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## The distribution of scleractinian corals in the Bay of Biscay, NE Atlantic

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### Abstract:

Studies on the distribution of scleractinian corals in the Bay of Biscay were relatively numerous during the nineteenth and the first half of the twentieth century. Yet, recent reports are scattered, sometimes unpublished, and therefore knowledge about the current coral occurrence in the area is limited. This study aims at compiling the available historical and more recently collected information on the occurrence of scleractinian corals in the Bay of Biscay. Data from two recent cruises are included and compared with previous explored coral sites from as early as 1830 up to 1995. A database of 347 records including 34 described species of scleractinians highlights that the slope of the Bay of Biscay is an important habitat for scleractinians. This could be expected due to the high topographic relief providing the necessary hard substrate and accelerated bottom current flow that corals require. Further exploration of the occurrence and ecology of corals in the area is recommended to support the conservation of cold-water coral reefs along the European margin.

**Keywords:** Cold-water corals - Scleractinia - Slope - Bay of Biscay - Biodiversity

# 1. Introduction

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Cold-water coral distributions in both shallow and deep, bathyal settings are well studied along the European margins in the North-East Atlantic Ocean, in the Mediterranean Sea, and recently in the Strait of Gibraltar (Zibrowius 1980, 1983, 1985; Rogers 1999; Roberts et al. 2003; Álvarez-Pérez et al. 2005; Taviani et al. 2005; Hall-Spencer et al. 2007). In this way it is shown that cold-water coral assemblages have been recorded from the continental margin of the NE Atlantic more frequently than from any other place in the world (Roberts et al. 2006). Yet, the NE Atlantic margin consists of many different marine environments and scientific documentation about the distribution of corals in each segment varies considerably. Intensive exploration and investigation on the Norwegian margins (Mortensen et al. 1995; Hovland et al. 1998; Freiwald et al. 2002; Lindberg and Mienert 2005; Fosså et al. 2005) was certainly facilitated through the relative shallow coral occurrences in some fjords and on various shelf banks, often less than 400 deep (Fosså et al. 2005). This has shed some light on the distribution, the biology and the geological settings of these coral ecosystems. The continental margin off Ireland and the UK with its hundreds of coral banks in water depths between 650 and 1000 m recently emerged as a hotspot of integrated multidisciplinary research at European scale (Van Weering et al. 2003; Weaver et al. 2004; Huvenne et al. 2003, 2005; Foubert et al. 2005; De Mol et al. 2002, 2005; Wheeler et al. 2005, 2007; Roberts et al. 2006). Further south, the Bay of Biscay was already an authentic hotspot for oceanographic exploration since the end of the 19<sup>th</sup> century until the 1950's. In the first decades of the 20<sup>th</sup> century, this wide area was regularly visited by French biologists who made a detailed investigation on the distribution and associated biodiversity of large coral reefs present in this area: the so-called 'massifs coralliens' (Joubin 1922a, b, 1923; Le Danois 1948). However, it is not known to which extent the available historical information represents the actual distribution of corals in the area, since the status of previously recorded coral locations may have completely changed (Hall-Spencer et al. 2007). Zibrowius et al. (1975) and Zibrowius (1980, 1985) already pointed to the presence of isolated patches of corals in the area with new observations of scleractinians from the French BIOGAS and INCAL expeditions to the Bay of Biscay. The latest species compilation of Cnidaria, including a list of Scleractinia, was published by Altuna (2006). Yet, information is scattered through various reports, while many scientific results remain unpublished resulting in a paucity of updated documentation for the Bay of Biscay (ICES 2003, 2004).

It is generally accepted that the Biscay region represents a suitable habitat for corals (Hall-Spencer et al. 2007). The presence of hard substrates has been observed to be essential for coral reef formation both in shallow-water and the deep sea (Dodge and Vaisnys 1977; Rogers 1990). Also a high bottom current flow, necessary for the delivery of food and larvae, as well as for the removal of waste and the excess of sediments (Grigg 1984) have been considered as critical for reef development. Many observations indicate that scleractinians indeed occur in areas where the interaction between currents and topography can generate accelerated flow (Rogers 1999; De Mol et al. 2002; Freiwald et al. 2004; Mienis et al. 2006). Further, it is likely that periodic oscillations in the vertical stratification of water density (internal waves) are important for corals. They indeed result in increased vertical and bottom mixing within the vicinity of the shelf break when interacting with the seabed. In this way, the influence of internal waves in controlling the particulate food supply by increasing resuspension of organic matter, has been described by Frederiksen et al. (1992). Finally the presence of nutrient-rich waters that stimulate high phyto- and zooplankton productivity, are providing a major food source for the corals (Freiwald et al. 2004). Given the notorious current-swept steep slope of the Bay of Biscay, cut by numerous canyons (Le Suavé et al. 2000; Bourillet et al. 2003, 2006; Zaragosi et al. 2006), it is expected that the water mixing over the slope may result in enhanced suspended material and indeed favours high concentrations of planktonic biomass which can sustain the coral growth.

This paper provides an overview of observations on scleractinian reef framework-forming species (stony corals) along the slope of the Bay of Biscay based upon historical and recent reports. Coral reports from the last two centuries collected in the Bay of Biscay are assembled in a database and mapped in a Geographical Information System (GIS) environment. The historical context of the successive exploratory surveys conducted along the slope of the Bay of Biscay, as well as the evolution of our knowledge on scleractinians is briefly addressed. The data from two recent research cruises, along the Banc de la Chapelle and in the Penmarc'h Bank area (PB) in the North,

and the Cantabrian margin in the South are also included. The disparity of the size and species assemblage of the reefs observed in the past compared to present-day reports and the wide occurrence of dead cold-water coral fragments are reported.

The main objective is to identify the recent past and present-day distribution and the diversity of scleractinians in the Bay of Biscay. This is of particular concern considering the low genetic differentiation of deep-water corals subpopulations along the NE Atlantic continental margin (Le Goff-Vitry et al. 2004; Le Goff-Vitry and Rogers 2005), suggesting a sporadic gene flow through larval dispersal over long periods of time. At a time where bottom fishing damage continues partly because coral-rich areas remain poorly mapped, it is essential to identify the potential and the importance of this region for the long-term protection of the European continental slopes.

