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The hydrodynamic drag and the mobilisation of sediment into the water column of towed fishing gear components

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ABSTRACT

The hydrodynamic drag of towed fishing gears leads to direct impacts on the benthic environment, and can play a major role in the overall economic efficiency of the fishing operation and emissions of nitrogen oxides, sulphur oxides and greenhouse gases such as CO_2. Here we investigate some of the underpinning processes which govern these issues and make direct hydrodynamic drag measurements and calculate the hydrodynamic drag coefficients for a range of well-defined gear components that, when fished, are in contact with the seabed. We measure the concentration and particle size distribution of the sediment mobilised into the water column in the wake of these gear elements, at a range of towing speeds, and demonstrate that as the hydrodynamic drag increases the amount of sediment mobilised also increases. We also vary the weight of the elements and show that this does not influence the amount of sediment put into the water column.

These results provide a better understanding of the physical and mechanical processes that take place when a towed fishing gear interacts with the seabed. They will permit the development of more fuel efficient gears and gears of reduced benthic impact and will improve the empirical modelling of the sediment mobilised into the turbulent wake behind towed fishing gears which will lead to better assessments of the environmental and ecological impact of fishing gears.

1. Introduction

The capture of fish species living on or close to the sea bed account for about 23% of global fisheries yield (FAO, 2009). In general, these are caught by towed demersal fishing gears that interact with the water column and the benthic environment through which they are towed. Eigaard et al. (2016) categorise these gears as being otter trawls, beam trawls, demersal seines and dredges (Fig. 1). They are made of a range of gear components or elements that are designed to spread the fishing gear (otter doors, sweeps and seine ropes), to maintain contact with the seabed (otter doors, beam trawl shoes, groundgear etc.) to protect the gear from the seabed (groundgear and seine ropes) and to ensure the gear fishes efficiently (tickler chains, dredge teeth etc.).

The physical impact of these components in the benthic environment can have broader ecological, environmental and biological implications and many studies have shown that towed demersal fishing gears damage habitats, cause benthic mortality, release nutrients and resuspend phytoplankton cysts and copepod eggs (Kaiser et al., 2006; Dounas et al., 2007; Gilkinson et al., 1998; Brown et al., 2013; Drillet et al., 2014; O'Neill et al., 2009). Additionally, studies of the fuel efficiency of fishing trawlers have demonstrated that the combined contact and hydrodynamic drag of a demersal towed gear can account for up to 80% of the fuel consumed (Curtis et al., 2006). Hence, these impacts can play a major role in the overall economic efficiency of the fishing operation and to emissions of nitrogen oxides, sulphur oxides and greenhouse gases such as CO_2 (Cheilari et al., 2013; Suuronen et al., 2012). In order to be able to assess and quantify the implications of fishing to the wider ecosystem; provide advice to policy makers in relation to the establishment of marine protected areas and the prioritisation of seabed usage; and develop more fuel efficient and environmentally friendly fishing techniques; we must understand the underpinning physical and mechanical processes taking place.

On soft sediments these physical processes have been classified as being either geotechnical or hydrodynamic. The geotechnical effects refer to the contact drag, the penetration and piercing of the substrate, lateral displacement of sediment and the influence of the pressure field transmitted through the sediment (O'Neill and Ivanović, 2016). The hydrodynamic effects refer to the hydrodynamic drag and the mobilisation of sediment into the water column where the mobilised sediment comprises both the larger particles that will quickly fall to the seabed and the finer ones that may go into suspension (O'Neill and Summerbell, 2011).

In this paper we focus on the hydrodynamic impacts and measure the hydrodynamic drag of a range of cylindrical and rectangular shaped objects that are in contact with the seabed and investigate the resulting mobilisation of sediment into the water column in their wake. Most studies of the hydrodynamic drag of fishing gears have been concerned

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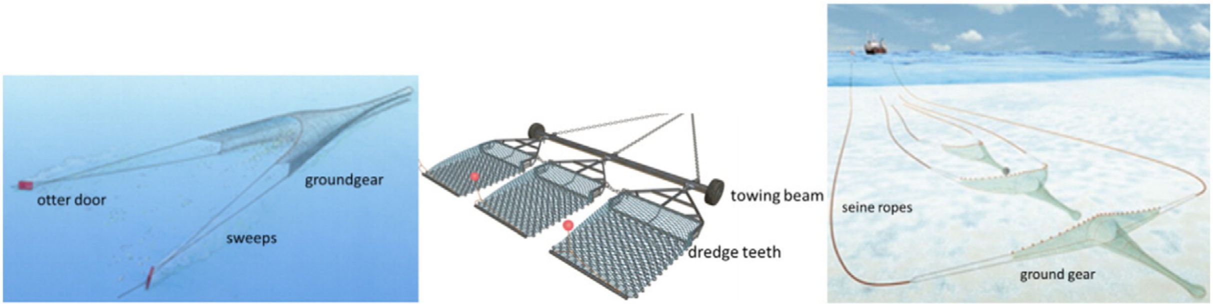

Fig. 1. A demersal otter trawl, three scallop dredges on a single beam and a demersal seine net demonstrating some of the components of towed demersal fishing gears that are in contact with the seabed.

