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Trawling-induced daily sediment resuspension in the flank of a Mediterranean submarine canyon

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ABSTRACT

Commercial bottom trawling is one of the anthropogenic activities causing the biggest impact on the seafloor due to its recurrence and global distribution. In particular, trawling has been proposed as a major driver of sediment dynamics at depths below the reach of storm waves, but the issue is at present poorly documented with direct observations. This paper analyses changes in water turbidity in a tributary valley of the La Fonera (=Palamós) submarine canyon, whose flanks are routinely exploited by a local trawling fleet down to depths of 800 m. A string of turbidimeters was deployed at 980 m water depth inside the tributary for two consecutive years, 2010–2011. The second year, an ADCP profiled the currents 80 m above the seafloor. The results illustrate that near-bottom water turbidity at the study site is heavily dominated, both in its magnitude and temporal patterns, by trawling-induced sediment resuspension at the fishing ground. Resuspended sediments are channelised along the tributary in the form of sediment gravity flows, being recorded only during working days and working hours of the trawling fleet. These sediment gravity flows generate turbid plumes that extend to at least 100 m above the bottom, reaching suspended sediment concentrations up to 236 mg l^{-1} close to the seafloor (5 m above bottom). A few hours after the end of daily trawling activities, water turbidity progressively decreases but resuspended particles remain in suspension for several hours, developing bottom and intermediate nepheloid layers that reach background levels ~2 mg l^{-1} before trawling activities resume. The presence of these nepheloid layers was recorded in a CTD+turbidimeter transect conducted across the fishing ground a few hours after the end of a working day. These results highlight that deep bottom trawling can effectively replace natural processes as the main driving force of sediment resuspension on continental slope regions and generate increased near-bottom water turbidity that propagates from fishing grounds to wider and deeper areas via sediment gravity flows and nepheloid layer development.

1. Introduction

Bottom trawling is a fishing technique that consists in pulling nets along the seafloor to harvest benthic and demersal living resources. The means to keep the net open and close to the bottom are diverse but invariably imply the use of heavy devices such as otter boards, bobbins, sweeplines or chains, that are in contact with the seafloor continuously or intermittently. In certain cases, beams or dredges designed to actively bulldoze the seafloor are used. Aside from the direct impacts on benthic fauna and their habitats, the dragging of these gears along the seafloor injects large amounts of surface sediments into the water column, particularly when trawling is carried out over soft bottoms (Black and Parry, 1994; Pilskaln et al., 1998). In fact, in certain trawling modalities such as otter trawling, the clouds of resuspended sediments constitute an integral part of the fishing strategy by "herding" fish swarms towards the mouth of the net (Main and Sangster, 1981). Given the global dimension and recurrence of commercial trawling (World Resources Institute, 2000; Bensch et al., 2009; Puig et al., 2012), the question arises whether this human activity can make a sizeable contribution to present-day sediment resuspension and water column turbidity over extensive areas of the world's continental margins. Churchill (1989) brought the issue into focus, proposing that trawling activities were able to rival storms as the main agent for sediment resuspension and transport on the middle and outer continental shelf of the Middle Atlantic Bight. More than 20 years after this pioneering work, the body of literature addressing this subject is still relatively slim and mainly devoted to coastal and continental shelf settings (Pilskaln et al., 1998; Palanques et al., 2001; Durrieu de Madron et al., 2005; Tragou et al., 2005; Dellapenna et al., 2006; Ferré et al., 2008), which leaves a big gap of knowledge on the effects of this practice at depths beyond the shelf-break. Filling this gap is a pressing issue because of two overlapping factors. First, bottom fisheries have progressively extended their activities from traditional shallow grounds towards the continental slope and further offshore during the last decades (Morato et al., 2006; Bensch et al., 2009; Benn et al., 2010). Second, it is generally agreed

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(though scarcely documented) that artificial disturbances of the seafloor tend to be more severe and long-lasting in deep-sea than in shallow water environments, due to the fact that the natural processes capable of overcoming human imprints are in general weaker in the former (Theil and Schriever, 1990; Kaiser et al., 2002).

Among deep-sea environments susceptible of being impacted by trawl industries, submarine canyons are regarded as relevant and fragile hotspots of biodiversity (WWF/IUCN, 2004; Fabri et al., 2014). Canyons incising the continental shelf act as preferential routes and/or traps for organic and inorganic particulate matter from both terrestrial and marine sources. Also, by promoting local upwelling, canyons can be sites of enhanced biological production (Allen et al., 2001). Their complex morphology offers diverse habitats and shelter to marine species, including some of high economic value and, consequently, prosperous fishing harbours are often based in the vicinity of submarine canyons (Würtz, 2012). La Fonera Canyon, also known as Palamós Canyon (Fig. 1), is one of the most prominent submarine canyons of the northwestern Mediterranean (Palanques et al., 2005; Martín et al., 2006; Lastras et al., 2011). Its flanks from ~400 to 800 m depth are intensely exploited by a local trawling fleet targeting the blue and red shrimp *Aristeus antennatus*. Trawlers are active on a daily basis and year round, except for weekends and holidays, mainly along the Sant Sebastià fishing ground in the northern canyon flank (Fig. 1). The same ground is usually swept several times a day, starting typically at 6–7 h (UTC) in an offshore direction. Subsequent hauls may be carried out until 15–16 h, when the boats head back to port. The bottom trawl gear used in this fishery consists of 2 otter boards, each up to 1 ton in weight, spread ~100 m apart during the trawling operation and connected to the net opening by 60–200 m-long sweeplines. The net measures 80–150 m in length and is ~50 m wide at its ballasted mouth. The daunting capacity of these otter trawling gears to resuspend big volumes of sediments is not new to fishermen: small trawlers' crews complain about their nets being clogged–and thus inoperative–by the mud propelled on the wake of the bigger trawlers sailing ahead (Alegret and Garrido, 2004). Studies conducted in 2001 showed that trawling gears operating in the Sant Sebastià fishing ground were able to trigger sediment gravity flows that were funnelled through a tributary valley (named Montgrí) and were observed reaching the main canyon axis at 1200 m depth (Palanques et al., 2006; Martín et al., 2007). Further studies also documented the consequences of these man-made flows in terms of downward sediment fluxes and sediment accumulation rates in the canyon axis (Martín et al., 2006, 2008). Recently, Puig et al. (2012) evidenced that the periodic sediment removal from La Fonera Canyon fishing grounds ultimately reshaped the continental slope morphology over large spatial scales.