## 2. Material and methods

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### Study area

The present study area covers the continental shelf, the shelf break, bathyal and abyssal zone of the Bay of Biscay (from 90 to 4830 m), stretching from 43° to 49°N and from 0° to 11°W (Fig. 1a). The Atlantic margin in the Bay of Biscay can be subdivided into five geographic regions (Fig. 1a) with in the North the French Celtic and the Armorican margins, and in the South the French Aquitaine margin and the Iberian Cantabrian and Galician margins. The Celtic and Armorican margin display a relatively broad shelf from the coast to the shelf break (wider than 200 km) and a steep slope with an average gradient about 2.86 to 5.15° (Le Suavé et al. 2000; Lallemand and Sibuet 1986) which extends from a depth of about 200 m to 4000 m towards the abyssal plain. The Cantabrian margin has a narrow shelf (5 to 40 km wide) with a very steep continental slope (17°) between 500 and 4500 m. A few marginal shelves (with a steep 10-12° slope) have been identified (Álvarez-Marrón et al. 1995). The most renowned of these Cantabrian marginal shelves, in relation to stony corals, is the 'Le Danois Bank' (Le Danois 1948). From the Norwegian margin to the Portuguese margin, the overall steep European continental slope is characterized by the presence of a multitude of canyons (Weaver et al. 2000). More than 80 canyons cut the 810 km of the Biscay slope (Le Suavé et al. 2000; Zaragosi et al. 2000; Canals et al. 2004). The hydrography of the Bay of Biscay is characterized by the presence of four main water masses. The North East Atlantic Central Water (NEACW) occupies the top 800 m of the water column. The large salinity maximum at 800-1200 m depth corresponds to the Mediterranean Outflow Water (MOW). Between approximately 1200 and 3000 m the North East Atlantic Deep Water (NEADW) is present, including the Labrador Sea Water (LSW) and the Iceland- Scotland Overflow Water (ISOW) (McCartney 1992). The LSW is recognized by a small salinity minimum at 1800-2000 m, and a small salinity maximum identifies the ISOW at ~2600 m. The deepest water mass is the Lower Deep Water (LDW) (McCartney 1992). By definition, the different water masses should tend to mix very slowly. However, hydrological measurements of the salinity, temperature and turbidity at the Celtic Margin along the Meriadzek Slope from 2120 to 4700 m depth (Vangriesheim 1985), pointed to overall water mixing at the seafloor in association with a layer of resuspended particulate material of the same thickness. The Celtic-Armorican margin has a wide continental plateau with little terrestrial input and intensive vertical mixing at the shelf break providing enhanced primary production. In contrast, the Cantabrian-Galician margin is characterized by a narrow shelf with strong continental input and by seasonal upwelling with high primary production. An important feature of the Northeast Atlantic is the slope current that flows along the continental slope from the Bay of Biscay to the Norwegian Sea (Pingree and Le Cann 1990; Ellett 1995). The Mediterranean Outflow Water (MOW) also flows poleward (Dickson et al. 1985).

### Data origin

Historical records were extracted from the following sources: Joubin (1922a, b, 1923), Le Danois (1948), Zibrowius et al. (1975), Zibrowius (1980, 1985), Monteiro Marques and Andrade (1981), Álvarez-Claudio (1994) and Altuna (1995). Taxon, latitude, longitude, depth range and station identification were entered into a separate Microsoft Access database for each author, research vessel (R/V) and cruise. Arc Map 9.2 GIS was used to plot each dataset in a map to illustrate the

distribution of cold-water corals in the area (Fig. 1b). Records are given in chronological order. Joubin (1922b) and Le Danois (1948), when reporting “white coral sites”, did not make the distinction between the generally associated species *Madrepora oculata* (Linnaeus 1758) and *Lophelia pertusa* (Linnaeus 1758). The station list extracted from these sources and including *L. pertusa* and/or *M. oculata* are also not making the distinction between the two species and hence not in detail exploited.

The Banc de la Chapelle (BC) and the Cantabrian margin were revisited during respectively the R/V *Victor Hensen* VH-97 cruise in 1997 and the R/V *Belgica* GALIPOR cruise in 2004. During the VH-97 cruise (Freiwald and Henrich 1997) several Van Veen grab samples and dredges were collected in order to explore canyon heads near the BC and in the Penmarc'h Bank area (PB) in water depths between 167 and 790 m (Fig. 2). The sample locations were based on the report of Le Danois (1948) in the area between 47°32'30"N to 47°51'50"N and 7°12'30"W to 7°25'W (BC) and in the area between 46°58'20"N to 46°58'30"N and 5°27'80"W to 5°28'W (PB). A 30 kHz and 18 kHz single-beam echosounder was used for depth and morphologic control within the upper canyon heads and thalwegs. The R/V *Belgica* 2004 GALIPOR cruise near the Cantabrian margin focused on an area between 44°05'00"N to 44°10'00"N and 7°10'W to 7°20'00"W, a sector highlighted by Le Danois (1948) and by Álvarez-Claudio (1994), as being rich in coral banks (see Fig. 1b). The area was surveyed with Simrad E1002 multibeam ecosounder and sampled with box cores (Foubert et al. 2004). Box cores were taken with a type NIOZ boxcorer, 30 cm diameter. These box cores allowed detailed biological sub sampling faunal analysis (cold-water corals and associated fauna). These recent records were added to the general database and coral distribution map.

## Results

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### Historical data on scleractinian corals in the Bay of Biscay

In this section an overview is given on the oceanographic campaigns realized in the Bay of Biscay from 1830 to 1995 as well as on the evolution of our knowledge on scleractinians from this area during this period. Cold-water coral research published up to now is presented in Table 1 and Figure 1b, indicating depth and reported species. The authors provide a more detailed compilation of species, geographic coordinates, depth and their station codes as Electronic Supplement Material in the FACIES web site. Although the list is not exhaustive, it clearly demonstrates the wealth of data on distribution of corals in the Bay of Biscay, as well as the extent of the research activities taken in this area. Special attention will be given to major biogeographic areas where cold-water corals were repeatedly reported in the Bay of Biscay.

### Historical overview of campaigns in the Bay of Biscay

During the end of the 19<sup>th</sup> century and the first half of the 20<sup>th</sup> century the Bay of Biscay was explored by the most eminent oceanographers. Audouin and Milne Edwards conducted in 1830 the first oceanographic dredge surveys along the French coasts at different water depths (Le Danois 1948). The first deep-sea research campaigns in the Bay of Biscay began in 1870 with the British expeditions of the *H.M.S. Porcupine* (Duncan 1870, 1873, 1878) followed from 1890 to 1896 by the expeditions of the *H.M.S. Research* in the North of the Bay of Biscay and in 1906 of the *H.M.S. Huxley* (Hickson 1907) on the Little Sole and the BC (Le Danois 1948). The French government provided the R/V *le Travailleur* (1880, 1881 and 1882) (De Folin 1887), the R/V *le Talisman* (1883) and then the R/V *Caudan* (1896) to the scientific community represented by Milne-Edwards (1881a, b), Roule (1896), Marion (1906) and Gourret (1906).

In 1885 the Prince of Monaco Albert I began a series of expeditions in the Atlantic. His first oceanographic campaign took place on board of the R/V *Hirondelle* (1886-1887) along the French coasts and in the Bay of Biscay (Jourdan 1895). On board of the R/V *Princesse-Alice* (1891 to 1896), he explored the entrance of the English Channel and returned in the Bay of Biscay. It is onboard of the R/V *La Princesse-Alice II* (1903 and 1904) that sampled in total 150 stations in the Bay of Biscay and then the waters around Belle-Isle (1910). He explored for the last time the Bay of Biscay on board of the R/V *Hirondelle II* (1912, 1913 and 1914). The deep-sea corals collected during a series of campaigns between 1893-1913 were studied by Gravier (1915, 1920). Finally, in

1910, the Norwegian R/V *Michaël-Sars*, with John Murray carried out a small expedition in the Bay of Biscay.

With the aim to produce a map of cold-water coral reef occurrences in the North East Atlantic, Joubin (1922a, b, 1923) inquired fishermen from the ports of Lorient, La Rochelle and Arcachon in France to report on the sites where they encountered coral fragments in their nets.

