Impact of fish-trawling in sediment accumulation rates in the deep sea

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Abstract

Commercial bottom trawling is an anthropogenic activity that is causing some of the biggest impacts on the sea floor. Bottom trawling has been documented to be one of the major drivers of sediments to depths, such as to canyons. The aim of this paper is to quantify variations in sediment accumulation rates in the Besòs (1238 m and 1487 m) and Foix (865 m and 1361 m) submarine canyons of the Northwestern Mediterranean, and to assess changes in seafloor impacts due to the industrialization of the trawling fleet. Sediment accumulation rates were estimated based on ^{210}Pb concentration profiles. A two-fold increase in sediment accumulation rate was detected, 865 m deep in the Foix canyon, by 2002-2003, from 0.62 ± 0.04 $g{\cdot}cm^{-2}{\cdot}y^{-1}$ to 1.53 ± 0.12 $g{\cdot}cm^{-2}{\cdot}y^{-1}$, associated to an increase in both horsepower and the total number of vessels operating in the flank of the canyon. This finding contrasts with previous observations in other submarine canyons that established a major change in sediment accumulation rates by the late 1970s, when the fishing sector experienced a rapid industrialization. On the contrary, no significant changes in sediment accumulation rates were detected in the Besòs canyon, limiting the area of influence towards the canyon head, close to the fishing grounds. Our results suggest that the impacts of fish trawling activities in sediment accumulation rates are localized and provide evidence of a recent increase of this impact at the beginning of the XXI century, presumably related to subsidies and aids provided by the European Commission to the fishing sector.

Resumen

La pesca de arrastre es una de las actividades de origen antropogénico que causa uno de los mayores impactos en el fondo marino. Esta actividad tiene una gran capacidad de transportar sedimentos a grandes profundidades, que se acumulan en el interior de los cañones submarinos. El objetivo de este artículo es cuantificar los ritmos de sedimentación del cañón del Besòs (1238 m y 1487 m) y del cañón del Foix (865 m y 1361 m) del Mediterráneo noroccidental, donde dos testigos de sedimento fueron

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extraídos en cada cañón para evaluar los ritmos de sedimentación debido a la tecnificación de la pesca. Éstos fueron estimados a partir de las concentraciones de ^{210}Pb*, las cuales indicaron un aumento en los ritmos de sedimentación, de 0.62 ± 0.04* $g \cdot cm^{-2} \cdot a^{-1}$ *a 1.53 ± 0.12* $g \cdot cm^{-2} \cdot a^{-1}$*, en el cañón del Foix a una profundidad de 865 m en el 2002-2003, asociado a un aumento tanto de la potencia como del número de barcos que operaban a lo largo del flanco del cañón. Estos resultados contrastan con investigaciones llevadas a cabo en otros cañones, en los cuales se observaron aumentos en los ritmos de sedimentación durante los años 70, debido a una rápida industrialización del sector pesquero. Sin embargo, no se detectaron cambios en el cañón del Besòs, donde las muestras fueron cogidas fuera de la influencia de los caladores de pesca. Los resultados sugieren que el impacto de la pesca de arrastre en los ritmos de sedimentación son localizados y que se evidencia un aumento de este impacto al comienzo del siglo XXI, probablemente ligado a un incremento de las ayudas y subsidios de la Comisión Europea para el sector pesquero.*

Resum

La pesca d'arrossegament és una de les activitats antròpiques que causa un dels majors impactes en el fons marí. Aquesta activitat té una gran capacitat de transportar sediments a grans profunditats, que s'acumulen a l'interior dels canyons submarins. L'objectiu d'aquest article és quantificar els ritmes de sedimentació del canyó del Besòs (1238 m i 1487 m) i del Foix (865 m i 1361 m) del Mediterrani nord occidental, on es van agafar dos testimonis de sediments a cada canyó per avaluar els ritmes de sedimentació causats per una tecnificació de la pesca. Els ritmes de sedimentació varen ser estimats a partir de les concentracions de ^{210}Pb*, les quals van indicar un augment en el ritme de sedimentació, de 0.62 ± 0.04* $g \cdot cm^{-2} \cdot a^{-1}$ *fins a 1.53 ± 0.12* $g \cdot cm^{-2} \cdot a^{-1}$*, en el canyó del Foix a una profunditat de 865 m, a l'any 2002-2003, associat a un augment tant de la potència dels vaixells de pesca com del total de vaixells que operaven al llarg del flanc del canyó. Aquests resultats contrasten amb investigacions en altres canyons en què es van observar augments en els ritmes de sedimentació durant els anys 70, degut a una ràpida industrialització del sector pesquer. En canvi, no es van detectar alteracions significatives en el canyó del Besòs, on les mostres es van prendre fora de la influència dels caladors de pesca. Els resultats suggereixen que els impactes de la pesca d'arrossegament en els ritmes de sedimentació són localitzats i que s'evidencia un augment d'aquest impacte a començaments del segle XXI, probablement lligats a un increment de les ajudes i subsidis de la Comissió Europea pel sector pesquer.*

Key words	***Palabras clave***	***Paraules clau***
Fish-trawling	*Pesca de arrastre*	*Pesca d'arrossegament*
Foix canyon	*Cañón del Foix*	*Canyó del Foix*
Besòs canyon	*Cañón del Besòs*	*Canyó del Besòs*
Sediment accumulation rates	*Ritmos de sedimentación*	*Ritmes de sedimentació*

1. Introduction

Fish trawling is a widespread fishing activity that has been carried out on the coasts of Catalonia for centuries, with improvements in its technology as well as an increase of vessel power during the seventies (Maynou *et al*., 2003).