with the geometry of the netting structure and/or the fuel efficiency of the fishing operation. They have tended to consider the hydrodynamic forces acting on the netting (O'Neill and O'Donoghue, 1997; O'Neill et al., 2005), the resulting deformation of the netting structure (Takagi et al., 2004; Lee et al., 2005; Hu et al., 2006; Tsukrov et al., 2002; O'Neill and Neilson, 2008) and how the fishing gear design influences fuel usage (Khaled et al., 2012; Parente et al., 2008). In comparison, little attention has been given to the hydrodynamic drag of the fishing gear components in contact with the seabed (Sala et al., 2009) or to the associated sediment mobilised in their wake. Studies of the mobilisation of sediment by fishing gears, have generally used direct sampling (Pranovi et al., 2004; Dounas, 2006; Dounas et al., 2007; Martín et al., 2014), optical technologies (Black and Parry, 1999; Durrieu de Madron et al., 2005; Dellapenna et al., 2006; O'Neill et al., 2013a) and/or acoustic methods (Lucchetti and Sala, 2012; Palanques et al., 2014; Humborstad et al., 2004; Depestele et al., 2016; Puig et al., 2012; O'Neill et al., 2013b) to investigate the sediment plumes behind full-scale towed gears. While these approaches have been very informative, they usually deal with a particular gear on a particular sediment and as a result it is difficult to generalise their results. Nevertheless, attempts have been made, using fishing effort data, to assess these impacts at a fleet/fishery level (Oberle et al., 2016b) and to contextualise predictions of the sediment put into the water column by trawling by comparing them to what occurs during natural processes (Diesing et al., 2013). Oberle et al. (2016a); Ferré et al. (2008) and Churchill (1989) compare estimates of what is mobilised by trawling, at a continental shelf scale, to estimates of what is mobilised by waves, currents and to the mass of sediment that enters the shelves through rivers. Accurate estimates of the amount of sediment put into the water column in the wake of different gears are critical to these types of assessments.

O'Neill and Summerbell (2011) address some of these issues by investigating the sediment mobilised into the wake of the components of a demersal trawl that are in contact with the seabed on soft sediments ranging from sand to sandy mud (Folk et al., 1970). They demonstrate that there is a relationship between the hydrodynamic drag of the gear element and the mass of sediment entrained in its wake, and that the finer the sediment the greater the mass of sediment mobilised into the water column.

Here, we extend their approach and carry out a systematic study of a well-defined range of gear components that, when fished, are in contact with the seabed. We have three main objectives.

- The first is to make direct hydrodynamic drag measurements and calculate hydrodynamic drag coefficients of the gear elements of our study. This contrasts with the study of O'Neill and Summerbell (2011) where the hydrodynamic drag coefficients used were compiled from experimental studies on similar shaped objects (Hoerner, 1965).
- The second is to measure the concentration and particle size distribution of the sediment mobilised into the water column in the wake of these gear elements at a range of towing speeds and investigate the relationship between the hydrodynamic drag of an element and the amount of sediment mobilised. Thus, in addition to varying drag by changing gear element (and changing frontal area) we also modify it by altering towing speed, which again is an extension of O'Neill and Summerbell (2011) where the towing speed was kept constant.
- The third is to investigate the relationship between the weight of a gear element and the amount of sediment mobilised into the water column.

2. Materials and methods

2.1. Towed sledge and instrumentation

Experimental sea trials were carried out on the RV Alba na Mara during October 2013 in the inner Moray Firth, Scotland (Fig. 2). A towed sledge, of height 0.9 m, width 2.1 m, length 3.0 m and weight 530 kg was used to tow a range of cylindrical and rectangular objects supported on an axle, which were chosen to simulate a range of gear elements that are in contact with the seabed (groundgear, doors, clumps etc.) (Fig. 3). The full range tested is presented in Fig. 4 and includes disks and cylinders of diameter 200, 300 and 400 mm, and rectangular doors of width 600 mm and height 200, 300 and 400 mm. In total 14 different configurations were examined, eight different cylinder designs, three configurations of separated disks and three of rectangular doors. These were fixed onto an axle that is 1.3 m long and of 63 mm in diameter and Strainstall 500 kg X-Y load cells were fitted at each end of the axle to measure forces in the horizontal plane at a rate of 10 Hz. The axle was attached to a framework (via the load cells) that was free to move in the vertical direction (Fig. 5). Hence, the vertical forces the gear elements exerted on the sea bed were the gravitational forces associated with the gear element and that part of the supporting framework that was free to move. It was also possible to increase the applied vertical forces by attaching weights to the framework and each of the configurations was tested having vertical weights (in water) of approximately 60, 120 and 180 kg. During each deployment the speed at which the sledge was towed was increased incrementally over a thirty minute period from 1 to 2 m/s. The vessels GPS recorded the speed of the sledge over the ground at a rate of 1 Hz. A LISST 100× was positioned centrally 1.9 m behind the axle, with the sampling head 35 cm off the seabed to measure the concentration and particle size distribution of the sediment mobilised into the wake of the gear components. The LISST 100× uses the laser diffraction principle to measure the concentration of particles in 32 logarithmically increasing size ranges between 2.5 and 500 μm and was set to take measurements at a rate of 1 Hz.

All drag, speed and concentration data were time-averaged into 10 s intervals and it is these data that are examined in the following analyses. Two types of experiments were carried out: the first set were related to measuring the hydrodynamic drag, during which the elements were not in contact with seabed; while, during the second set, the elements were