The zoologist Le Danois, first in collaboration with Charcot on board of the R/V *Pourquoi-Pas?* (1912, 1913, 1914), then on board of the R/V *Perche* in 1920, the R/V *Tanche* from 1921 to 1928, and finally the R/V *President-Theodore-Tissier* from 1934 to 1939 sampled hundreds of stations along the French and Spanish coasts. During these investigations, he discovered the bank now bearing his name, Le Danois Bank.

During the following 30 years the Bay of Biscay only received occasional attention. Samples and collections coming from the expeditions on board of R/V *Job ha Zélian* (1963 to 1972), R/V *Thalassa* (1967 to 1973), R/V *Jean Charcot* "Gestlante 2" 1967, R/V *Jean Charcot* "Noratlante" 1969, R/V *Jean Charcot* "Hespérides" 1976, R/V *Walther Herwig* 1974-1975 and R/V *Sarsia* 1954 to 1976 were studied by Zibrowius et al. (1975) and Zibrowius (1980). Zibrowius et al. (1975) reported and described numerous stations with scleractinians in the NE Atlantic, including the Bay of Biscay. Stations from the Hespérides 1976 cruise off the Atlantic coast of the Iberian Peninsula were additionally reported from Monteiro Marques and Andrade (1981).

More intensive bathyal and abyssal research was resumed in the area in the framework of the French BIOGAS (Biology Gascogne) program, running from 1972 to 1981 (Laubier and Monniot 1985). Several selected stations within the northern and southern Bay of Biscay were visited during a total of 12 cruises on a variety of vessels including *La Perle*, *Jean Charcot*, *Cryos*, *le Noroit* and *Capricorne* (Zibrowius 1985).

From 1987 to 1990, a French-Spanish project was conducted in the Cap Breton canyon (SE Biscay margin) on board of the *Côte de Aquitaine* (CNRS) (Sorbe 1990). Two bathymetric zones were selected at respectively 70-400 m and 500-1000 m in order to follow up the investigations of Le Danois (1948). Altuna (1994, 1995) studied the bathyal Scleractinia from this campaign and summarized the state of knowledge on this taxon in the area.

Finally, 25 stations were sampled during the 1987 COCASE cruise (Central Cantabric Oceanographic Cruise) in a small area of the Cantabrian margin, studied by Álvarez-Claudio (1994).

### **Evolution of the knowledge on Scleractinians in the Bay of Biscay**

The majority of knowledge on corals reported from 1870 to 1920 (Duncan 1870, 1873, 1878; Milne-Edwards 1881a, 1881b; De Folin 1887; Jourdan 1895; Roule 1896; Marion 1906; Gourret 1906; Hickson 1907; Gravier 1915, 1920) is reviewed in Zibrowius (1980).

Joubin (1922a, b, 1923) mainly investigated the distribution of the two white coral species *L. pertusa*, which was at that time still called *Lophohelia prolifera*, and *M. oculata* called *Amphihelia oculata*. Also information on the coral species *Dendrophyllia cornigera* (Lamarck 1816) and *Dendrophyllia ramea* (Linnaeus 1758) were provided. He reviewed a total of 70 cold-water coral reef reports in the Bay of Biscay and described massive cold-water coral reefs so large and dense that fishermen fishing in these waters were afraid to damage their nets.

Le Danois (1948) also described the distribution of *L. pertusa* and *M. oculata*, while he recognized them as the two main reef forming species. Also *Desmophyllum dianthus* (Esper 1794), *Caryophyllia smithii* (Stokes and Broderip 1828) and *Flabellum alabastrum* Moseley, 1873 are often found associated with these framework-builder species (Le Danois 1948). Furthermore, the yellow coral *D. cornigera* was mentioned in this work as well. Usually forming low patches with a mean size of about 30 cm, this species occurred in large quantities within large patches of white corals. Among some isolated patches, Le Danois further identified five sites where the density of these species was high enough to form coral reefs along the margins of the Bay of Biscay: the "Massif du Banc de la Chapelle" (a surface of about 3500 km<sup>2</sup>), the much smaller "Massif de la Grande

Vasière" (south of Armorican Margin, with a length of 180 km), the "yellow coral" "Le Danois Bank" or "Massif Cantabrique", the "Massif Galicien de l'Est" (situated about 7°W) and the "Massif Galicien de l'Ouest" (stretching from 9°00 to 9°40').

Zibrowius et al. (1975) reported eight scleractinian species associated with the polychaete *Lumbriconereis flabellicola* (Fage 1937). In 1980 he reported thirty-four coral species from the Bay of Biscay including shallow-water species. In 1985, he reviewed the collections from the more recent cruises conducted in the Bay of Biscay (Programmes BIOGAS and POLYGAS, INCAL) and reported 11 species of scleractinians (Zibrowius 1985). The coral fauna from station 1 BIOGAS (1920-2350 m, northern Biscay margin) was characterized by a very high abundance of *Caryophyllia ambrosia* Alcock 1898 (2000 to 3000 individuals collected in one trawl) and *Premocyathus cornuformis* (Pourtalès 1868) and by the lower abundance of *Stephanocyathus nobilis* (Moseley 1873), *F. alabastrum* Moseley 1873 (about 200 living individuals) and *Flabellum angulare* Moseley 1876. Zibrowius (1985) identified this coral assemblage as typical for soft bottoms. He described BIOGAS station 6 (1894-2430 m, southern Biscay margin) as a site of harder substrates where typical hard-bottom species were collected. Grasshoff (1981a, b) already concluded the same through the study of other groups of Anthozoa, mainly Octocorallia. At the deepest stations (>4000 m) a single species was collected, *Fungiacyathus marenzelleri* (Vaughan 1906).

Álvarez-Claudio (1994) reported 1100 cold-water coral specimens in a depth range from 50 to 1347 m, belonging to 15 scleractinian species and 5 families. The analysis of the scleractinian species richness in the small sampling area of Cantabrian margin showed that only a few scleractinian species, such as *C. smithii*, settled on soft sandy shelf bottom substrates. On the contrary, in deeper areas where the slope was less steep and bottoms were composed of very fine sand and mud, the scleractinian fauna was more diverse, comprising 5 to 7 species within *L. pertusa* and *M. oculata* banks. Álvarez-Claudio (1994) reported *C. smithii* (depth 146-468 m), *Caryophyllia abyssorum* Duncan 1873 (depth 702-1189 m) and *L. pertusa* (depth 702-1347 m) as the most commonly represented species along the Cantabrian margin and *D. cornigera* as the most shallow occurring species (50 m).

Altuna (1995) found seven species in total. He reported *Fungiacyathus fragilis* Sars 1872 for the first time in the Bay of Biscay. Numerous colonies and fragments of *L. pertusa* and *M. oculata* were obtained at 948 m water depth. *Caryophyllia seguenzae* Duncan 1873 was also very frequently present in some stations.

According to the biogeographic analysis of Cairns and Chapman (2001), who compiled all data available at that time, a third of the scleractinian species that are known to occur in the two deep-water coral provinces embracing the Bay of Biscay (1. province: from North Sea to northern Bay of Biscay; 2. province: southern Bay of Biscay) are endemic to the eastern Atlantic, while the others are amphi-Atlantic. Table 1 lists 34 scleractinian species collected from the Bay of Biscay in about 350 stations (see Fig. 1b). Eight species are colonial (23.6 %) and were present on most sampling sites. *Lophelia pertusa* was encountered on 102 (29.1 %) stations, followed by *Madrepora oculata* on 86 (24.6%) and *Dendrophyllia cornigera* on 36 (10.3 %). Amongst the solitary corals, *Caryophyllia smithii* (28 stations, 8 %), *Desmophyllum dianthus* (25 stations, 7.1 %) and *Caryophyllia seguenzae* Duncan 1873 (24 stations, 6.9 %) represent the most commonly found species (Table 1). A detailed account on species, depth ranges and stations is provided as Electronic Supplementary Material species-wise and can be downloaded from the journal's online documentary website.