The Catalan continental margin supports an important commercial fishing industry due to the presence of several submarine canyons. One of the target species of this activity is the blue and red deep-sea shrimp, *Aristeus antennatus* (Risso, 1816), whose life cycle is closely related to submarine canyons.

Fish-trawling has many biological and physical effects in the aquatic environment. Some biological impacts include destruction of the benthos such as seagrass meadows, coral reefs and other benthic communities (Roberts *et al*., 2006; Pusceddu *et al*., 2014; Martín *et al*., 2014). This activity can also lead to post-fishing mortality and long-term trawl-induced changes to the benthos (Jones, 1992). The physical effects are poorly known. Research showed that fish-trawling can cause sediment resuspension, highly turbid plumes near the seabed, sediment gravity flows, and an increase of sediment accumulation rates (Churchill, 1989; Schoellhamer, 1996; Martin *et al*., 2008; Palanques *et al.*, 2006; Puig *et al.*, 2012).

The resuspended sediment can be intercepted by canyons which funnel them down-canyon, thus increasing sediment accumulation rates in certain areas of the canyon axis (Martin *et al*., 2008; Toro, 2013), which may affect the complex benthos inhabiting in canyons (Jones, 1992).

Previous studies conducted in the Palamós Canyon have proven a clear relationship between sediment fluxes, as well as sediment gravity flows with the operation of fish-trawlers in the eastern flank of the canyon. Furthermore, there has been an increase in sediment accumulation rates in some areas of the canyon axis after an increase of vessel power engine during the seventies (Martin *et al.*, 2008, 2013; Palanques *et al*., 2006; Puig *et al*., 2012). In the Arenys Canyon, an increase in sediment accumulation rate of 0.052 ± 0.002 $g \cdot cm^{-2} \cdot y^{-1}$ to 0.190 ± 0.009 $g \cdot cm^{-2} \cdot y^{-1}$ was observed in the canyon's axis close to its head at 1074 m in depth during the seventies (Toro, 2013).

This project was designed to study the impacts of fish-trawling activities of two canyons by modeling the concentration profiles of the natural radionuclide ^{210}Pb (half-life: 22.3 y) in bottom sediments in order to quantify sediment accumulation rates (Appleby and Oldfield, 1978).

Samples for the Besòs canyon were obtained in mid-canyon regions. Sediment cores from the Foix canyon correspond to the same locations analyzed in 1993 (Sánchez-Cabeza *et al*., 1999), thus allowing the analysis of the evolution of sediment accumulation rates in the last 20 years. The results obtained from both canyons will be compared with the changes in sediment accumulation rates observed during the seventies as a consequence of fish-trawling activities in the flanks of the Palamós and Arenys canyons.

2. Study area

This project is focused on two canyons located in the Mediterranean Catalan margin, the Foix (FC) and the Besòs (BeC) canyons. The regional circulation in this margin is a geostrophic slope current referred to as the Northern current. This current is the main transport-agent of particulate matter in suspension, and deposition takes place on the inner and mid-shelf during prolonged low-energy conditions (Durrieu de Madron *et al*., 1990; Monaco *et al*, 1990; Palanques and Drake, 1990; Puig and Palanques, 1998). Canyons may intercept particulate matter being transported by currents, which depends mainly on canyon's incision length and distance to shoreline (Canals *et al.,* 2013, Puig *et al.,* 2014).

2.1. Besòs Canyon

The Besòs Canyon is located in the coast of Sant Adrià del Besòs, Badalona, close to the mouth of the Besòs River. Its head is about 18 km from the coastline and it has a length of 18 km. The canyon is rather steep, with an approximate slope of 6.25% from the head of the canyon (600 m deep) to mid-canyon (1100 m deep), which then gradually reduces its gradient until reaching the canyon's mouth. The slopes from the canyon's flanks are also steep, approximately 22%.

Fishing activities occur in both flanks of the canyon and at its head (Figure 1). The vessels that operate in this area correspond to two different ports, Barcelona and Arenys de Mar. Vessels from Arenys de Mar port fish on the eastern flank of the canyon, mostly at low depths and close to the canyon's head, while the western flank of the canyon are mainly fished by vessels from Barcelona port, which also trace a clear path perpendicular to the canyon's head.

