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Large-scale impacts of bottom trawling on shelf primary productivity

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Abstract

Disturbance of the seabed resulting from bottom trawling affects ecosystem processes, such as the rate and magnitude of nutrient regeneration. The potential responses of the plankton community arising from such effects can be modelled, provided that reliable data on the effects on nutrient fluxes are available. In a north Cretan outer continental shelf and upper slope fishing ground (Heraklion Bay, Crete, Eastern Mediterranean) we applied a new field instrument which can simulate the passage of trawl groundropes across the sea floor and made direct seasonal measurements of the rate of dissolved and particulate nutrient releases resulting from seabed disturbance. These observational data were then integrated in a 3D ecosystem model. Results revealed that bottom trawling may trigger off considerable productivity pulses, in addition to pulses from the natural seasonal cycle.

Keywords: Bottom trawling; Ecosystem disturbance; Nutrient releases; Nutrient recycling; Resuspension; Primary production; Modelling

1. Introduction

Every year, the world fishing fleet comprising ca. 60,000 trawlers sweeps more than 15 million km^2 of seabed, mainly on the continental shelves (Watling and Norse, 1998). Commercial fishing has been identified as the primary anthropogenic disturbance not only in the intensively fished coastal areas of Europe and North America but, more recently, throughout the world (Jackson et al., 2001). The impact of the physical contact of bottom trawl fishing gear on the seabed produces a significant aftermath: it releases clouds of suspended sediment (Churchill, 1989; Palanques et al., 2001); it can both resuspend and bury biologically recyclable organic material (Mayer et al., 1991); it releases nutrients to the overlying water (Pilskaln et al., 1998; Durrieu de Madron et al., 2005); it is responsible for an increase in the mortality of benthic fauna (e.g., Hall, 1999).

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Though the potential of trawling to affect regional nutrient budgets has been noted (Pilskaln et al., 1998), yet direct measurements are rare (Durrieu de Madron et al., 2005; Dounas et al., 2005; Dounas, 2006). Resuspension of bottom sediments in coastal waters stimulates water column microbial production (Wainright, 1987; Ritzrau and Graf, 1992; Gotner et al., 2000), causing a substantial increase in total system organic matter mineralisation (Wainright and Hopkinson, 1997; Dale and Prego, 2002) which may persist for much longer (from days to weeks) than the resuspension event itself (Wainright, 1990). Suspended particulate matter by natural hydrodynamic forcing is advected very close to the seabed rather than whisked high into the water column in both shallow (Leipe et al., 2000) and deep sea environments (Thomsen et al., 2002). This transport in proximity to the sediment–water interface has important implications for the distribution of organic matter as food for benthic suspension feeders (Beaulieu, 2002, 2003). In contrast, sediment mechanically resuspended by trawling extends, in significant concentrations, to more than 10 m above the bottom (Churchill, 1989 and references therein; Pilskaln et al., 1998). This process may further prolong the exposure of sedimentary organic matter to oxic conditions, accelerate mineralisation and decrease denitrification rates, thereby making more nitrogen available to phytoplankton (Wainright and Hopkinson, 1997). The effects of bottom trawling-induced disturbance on large-scale ecosystem processes, such as nutrient regeneration and primary productivity, are still difficult to predict for open coastal and outer shelf ecosystems where most trawling activity is concentrated (National Research Council, 2002).

We performed seasonal observations of the sediment resuspension by using a benthic sledge adapted to simulate the passage across the sea floor of a trawl groundrope typical of the kind (commonly) used in the Cretan fisheries (Dounas, 2006). Previous experimental results indicated that almost all the biologically active compounds of the sediment are resuspended by a single passage of the trawl-simulating gear implying that the upper, extremely thin, layer of shelf non-permeable sediments (<1 mm) contains a considerable reservoir of dissolved and particulate nutrients in much higher concentrations than in the immediately underlying surface layers (Dounas et al., 2005). These results are consistent with new findings which also suggest that in shelf muddy bottoms the particulate matter load injected by a trawling rig into the water column comes from the resuspension of less than 1 mm thickness of the surface sediment (Durrieu de Madron et al., 2005). Thus, the new sampling apparatus enables direct measurements of the amount of sediment and nutrients raised into suspension per unit length of trawl track or seabed surface area. These observational data were integrated in a 3D ecological model in order to investigate potential large-scale effects of bottom trawling on shelf primary productivity which was the major aim of this study.

2. Methods

2.1. Study area

All field experiments were conducted in the outer continental shelf and upper slope of Heraklion Bay (Cretan Sea) at 100, 200 and 300 m depths (Fig. 1) on four occasions: April, June, October 2000 and February 2001. The sea floor sediment is predominantly mud, with low organic carbon concentrations and positive redox potential values (Tselepides et al., 2000a). The area is characterised as oligotrophic with mean annual gross primary productivity of 80 and 59 g carbon $m^{-2}\,year^{-1}$ on the shelf and slope, respectively (Psarra et al., 2000).

The circulation in the broader study area (central Cretan Sea) is influenced by a mesoscale dipole consisting of two gyres (Fig. 1), an anticyclonic eddy in the West and a cyclonic eddy in the East (Theocharis et al., 1999; Hamad et al., 2006). The experimental sampling stations were located at the basis of the boundary zone between these aforementioned eddies, an area dominated by a very stable southward current that turns gradually to a SE–ESE direction when it reaches the upper slope and the continental shelf of Heraklion Bay (Georgopoulos et al., 2000). According to Tselepides et al. (2000b), this particular circulation in the central Cretan Sea acts as a pump, transporting water masses southward and upwelling them up onto the euphotic zone of the Cretan continental shelf.

Before sampling, the study area was surveyed by underwater towed-video operations. Heavy commercial trawling activity was indicated especially at the 100 m depth sampling station, as evidenced by numerous heavy plough furrows (door impacts), lightly scraped sediment surfaces (wire impacts) and completely flattened and scraped surfaces (groundrope and net impacts). These impacts have also been recorded by Smith et al. (2003) from the