## New data

The grab samples (Fig. 2) on the shallow sandbank dominated top of the BC area, yield quartz sands rich in the solitary scleractinian *C. smithii*. In the deeper canyon heads, grab sampling often failed due to rough seabed morphology. Dead colonies of *L. pertusa*, *M. oculata* and *D. dianthus* occurred from 340 (few) to 790 m (abundant). No living scleractinians were encountered. Further south, the outer Penmarc'h Bank was also explored (Fig. 2) but here, only Late Pleistocene *C. smithii* specimens were found which yielded calibrated U-Th ages of  $13960 \pm 120$ ,  $13060 \pm 240$  and  $11170 \pm 180$  a BP (Schröder-Ritzrau et al. 2005) at 240 m. The only live coral in this area were colonies of *D. cornigera* ("coral jaune") (Fig. 3).

Along the Cantabrian margin, three out of 32 boxcores were filled with dead coral fragments. *M. oculata*, numerous small pieces of *Lophelia* and one fragment of *D. dianthus* were observed.

### 3. Discussion

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Worldwide it is aimed for a better understanding of coral distributions and the factors that regulate them, in order to manage these ecosystems more effectively (Cairns and Chapman 2001; Hall-Spencer et al. 2007; Bryan and Metaxas 2006, 2007; Davies et al. 2007). The NE Atlantic has the most extended historical literature available on deep-water corals. Out of 347 historical and new records, this study reports in total thirty-four species of scleractinians in the Bay of Biscay (see Table 1). The extraction of bathymetric information from these records shows a characteristic 'shallow-water' coral assemblage which is found on the shelf and incised upper canyon heads. From 10 to 500 m water depth, *Balanophyllia cellulosa*, *Caryophyllia smithii*, *Dendrophyllia cornigera* and *Paracyathus pulchellus* forms a characteristic neritic community (Fig. 4). A transitional group of corals exists on the outer shelf edge canyon heads at around 200 m and upper slope down to 2000 m water depth. Thus group consists of *Balanophyllia thalassae*, *Caryophyllia calveri*, *Deltocyathus moseleyi*, *Desmophyllum dianthus*, *Dendrophyllia alternata*, *Eguchipsammia cornucopia*, *Stenocyathus vermiformis*, *Stephanocyathus crassus*, *Lophelia pertusa* and *Madrepora oculata* (Fig. 4). The latter two framework-building species show a wide depth range from 200 m down to 2000 m, however the majority of findings is in the shallow canyon heads (200-400 m depth interval). Corals confined to the upper slope from 500 to 3000 m are *Anomocora fecunda* (1000 m), *Caryophyllia abyssorum* (600-1400 m), *C. Ambrosia* (1600-3000), *C. atlantica* (1200-1500), *C. cyathus* (700-800), *C. sarsiae* (500-1100 m), *C. seguenzae* (1000-2100 m), *Deltocyathus conicus* (1100-2500 m), *Enallopsammia rostrata* (1000-2500 m), *Flabellum alabastrum* (800-2500 m), *F. macandrewi* (800-1000 m), *Fungiacyathus fragilis* (1000-1900 m), *Javania cailleti* (1200-2500 m), *Premocyathus cornuformis* (700-2400 m), *Solenosmilia variabilis* (700-2500 m), *Stephanocyathus moseleyanus* (1000-1700 m), *S. nobilis* (1500-2500 m) and *Vaughanella concinna* (1200-2500 m). True deep bathyal corals are *Flabellum angulare* (1900-3900 m) and *Fungiacyathus marenzelleri* (1900-4900 m) (Fig. 4).

Based on the reports of Joubin (1922a, b, 1923), Le Danois (1948), Zibrowius et al. (1975), Zibrowius (1980, 1985), Monteiro Marques and Andrade (1981), Álvarez-Claudio (1994) and Altuna (1995) scleractinian corals appear to cluster in several key regions: the Meriadzek Terrace (MT), the Banc de la Chapelle (BC), the Aquitaine margin, the Cap Breton Canyon, Le Danois Bank and the Cantabrian-Galician margin (Fig. 1b). The boxcore samples acquired both from the BC area in 1997 and from the Cantabrian-Galician margin in 2004 contained a large amount of dead fragments and coral rubble rather than pieces of living corals. Yet, the same coral reef building species as the ones described by Le Danois (1948), i.e., the triad *L. pertusa*, *M. oculata*, *D. dianthus* were retrieved. A few live specimens of *D. cornigera* were observed in the BC (Fig. 3). However, the sampling intensity was certainly not enough to formulate a final statement on the presence of healthy corals, both in the BC and the Cantabrian-Galician margin. Moreover, the steep Biscay slope proved difficult to be sampled. Some coordinate shifts from the ones provided by Le Danois were observed in the Cantabrian-Galician margin. The source of inaccuracy in estimating the distribution of *L. pertusa* in this region may lie in the combination of the very steep topography of the slope, as well as in the randomly located transects, relative to isolated occurrences of these reefs.

It is likely that localized regions characterized by stronger bottom currents exist that may support the development of coral colonies and their associated assemblages in the area. There are few direct measurements of currents in the Bay of Biscay. However, the range of bottom current velocities can vary from 19.7 cm s<sup>-1</sup> at a shallow (2120 m) to 4.6 cm s<sup>-1</sup> at deep (4700 m) locations at the northern Bay of Biscay (Vangriesheim 1985). These data suggest bottom currents greater than 15 cm s<sup>-1</sup> at shallower depths (<1500 m), where corals are found in high abundance. This velocity is indeed a likely threshold for resuspension of surface sediments in the NE Atlantic continental margin (Thomsen and Gust 2002). Ripple marks were also observed on the Meriadzek Terrace indicating the presence of strong bottom currents (Laubier and Sibuet 1977). These bottom currents, strong enough to resuspend the sediment may be related to internal tides (internal waves