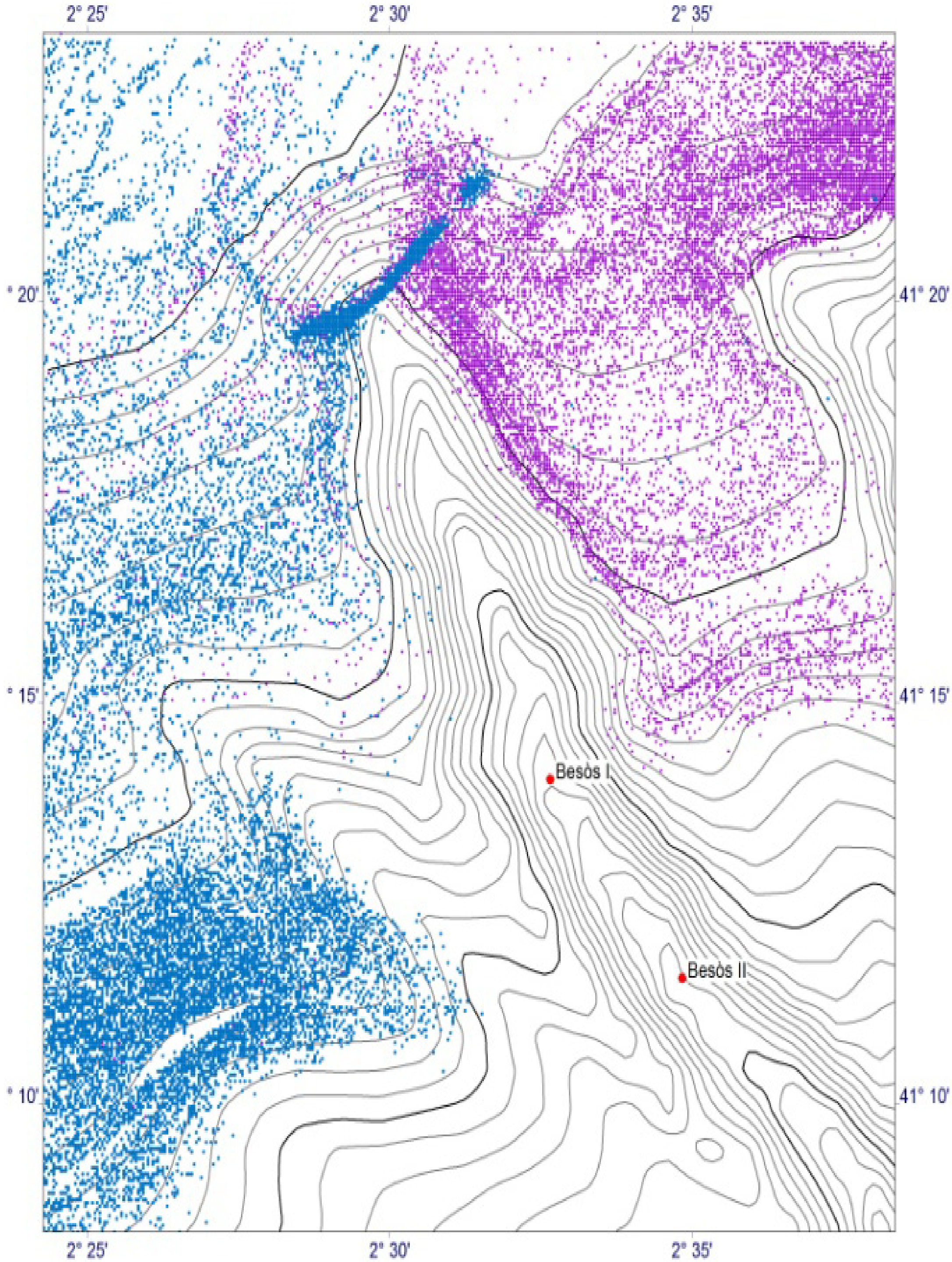

Figure 1 – Bathymetry of Besòs Canyon. Sampling positions Besòs I (1238 m) and Besòs II (1487 m) are shown in dots with its corresponding label. Vessel Monitoring Systems are shown in dots for the period from the 1st of January 2005 to the 13th of October 2011 (see section 3.3).

2.2. Foix Canyon

The Foix Canyon is located in the coast of Vilanova i la Geltrú. This canyon incises in the Catalan continental margin and intercepts and traps organic matter rich in sediments from the continent and the inner shelf carried by the geostrophic circulation of the Northern Current, or by strong sporadic events such as storms, river discharges, and vertical mixing (Puig and Palanques, 1998; Tubau *et al*., 2013). It receives sediments mostly from the Llobregat and Besòs rivers (Puig and Palanques, 1998). The head of the Foix canyon is found at about 11 km from the coast-line and has an incision length of 3,5 km (Canals *et al*., 2013, Tubau *et al*., 2013), which explains its importance as a sediment depocenter of the continental margin.