This paper aims to improve our understanding of trawling-induced sediment resuspension events along the northern canyon flank, describing in detail the daily and seasonal variability of water turbidity and discussing also the implications of such resuspension process in the generation of nepheloid layers along continental margins.

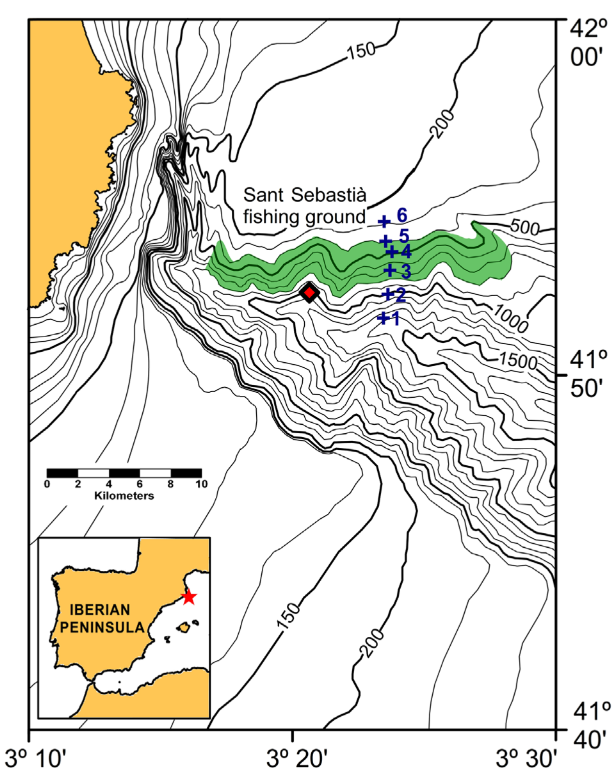

Fig. 1. Bathymetric chart of the La Fonera (=Palamós) submarine canyon in the Northwestern Mediterranean, showing the position of the mooring line (red diamond) in the Montgrí tributary valley deployed in 2010 and 2011. The main fishing ground (San Sant Sebastià) on the northern canyon flank is marked as a shadowed area. Crosses indicate the positions of consecutive CTD casts carried out during 11 May 2011 (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Materials and methods

An instrumented mooring array was deployed in the Montgrí tributary traversing the northern flank of the La Fonera Canyon (red diamond in Fig. 1). The mooring line was positioned at 41°52.49′N; 3°20.66′E, in a water depth of 980 m, ~200 m deeper than the maximum working depth of the local trawling fleet, during two consecutive years. From 1 July to 7 November 2010, the line was equipped with 10 Seapoint turbidimeters (AQUA logger 520, AQUATEC; wavelength 880 nm, scatterance angles 15–150°) at 5, 10, 15, 20, 25, 30, 40, 50, 70 and 100 m above the bottom (mab). These instruments were programmed to measure turbidity, expressed in Formazin Turbidity Units (FTU), at 1 min intervals in auto-gain mode. The mooring line was also equipped with a downward-looking 300 kHz Teledyne RDI Acoustic Doppler Current Profiler (ADCP) placed above the turbidimeters. Unfortunately, during 2010 the ADCP did not record data due to a technical issue affecting the Firmware 5x.37–5x.39 of RDI Workhorse sentinel platforms (Teledyne Field Service Bulletin FSB-194; 08/11/2010) and the 20 mab turbidimeter ceased prematurely to record due to a problem with the batteries. The same site was reoccupied from 10 May to 12 October 2011. In this occasion, 3 turbidimeters were placed at 5, 20 and 50 mab and the ADCP provided valid current data from 12 to 78 mab in 2 m-wide bins at 5-min intervals. The N-E current components were rotated to obtain along- and across-slope components taking into account the main orientation of the tributary valley (191° from North). To complement these measurements with observations of the horizontal distribution of resuspended particles in the water column, a CTD transect (see Fig. 1 for CTD cast positions) crossing the northern canyon flank was conducted on 11 May 2011 after the end of the daily trawling activity. A Seabird SBE 911 CTD probe equipped with a Seapoint turbidimeter was used.

FTU readings from the CTD and moored turbidimeters were converted to estimates of suspended sediment concentration (SSC) after the general calibration by Guillén et al. (2000):

$$SSC(\text{mg l}^{-1}) = 1.74 \times (FTU - FTU_{min})$$

where FTU_{min} is the minimum turbidity recorded by the sensor during a given deployment period.