of tidal frequency) mainly occurring along the canyon axis (Gardner 1989). Indeed strong, localized internal tides in the Bay of Biscay (New 1988) result from a combination of a favourable stratification, a steep topography and strong barotropic tidal currents directed cross-isobath (Cartwright et al. 1980; Baines 1982; Pingree et al. 1986; Le Cann 1990; Pingree and New 1991). At the bottom within the canyons, such as the Shamrock Canyon (north of Meriadzek Terrace), water mixing is responsible for resuspension of organic matter (Vangriesheim 1985). The canyons, mostly erosive and thus not filled with sediments (Le Suavé et al. 2000) probably induce locally strong currents and mixing which is essential for the corals to flourish. On the Nova Scotia margin fishermen identified canyons as sites where dense gorgonian coral assemblages were thriving (Breeze et al. 1997). The significance of submarine canyons as coral habitats (Mortensen and Mortensen 2005) may be due to their capacity to accumulate organic debris (Vetter and Dayton 1998), which may directly benefit to suspension feeders. Submarine canyons are known to support high densities and diversity of megafaunal organisms (Hecker et al. 1980; Tyler and Zibrowius 1992), in greater abundance than in nearby slope areas (Hecker et al. 1980; Harrison and Fenton 1998; Vetter and Dayton 1998). Valuable reports are provided on higher fish occurrences in canyons and in relation to micro topography (Lorance et al. 2002). Other examples document rich populations of stalked crinoids, *Diplocrinus whyvillethomsoni* (Conan et al. 1981) and pectinid bivalves (Schein 1989) on the bathyal slope of the Bay of Biscay. It is likely that this water mixing above the seabed results in enhanced levels of suspended material and favours higher concentrations of filter/suspension feeders. Indeed, high faunal biomass occurs especially where internal waves result in an increase in suspended material (Rex 1981). Additionally, there appears to be a direct link between higher coral densities and high productivity levels in the overlying surface waters (White et al. 2005, 2007). The rapidly sinking seasonal blooms of surface primary production have been observed to have an effect on the reproductive biology of benthic invertebrates (Billett et al. 1983; Rice et al. 1991; Waller and Tyler 2005). A mass seasonal deposition of aggregated phytodetritus to the ocean floor was revealed for the first time at the Porcupine Seabight (Rice et al. 1991). It was also observed at a variety of other continental margin sites in the NE Atlantic, including the carbonate mounds in UK waters (Rockall Trough) (Kenyon et al. 2003) and on the Galicia Bank (Duineveld et al. 1994). Each year from May to September, the Celtic-Armorican shelf break exhibits a summer surface cooling of 0.5-1.5 °C (Dickson et al. 1980; Pingree et al. 1982), coupled to high chlorophyll levels (Pingree et al. 1986) and to an augmentation of new production. A seasonal recurring upwelling of cold waters is thought to be mainly due to the propagation of exceptionally large internal waves, generated by the interaction of strong barotropic tidal currents with the steep shelf break topography (Dickson et al. 1980; Pingree et al. 1986). On the Cantabrian margin, the surface currents generally flow eastwards during winter and spring and change westwards in the summer. These changes in the direction of currents produce seasonal coastal upwelling. A combination of (a) a high production in the surface waters (Dickson et al. 1980; Pingree et al. 1982), (b) the availability of suitable seabed surfaces for reef formation, and (c) favourable hydrodynamic conditions (New 1988; Le Cann 1990) to produce enhanced bottom currents and to promote the transport of organic material to the seafloor is probably responsible for the occurrence of a dominant fauna of filter and suspension-feeders in the Bay of Biscay.

Besides cold-water corals, also a high diversity and abundance of associated species assemblages were found in the Cantabrian-Galician region. Dead shells of the bivalves *Spondylus gussoni* (Costa, 1829) and *Lima marioni* (Fischer, 1882) were identified in large quantities. Echiurids (*Bonellia viridis* Rolando, 1821), polychaetes (*Eunice* spp.), molluscs (*Limopsis aurita* Brocchi, 1814), *Delectopecten vitreus* (Gmelin, 1791), crustaceans (*Munida sarsi* Huus, 1935), and many commercial fish are reported in a high quantity along the Cantabrian-Galician margin. Although no species is actually stated as restricted to cold-water corals, these species are frequently found associated with cold-water corals (Jonsson et al. 2004; Freiwald et al. 2004; López Correa et al. 2005; Henry and Roberts 2007). A unique highly diverse and abundant suprabenthic community was also observed on Le Danois Bank. Also a species of crustacean, new to science was reported too (Guerra-García et al. 2008). Finally, sponges are reported with high abundance (Le Danois 1948; Sánchez et al. 2002; Guerra- García et al. 2008). As major filter feeders, they may benefit from the same topographic and hydrological conditions required by stony corals. Some are used to discriminate on- and off-mound habitats in the NE Atlantic (Henry and Roberts 2007).



The presence of probably larger amounts of coral rubble beds in the area is yet a critical issue, i.e., on Le Danois Bank. Live corals indeed attract a huge international attention (Roberts et al. 2006). Yet, dead and live coral reefs are inevitably associated with each other. Both are co-occurring on carbonate mounds along the continental margin of the NE Atlantic (Van Weering et al. 2003; Huvenne et al. 2005; Foubert et al. 2005; De Mol et al. 2002, 2005) and both participate to the reproductive cycle of coral reefs (Wilson 1979). Hard substrate on which to attach such as coral rubble and dead fragments is fundamental for any putative recolonization (Freiwald and Wilson 1998). The numerous dead cold-water corals may hence play a critical role for colonization by larvae from neighbouring isolated coral reefs in the Bay of Biscay (Roberts et al. 2006). Besides, there where live cold-water corals mainly provide protection and even nurseries for some mobile species (Rogers 1999), dead stony corals have been observed to provide a substrate for an associated fauna which is even more diverse (Mortensen et al. 1995; Freiwald 2002). It is likely that coral skeleton, found in high quantity in the area, provide additional hard substratum for attachment of epifaunal organisms. Conversely, disturbance of coral remnants prevents the maintenance of an area free of resuspended sediment and may even provoke polyp suffocation. In shallow water, Dodge and Vaisnys (1977) have shown that extended dredging operations have had a destructive effect on coral communities. Damage in cold-water coral areas inflicted by significant coral by-catch when trawling is well documented in the Porcupine Seabight (Hall-Spencer et al. 2002; Grehan et al. 2005). Genetic analysis of populations in the Darwin mound province, NE Rockall Trough (Masson et al. 2003) revealed the least genetic diversity of any of the sites in the NE Atlantic (Le Goff-Vitry et al. 2004). Reproductive analysis studies also showed that no reproductively active polyps in *L. pertusa* taken from the Darwin mounds were here observed (Waller and Tyler 2005). Intense trawling areas were actually observed in this area (Hall-Spencer et al. 2002). It was hypothesized that the damage from these operations may impede *L. pertusa* to reach the size necessary for gametogenesis (Waller and Tyler 2005). Many scleractinian colonies indeed have to reach a certain size before acquiring reproductive maturity (Szmant 1986), while stress may reduce reproductive output, and even cause death in some cases (Brown and Howard 1985). A small, but non-permanent deep-sea fishery (e.g. *Hoplostethus atlanticus* Collett 1889, commonly named orange roughy) is established off France in the Bay of Biscay (Koslow et al. 2000). Fishermen, mainly looking for orange roughy, mainly within the vicinity of canyon heads in the northern part of the Bay of Biscay (47° N/ 49°N), report living *L. pertusa* by-catch until 1100 m (Le Guilloux personal observation). Anthropogenic impact on this area, e.g. in terms of fishery has not yet been addressed so far. The consequences may be of a great extent because the fishing activity occurs within a narrow continental margin. Yet the steep topography could partially protect the coral communities by their inaccessibility for benthic trawling. However, it is also possible that many of the reefs of the Bay of Biscay may have been like in other areas, obliterated by slumping and erosion (Gage and Tyler 1991). There has actually recently been an increase in evidence that deep-water reefs are fragmented (Rogers 1999; Waller and Tyler 2005). Yet localized regions of high coral abundance exist that may support cold-water coral recolonization. Genetic and phylogeographic analysis of deep-water corals in the NE Atlantic (Le Goff-Vitry et al. 2004; Le Goff-Vitry and Rogers 2005) suggest that *L. pertusa* does not form a panmictic population. Instead, there is a high genetic differentiation between subpopulations in fjords and those offshore. Along the NE Atlantic continental margin, the genetic differentiation can be regarded as moderate suggesting sporadic, but not continuous, gene flow through larval dispersal over long periods of time. These last genetic analyses actually suggest that a certain genetic cohesion is maintained through larval dispersal over the slope of the Bay of Biscay. Consequently, the Biscay margin presumably acts as a semi-continuous habitat for larval dispersal of stony corals. The species distribution analysis of Cairns and Chapman (2001) also highlights that the Bay of Biscay nicely fits into the NE Atlantic biogeographic cluster. The wide Bay of Biscay canyons and slopes may hence represent a stepping-stone for dispersal. Indeed due to its central position within the European margins and in a scenario of a possible recolonization, the relative importance of the Bay of Biscay for the global distribution of cold-water coral reefs in the NE Atlantic is highlighted. The Bay of Biscay sits as a crucial and obligate transit route for cold-water coral colonization, from or to the Mediterranean Sea and to the NE Atlantic. During interglacial periods, deep and intermediate-water flow is directed poleward along the NE Atlantic continental margins (Kenyon 1986), thus supporting a northward migration of deep-water corals. The opposite, a southern retreat of corals and other shelly benthic invertebrate assemblages from northern to southern latitudes occurred during the transition from warm to cold climatic conditions. This phenomenon is evidenced by the immigration of a boreal fauna into the Mediterranean Sea, both in shallow and deep-water environments (Taviani et al. 1991; Schröder-Ritzrau et al. 2005). In this sense, the “boreal guests” in the