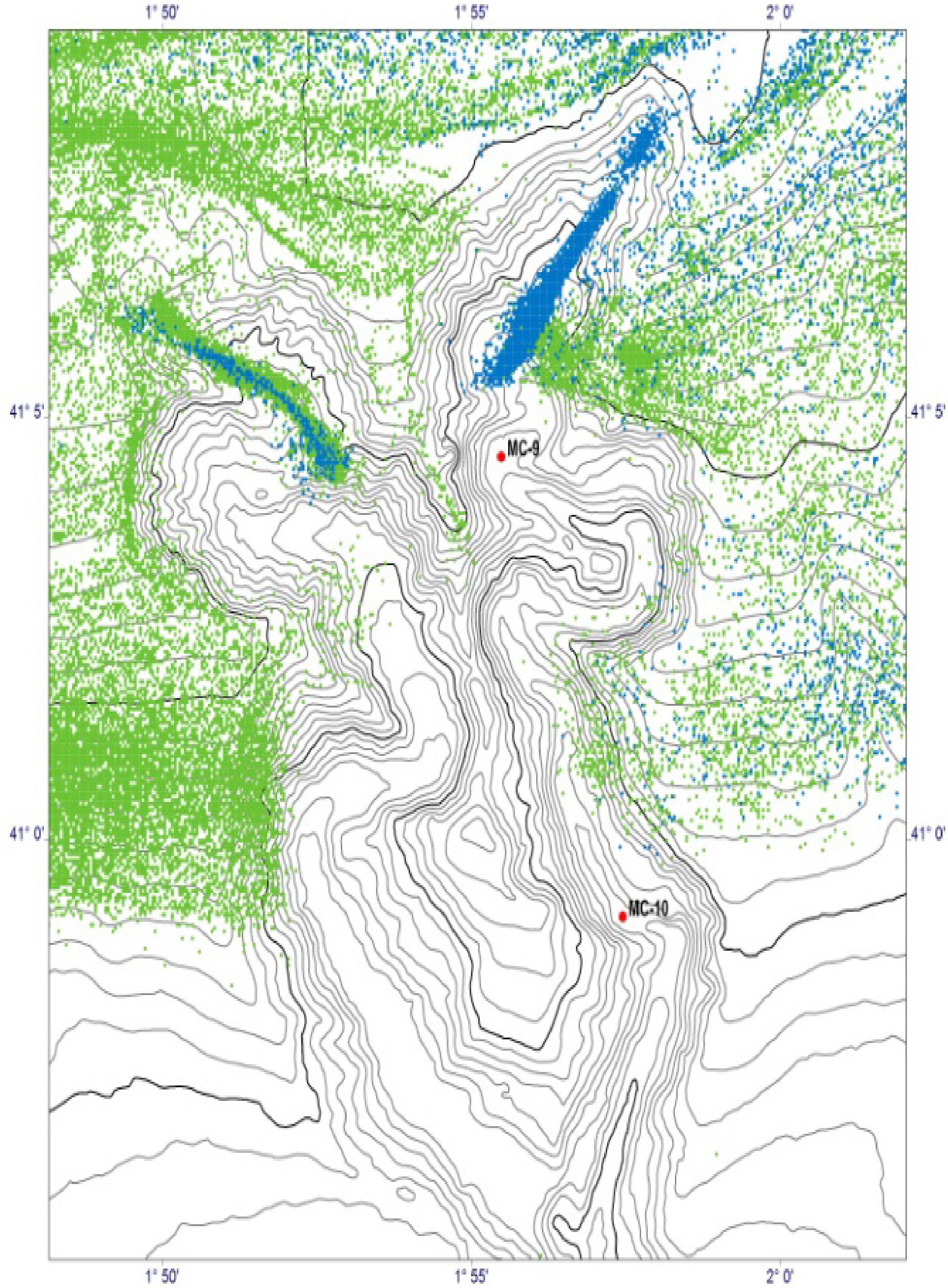

Figure 2 – Bathymetry of Foix Canyon. Sampling positions MC-9 (865 m) and MC-10 (1361 m) are shown in dots with its corresponding label. Vessel Monitoring Systems from Barcelona are shown in dots for the period from the 1st of January 2005 to the 13th of October 2011 (see section 3.3).

Fish-trawling activities on the eastern flank are equally dominated by vessels from Barcelona and Vilanova de la Geltrú ports. Vessels from Barcelona trace a clear path entering the head of the canyon´s eastern branch, while vessels from Vilanova de la Geltrú mostly fish on the flank of the canyon, close to the head of the eastern branch (Figure 2). These activities at times occur at depths greater than 1000 m.

3. Methodology

3.1. Sediment sample collection

Sediment cores from the Besòs (BeC) and Foix (FC) submarine canyons were obtained using a multicore system during the oceanographic cruises HERMIONE-III and FORMED-II in July 2012 and in October 2013, respectively, onboard the R/V *Garcia del Cid*.

In the Besòs canyon, sediment samples were obtained at 1238 m and 1487 m (Figure 1). In the Foix canyon, sediment samples were recovered in two previously sampled locations at 865 m and 1361 m in depth (Figure 2). These sediment cores were subsequently cut in layers of 1 cm and stored in polyethylene bags appropriately labeled at 4 °C until analysis in the laboratory.

3.2. Analytical methods

Granulometric analyses were carried out using a *Horiba Laser Difraction for Particle Size Analysis*. H_2O_2 (7%) was added to all samples to oxidize and remove all organic matter. Afterwards, $P_2O_7^{4-}$ was added to separate all the aggregates.

The concentrations of ^{210}Pb were determined through the analysis of its granddaughter ^{210}Po by alpha spectrometry, following the method described by Sanchez Cabeza *et al.* (1998), assuming secular equilibrium between both isotopes at the time of analysis.

^{210}Pb can be incorporated in the water column, mainly by atmospheric deposition. Once dissolved in the water column, it will quickly associate to particles and be transported to the sea floor and incorporate itself in the sediment. This concentration of ^{210}Pb in the sediment is the *excess or unsupported ^{210}Pb*. Another input of ^{210}Pb is through the decay of ^{226}Ra in the sea floor, due to the natural composition of the sediments. This concentration of ^{210}Pb is the *supported ^{210}Pb*.

