plume dimensions (see O'Neill and Summerbell (2011) for details).

The chain section was made from long link, grade 80 alloy steel fishing chain, was 1.4 m long and weighed 3.5 kg. The rubber discs section was made from discs that were 15 cm in diameter and 3.5 cm thick and was 1.36 m long and weighed 20.6 kg. The rockhopper section was made from five rockhopper rubber discs that were 37 cm in diameter and 8 cm thick and separated by smaller 10 cm diameter rubber discs that were 3.5 cm thick. This section was 1.3 m long and weighed 56.4 kg. The trawl door was rectangular, 1.37 m wide and 0.88 m high and weighed 101 kg.

Five or six replicate 10 min tows were made with each gear component at each site and the resulting sediment plume was sampled using 20 μm mesh size plankton nets with a circular mouth opening of diameter 6.0 cm the centre of which was positioned 35 cm from the sea bed. After recovery of the sledge, plankton net samples were stored in 1 L nalgene bottles and anoxic conditions were maintained by completely filling the bottles with sea water and sealing the lids with insulating tape. All samples were stored in darkness at 4 °C until analysed.

To illustrate the abundance and composition of phytoplankton cysts that are present in these areas for comparative measures, sediment core samples were collected at Burghead and Nairn. It was not possible to collect core samples at Dornoch as the corer was unable to penetrate the firmer, harder sediment at this site. To investigate depth distribution of cysts in the sediment, the core