Mediterranean Sea found a refugium to survive and to expand distribution back into the Atlantic, when climatic conditions switched back to an interglacial mode. It is tempting to suggest, that Mediterranean deep-water coral dispersal into the NE Atlantic was supported by the oceanographic circulation that carried the genetic information from Gibraltar as far north as to the Barents Sea (De Mol et al. 2005). Establishment of water masses of different properties might have introduced larvae of the cold-water corals to the northeast Atlantic and initiated the carbonate coral mounds in the Porcupine Seabight (Mol et al. 2002, 2005). After the Last Glacial Maximum between 14 to 10 ka BP, corals began to recolonize the Bay of Biscay canyons and open slopes and settled on the pre-existing mounds in the Porcupine Seabight and Rockall Trough (Frank et al. 2005; Schröder-Ritzrau et al. 2005). Late Pleistocene scleractinians, 14-11 ka BP (Schröder-Ritzrau et al. 2005), as well as primnoid octocorals about 11 ka BP (Noé et al. 2007) recovered in the BC and the Cantabrian-Galician margin, offer new data to get a better insight into the migration pattern in space and time and the relation between the Atlantic and Mediterranean coral communities.

## Conclusions

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The compilation of historical information on deep-water habitats provided a wealth of information about scleractinian distribution in the Bay of Biscay. Considering the several cold-water coral rich areas as potential stepping-stones for larval dispersal, it highlights the need for additional visual surveying and mapping for cold-water corals in the area. Indeed at a time where more advanced seabed mapping and sampling tools are now more accessible than ever before, it is highly recommended to get deeper insight into the current state of cold-water corals over the whole Bay of Biscay. The Bay of Biscay is an integral sector of the European Margin, therefore better knowledge about corals in the area will help to take decision on the management and the conservation of the deep-water coral environment along the European continental margins.

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## Tables

Species	Depth [m]	<i>n</i>	Coloniality
<i>Anomocora fecunda</i> (Pourtalès, 1871)	1000	1	C
<i>Balanophyllia cellulosa</i> Duncan, 1873	137-463	5	S
<i>Balanophyllia thalassae</i> Zibrowius, 1980	380-1150	12	S
<i>Caryophyllia abyssorum</i> Duncan, 1873	600-1340	13	S
<i>Caryophyllia ambrosia</i> Alcock, 1898	1520-2940	8	S
<i>Caryophyllia atlantica</i> (Duncan, 1873)	1107-1470	6	S
<i>Caryophyllia calveri</i> Duncan, 1873	200-1050	7	S
<i>Caryophyllia cyathus</i> (Ellis and Solander, 1786)	695-760	1	S
<i>Caryophyllia sarsiae</i> Zibrowius, 1974	500-1100	7	S
<i>Caryophyllia sequenzae</i> Duncan, 1873	910-2100	24	S
<i>Caryophyllia smithii</i> Stokes and Broderip, 1828	118-468	28	S
<i>Deltocyathus conicus</i> Zibrowius, 1980	1100-2430	4	S
<i>Deltocyathus moseleyi</i> Cairns, 1979	532-1372	9	S
<i>Dendrophyllia alternata</i> Pourtalès, 1880	450-688	2	C
<i>Dendrophyllia cornigera</i> (Lamarck, 1816)	50-620	36	C
<i>Desmophyllum dianthus</i> (Esper, 1794)	310-2350	25	S
<i>Eguchipsammia cornucopia</i> (Portalès, 1871)	330-960	7	C
<i>Enallopsammia rostrata</i> (Portalès, 1878)	915-2430	10	C
<i>Flabellum alabastrum</i> Moseley, 1873	800-2430	7	S
<i>Flabellum angulare</i> Moseley, 1876	1884-3800	8	S
<i>Flabellum macandrewi</i> Gray, 1849	790-930	3	S
<i>Fungiacyathus fragilis</i> Sars, 1872	910-1810	3	S

<i>Fungiacyathus marenzelleri</i> (Vaughan, 1906)	1884-4825	8	S
<i>Javania cailleti</i> (Duchassaing and Michelotti, 1864)	1200-2430	4	S
<i>Lophelia pertusa</i> (Linneus, 1758)	150-2000	102	C
<i>Madrepora oculata</i> (Linneus, 1758)	150-2000	86	C
<i>Paracyathus pulchellus</i> (Philippi, 1842)	121	1	S
<i>Premocyathus cornuformis</i> (Pourtalès, 1868)	700-2350	5	S
<i>Solenosmilia variabilis</i> Duncan, 1873	676-2430	10	C
<i>Stenocyathus vermiformis</i> (Pourtalès, 1868)	450-960	9	S
<i>Stephanocyathus crassus</i> (Jourdan, 1895)	476	1	S
<i>Stephanocyathus moseleyanus</i> (Sclater, 1886)	910-1570	14	S
<i>Stephanocyathus nobilis</i> (Moseley, 1873)	1430-2430	11	S
<i>Vaughanella concinna</i> Gravier, 1915	1175-2430	7	S