To determine the sediment accumulation rates of each core, the CF:CS model was used. This model assumes that the flux of ^{210}Pb to the sediment ($Bq\cdot m^{-2}\cdot y^{-1}$) and the sediment mass accumulation rate ($g\cdot cm^{-2}\cdot y^{-1}$) are both constant through time (Krishnaswamy *et al*. 1971).

3.3. Ancillary data

Positioning of fish-trawlers operating near the studied canyons was obtained from the Fishing Monitoring Centre of the Spanish General Secretariat of Maritime Fishing (SEGEMAR), as Vessel Monitoring Systems (VMS), established by the Common Fisheries Policy of the European Union (Comission Regulation (EC)). The VMS recorded in this study correspond to 23 active vessels near the Besòs canyon and 32 vessels near the Foix canyon for the period from 1st of January 2005 to the 13th of October 2011.

Additional information of the operating vessels was obtained from the European Union's Fleet Register (European Comission Fisheries & Maritime Affairs). This database provides information of each vessel's power (CV) as well as the time period of operation of each vessel in its harbor.

4. Results

4.1. Besòs I

The content of silt and clay was 76 ± 4 % and 23 ± 4 % respectively, with no gravel and nearly no sand. Dry bulk density increased with fluctuations from 0.2 $g\cdot cm^{-3}$ at the surface to 0.9 $g\cdot cm^{-3}$.

In Besòs I, two slopes were observed, and a relatively constant ^{210}Pb concentration of 109 ± 13 $Bq\cdot kg^{-1}$ in between layers 5 to 12 $g\cdot cm^{-2}$ that took place in the year 1953 ± 2.

A mixed superficial layer in the first 4 cm was observed (Figure 3; Table 1). The accumulation rate of the upper section (5 to 14 cm) was 0.081 ± 0.005 $g\cdot cm^{-2}\cdot y^{-1}$, while for the inferior section (20 to 27 cm) it was of 0.076 ± 0.011 $g\cdot cm^{-2}\cdot y^{-1}$ (Figure 3). However, if mixing is not considered, a sediment accumulation rate of 0.12 ± 0.05 g·cm^{-2}·y^{-1} would be obtained.

4.2 Besòs II

The content of silt and clay was 66 ± 3 % and 33 ± 3 %, respectively, while neither gravel nor sand was detected. Dry bulk density increased in depth from 0.2 g·cm^{-3} at surface to 0.98 g·cm^{-3}.

In Besòs II, only one trend was identified, with a sediment accumulation rate of 0.078 ± 0.004 g·cm^{-2}·y^{-1} from 4 to 18 cm (Figure 3). A mixed layer in the first 3 cm was observed (Figure 3, Table I).

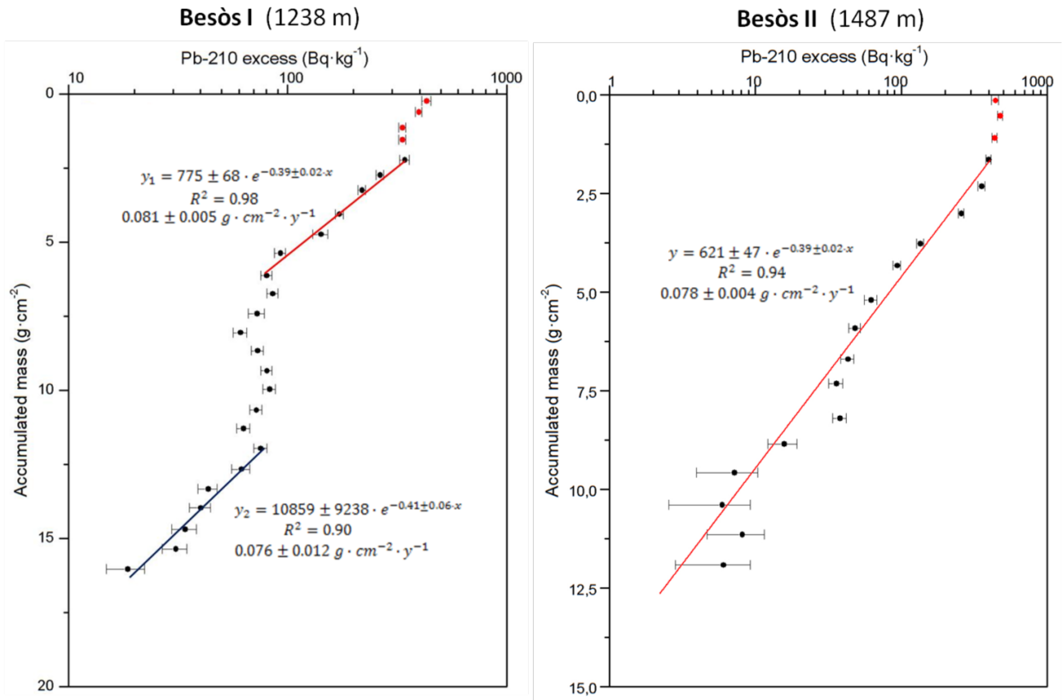

Figure 3 – ^{210}Pb excess concentration profiles of sediment cores collected in the Besòs canyon, indicating the different sediment accumulation rates.

Table 1 - Accumulation rates for Besòs I and Besòs II.

	Range (cm)	Accumulation rate (g·cm^{-2}·y^{-1})
Besòs I	0 – 14[1]	0.12 ± 0.05
	5 - 14	0.081 ± 0.005
	20 - 27	0.076 ± 0.012
Besòs II	4 - 18	0.078 ± 0.004

[1] No mixing considered

4.3 Foix MC-9

The content of silt and clay was 79 ± 3 % and 17 ± 2 %, respectively, and the proportion of sand was 4 ± 2 %. Dry bulk density increases in depth from 0.6 g·cm^{-3} to almost 0.8 g·cm^{-3} in the last layer, 54.5 cm, and reaches a maximum value of 0.96 g·cm^{-3} at a depth of 30.5 cm.

It should be pointed out that the supported ^{210}Pb was not reached in Foix MC-9, which suggests a high sedimentation rate.

The ^{210}Pb concentration profile of Foix MC-9 core evidences two trends. For the upper 22 cm an accumulation rate of 1.53 ± 0.12 g·cm^{-2}·y^{-1} was quantified, which took place in 2002-2003. For the inferior section an accumulation rate of 0.62 ± 0.04 g·cm^{-2}·y^{-1} was calculated that occurred in the sixties (Table 2; Figure 4).

4.4 Foix MC-10

The content of silt and clay was 74 ± 4 % and 22 ± 3 %, respectively, with a proportion of sand of 4 ± 5 %. There is an increase of 15% in sand between 30 and 38 cm, reaching a maximum at 34 cm of depth. Dry bulk density increased from 0.6 to 1.3 g·cm^{-3}, fluctuating mostly between 1.0 and 1.2 g·cm^{-3}.

In Foix MC-10, only one trend was observed, with a sediment accumulation rate of 0.083 ± 0.009 g·cm^{-2}·y^{-1}, whereas mixing was not present (Figure 4).

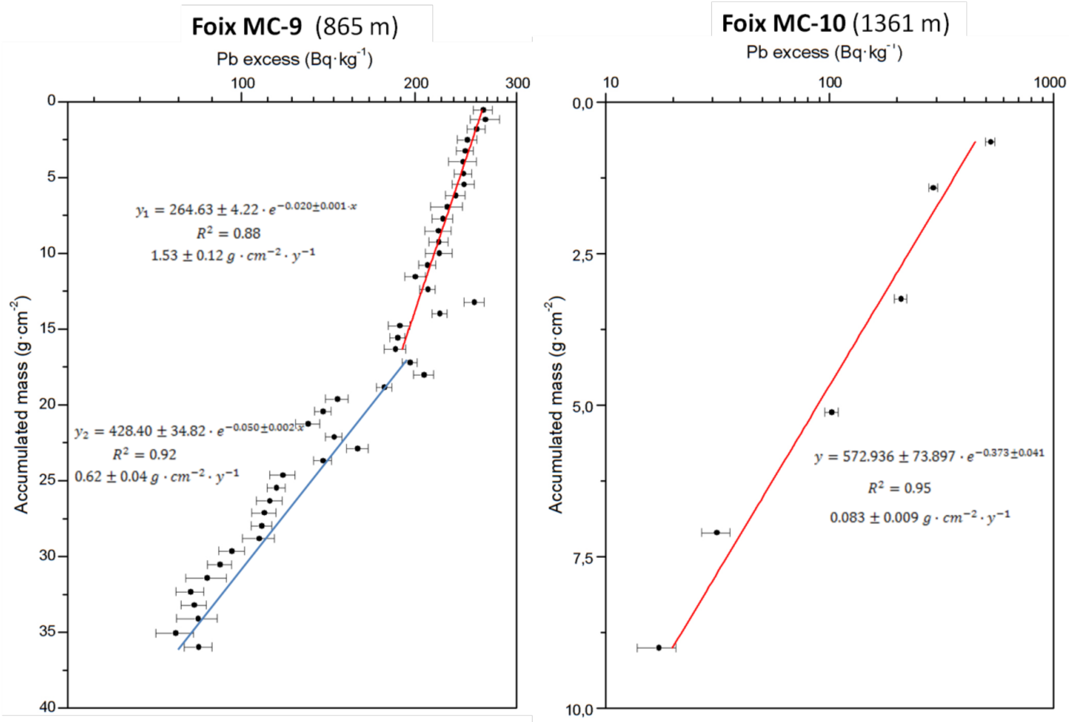

Figure 4 – $^{210}Pb_{ex}$ activity profiles of sediment cores collected in the Foix canyon, indicating the different sediment accumulation rates.

4.5 Evolution of sediment accumulation rates after 20 years.

The results obtained for core Foix MC-9 retrieved in 2013 were compared to those for core CN-36, collected in 1993 (Sanchez-Cabeza, *et al.*, 1993), from almost the same location (at a distance of 200 m).

The ^{210}Pb concentrations of core CN-36 were corrected to the date at which the MC-9 core was collected. The accumulated dry mass of CN-36 was then corrected based on the sediment accumulation rates of MC-9 (1.53 ± 0.12 g·cm^{-2}·y^{-1} and 0.62 ± 0.04 g·cm^{-2}·y^{-1}), to obtain a combined ^{210}Pb profile (Figure 5)

From the combined ^{210}Pb sediment, the bottom layers of MC-9 overlap with the top layers of CN-36, with equivalent sedimentation rates considering their uncertaintinities (Table 2). An increase in sediment accumulation rates is also detected, starting from 0.39 ± 0.13 g·cm^{-2}·y^{-1} to 0.62 ± 0.04 g·cm^{-2}·y^{-1} dated in the 1930s and a final increase in sediment accumulation rate of 1.53 ± 0.12 g·cm^{-2}·y^{-1} which began in 2002-2003.