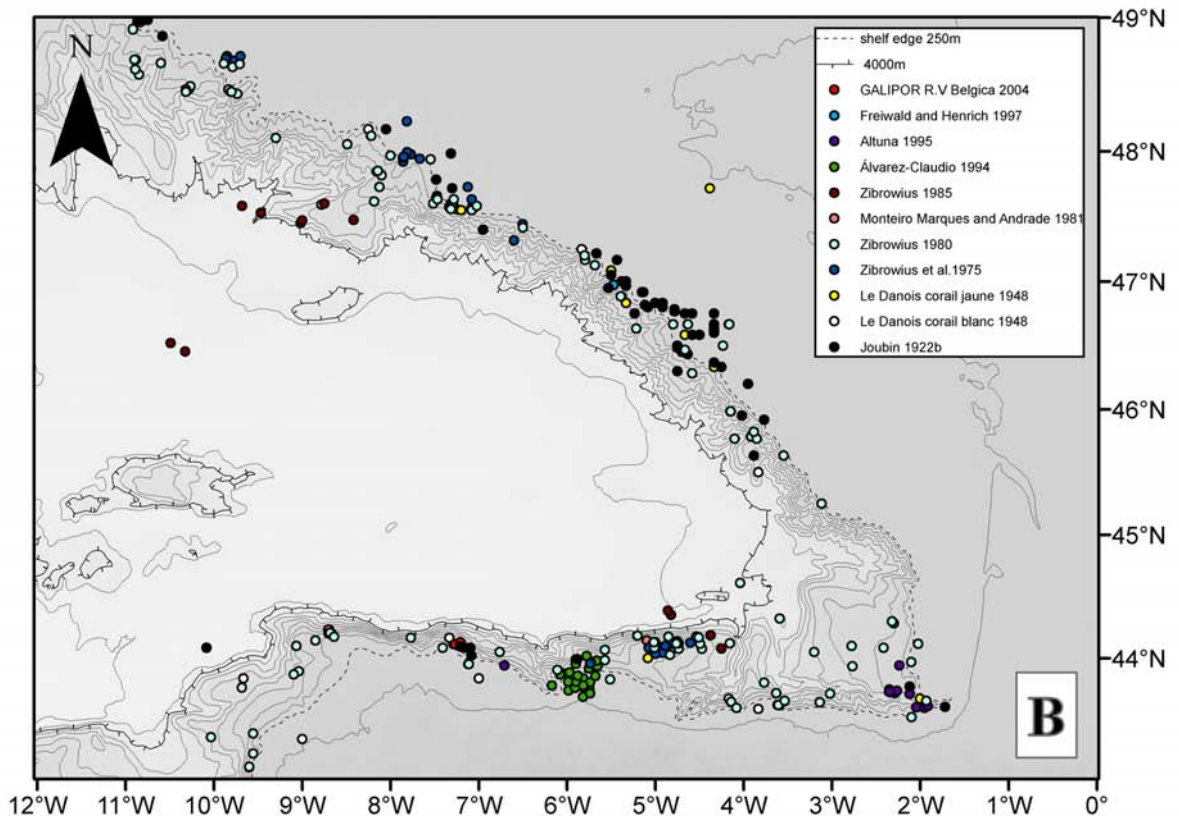
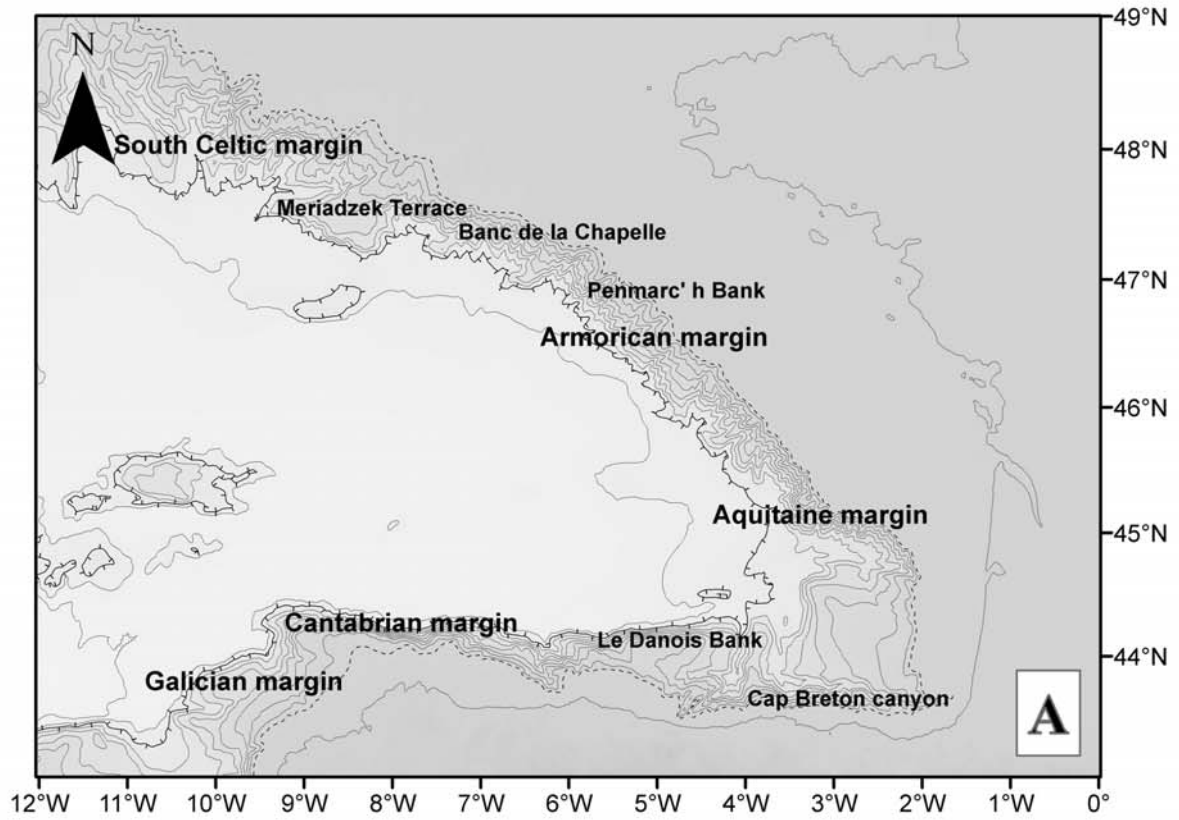
**Table 1** Scleractinian species reported from the Bay of Biscay outer shelves, canyons and slopes based on Cairns and Chapman (2001) and few other sources cited in the text with depth ranges, numbers of samples and information on coloniality (C = colonial, S = solitary)

Electronic Supplementary Material

Table with station coordinates and sampling depths of scleractinian corals from various research cruises dedicated to the Bay of Biscay, grouped by species