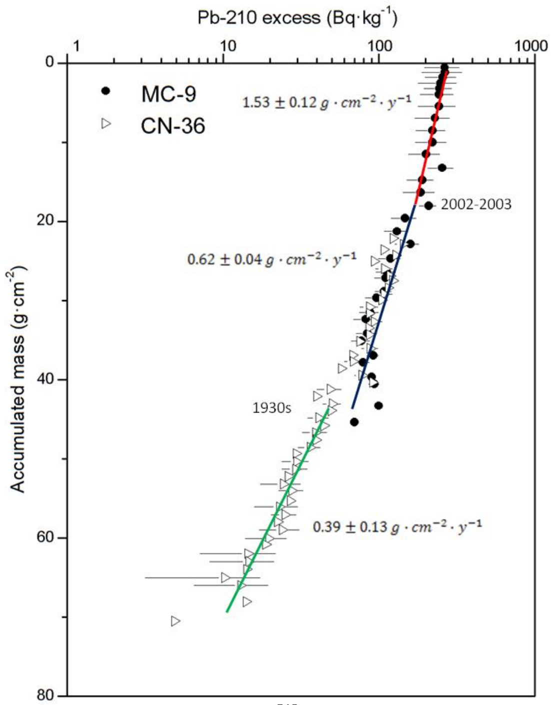

Figure 5 – Combined excess ^{210}Pb concentration profiles of MC-9 and CN-36.

Table 2 – Sediment accumulation rates of CN-36 and MC-9 cores of Foix canyon. Data of CN-36 was obtained from Sánchez-Cabeza et al., 1999.

	Range (cm)	Accumulation rate ($g \cdot cm^{-2} \cdot y^{-1}$)
CN-36 (1993)	6 - 37	0.51 ± 0.02
	37 - 65	0.39 ± 0.13
MC-9 (2013)	0 - 22	1.53 ± 0.12
	22 - 44	0.62 ± 0.04

5. Discussion

No changes in sediment accumulation rates were detected in the Besòs Canyon. At Besòs I, independently of whether mixing was considered or not, the two sediment rates nearly have the same values, considering their uncertainties (Table 1; Figure 3), which indicates a similar sediment accumulation rate, 0.081 ± 0.005 $g \cdot cm^{-2} \cdot y^{-1}$ in the upper section of Besòs I and 0.076 ± 0.012 $g \cdot cm^{-2} \cdot y^{-1}$ in the lower section.

In between these two slopes there is a constant activity of ^{210}Pb of 109 ± 8 $Bq \cdot kg^{-1}$ (Figure 3). This constant activity was attributed to an avalanche of material from the canyon itself, such as a natural canyon-flank failure, since both the texture and the structure of the sediment core were the same. Considering Besòs II, sediment accumulation rates remained at 0.078 ± 0.004 $g \cdot cm^{-2} \cdot y^{-1}$ (Figure 5.7, Table 5.3), similar to both sediment accumulation rates quantified at Besòs I.

Even if no changes in sediment accumulation rates were recorded at the sites investigated in the Besòs Canyon, it does not imply that no changes in sedimentary dynamics have occurred over the last century. These effects may be localized, and thus, changes may be present but within the influence of fishing grounds at the canyon head, where fish-trawling activities occur to a greater extent along this flank of the canyon, as observed by Toro (2013) in Arenys Canyon. Further studies should be carried out at the head of the Besòs canyon to corroborate this hypothesis.

In Foix MC-9, an increase in sediment accumulation rate of 0.62 ± 0.04 $g \cdot cm^{-2} \cdot y^{-1}$ to 1.53 ± 0.12 $g \cdot cm^{-2} \cdot y^{-1}$ was detected 22 cm below the surface, which would have occurred in 2002-2003. This increase can be attributed to fish-trawling activities since, according to data obtained of fish-trawlers operating near the Foix canyon (Figure 2), there was an increase of the total number of vessels operating in the flanks of the Foix canyon, as well as the number of vessels with a main power greater than 400 CV, precisely in 2002-2003 (Figure 6). An increase in power is usually linked to the expansion of fishing grounds to greater depths (Ragnarsson and Steingrimsson, 2003), therefore, the influence of each of these parameters in sedimentary dynamics should be taken into account.

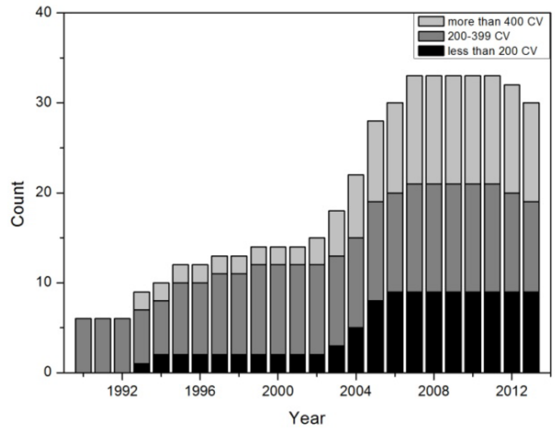

Figure 6 – Evolution of fish-trawlers operating near the Foix Canyon with its corresponding registered power (CV) 1990-2013. Source: *Fleet Register on the Net, European Union*.

After analyzing the evolution of sediment accumulation rates between CN-36 and MC-9, a remarkable increase in sediment accumulation rates can be observed from the combined ^{210}Pb profiles (Table 2; Figure 5). This continuous increase emphasizes the vulnerability of the canyon to suffer the impacts from increases in sediment resuspension due to, for example, fish-trawling activities. These resuspended sediments may then be intercepted by the canyon, which acts as a preferential conduit of sediments from the shelf to the slope (Puig and Palanques, 1998), thus leading to increases in sediment accumulation rate in the canyon axis.

The increase in sediment accumulation rates as one of the consequences of fish-bottom trawling was observed in some sites of the Arenys (Toro, 2013) and Palamós Canyons (Martín et al., 2008), occurring during the late seventies, when the fishing sector experienced a rapid industrialization. These findings contrast with those observed in the Foix canyon detected in the XXI century.

In all three canyons, Arenys, Palamós and Foix, an increase in sediment accumulation rates is detected in sites where fish-trawlers operate at the contiguous flank of the canyon (Martín *et al.*, 2008; Toro, 2013). On the other hand, samples that are retrieved from canyon axis where no fishing activity occurs in the adjacent canyon flank do not present an increase in sediment accumulation rate, which is the case of the samples of the Besòs Canyon (Figure 1 and 3).

In Arenys Canyon, only one site experienced an increase in sediment accumulation rate (Toro, 2013). In this canyon, resuspended sediments travel at least down to 1100 m depth, 1600 m away from the fishing grounds at the canyon flank, altering sediment accumulation rates at the Arenys 1 site (Toro, 2013). Similar to this, increase in sediment accumulation rate was detected in Foix MC-9, where dense fish-trawling activities occur (Figure 2 and 4). In contrast, when fishing does not occur in the contiguous eastern flank of the other sampling sites, no changes in sediment accumulation rates were detected, as is the case for Arenys 2 and 3 (Toro, 2013), and Foix MC-10 (Figure 2 and 4).

Concerning Palamós Canyon, changes in sediment accumulation rates were quantified at greater depths, 1750 m, and at greater distance from fishing grounds, almost 3 km (Martin *et al.,* 2008). This emphasizes how the presence of gullies in this canyon, as well as its steepness, may channel resuspended sediments toward greater depths as sediment gravity flows. (Martín *et al.,* 2014; Palanques *et al.,* 2006).

Given the ecological importance of canyons (Company *et al.,* 2012; Gili *et al.,* 1998, 1999, 2000; Marques *et al.,* 2005; Morais *et al.,* 2007; Pusceddu *et al.,* 2014), and in particular to their relevance in the life cycles of commercially targeted species (Stefanescu *et al*., 1994; Brodeur, 2001;), a sustainable management of fisheries in deep-sea environments should be implemented. Management should be aimed to reduce the impact of fishing activities to deep-sea ecosystems, as these are, in general, adapted to a limited variability of physical conditions, resulting in high vulnerability and low resilience from anthropogenic perturbations such as bottom trawling (Glover and Smith, 2003; Mc-Connaughey *et al.,* 2000).

Fishing management should take into account that the granulometric composition of sediments in continental slopes is finer, hence, if these particles are resuspended, their residence time in the water column is greater, creating nepheloid layers that cover great extensions and may reach greater depths, which may alter the ecological environment in the surroundings (Martin *et al.,* 2014).

Also, if fish trawling occurs at greater depths, heavier and bigger gears need to be dragged by more powerful engines, resulting in an enhanced capacity to impact the seafloor (Ragnarsson and Steingrimsson, 2003).

Finally, fishing bans should be adapted to the morphology of each canyon, since steep canyon environments may provoke strong sediment gravity flows (Puig *et al.,* 2012; Martín *et al.,* 2014), which would increase the impacts of this activity in sea-floor environments.

6. Conclusions

The results obtained in all canyons suggest that the impacts of fishing activities in sediment accumulation rates are localized and provide evidences for a recent increase in sediment accumulation rates at the beginning of the XXI century, contrasting with those detected in the seventies.

These impacts, induced by fish-trawlers, may reach greater distances and have a greater impact in sediment accumulation rates in canyon axis when this activity is carried out intensively along the flank of the canyon rather than when it occurs only at the canyon's head. Further on, canyon topography also plays an important role, since steep canyons can flush sediments down-canyon to greater distances such as in the Palamós and Foix canyons.

A shift in the paradigm of fishing practices should be taken into account given the variety and magnitude of derived impacts resulting from this activity, including sediment gravity flows (Palanques *et al*., 2006; Martin *et al*., 2006), reduction of the complexity of continental slopes (Puig *et al.,* 2012), as well as nutrient and food source availability, and specie biodiversity and biomass (Sañé *et al.,* 2013). Appropriate fishing management should be implemented and investigated, since the overall impact of trawling is still largely unknown, while the extension of continental slopes where fishing activities are taking place in the vicinities of steep environments such as submarine canyons, ridges, and seamounts has recently been estimated to be 4.4 million km^2 (Puig *et al*., 2012).

7. Acknowledgements

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