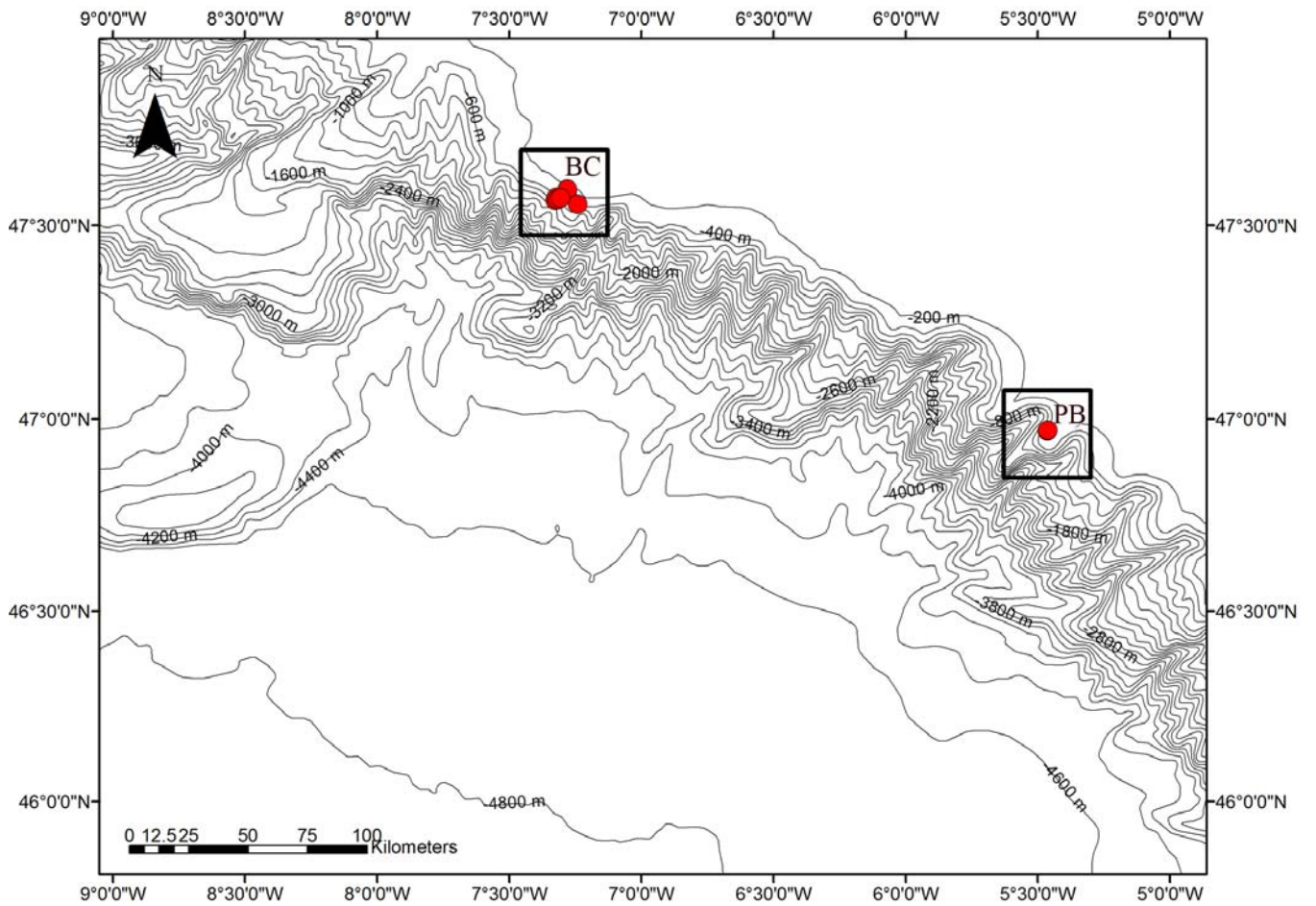
## Figures

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**Fig. 1a** The continental margin of the Bay of Biscay with geographic names used in the text. The shelf edge is on average at 250 m (dashed line) and the foot of the continental margin is at 4000 m water depth (crossed line). Spacing of contour lines is 500m. **b** Findings of cold-water

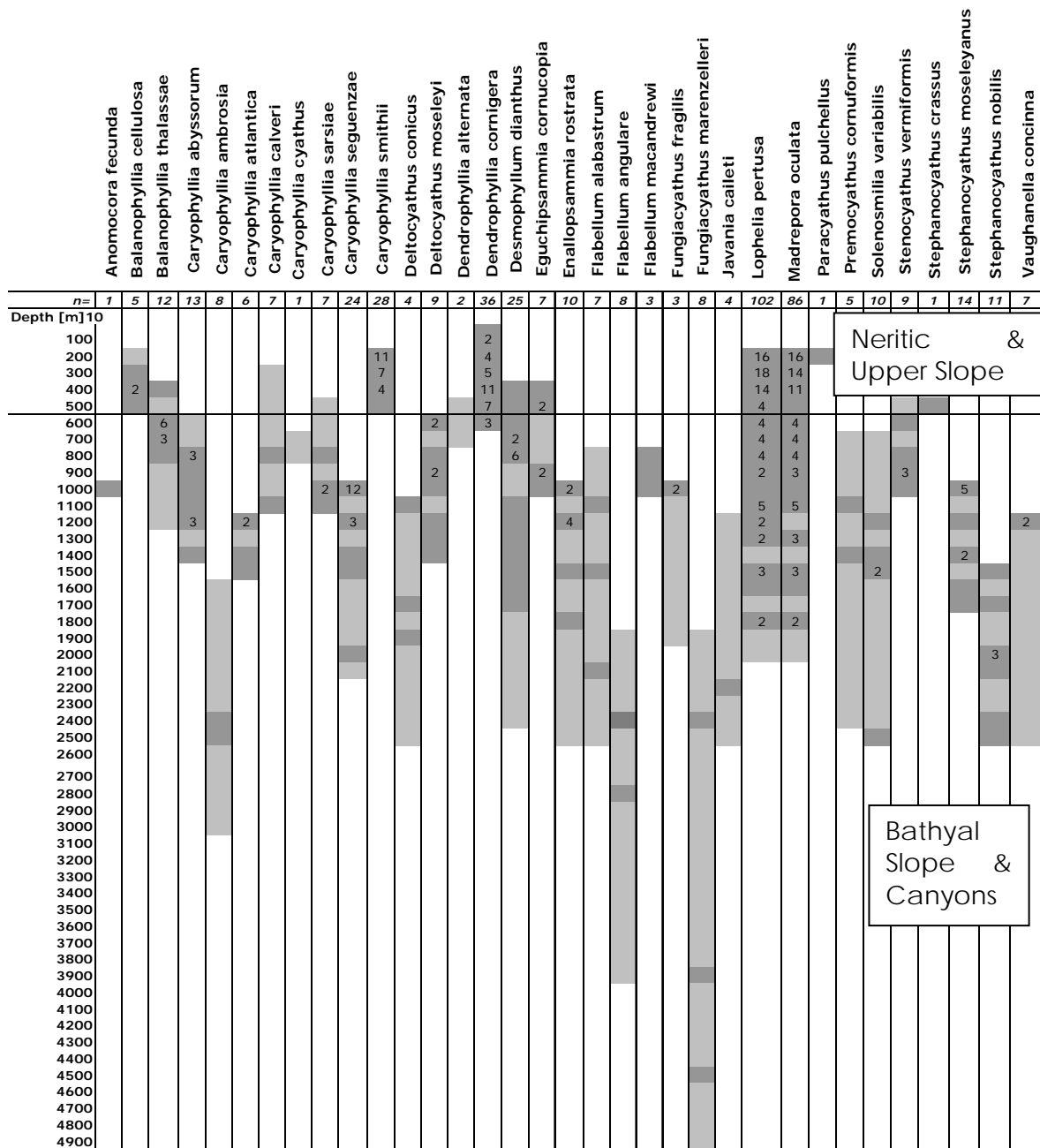
scleractinians cluster along the continental margin in the Bay of Biscay. The map is modified from Sibuet et al. 2004.



**Fig. 2** Deep-water coral samples in the Banc de la Chapelle (BC) and Penmarc'h Bank area (PB), collected during the R/V *Victor Hensen* cruise VH-97.



**Fig. 3** *Dendrophyllia cornigera* collected alive from outer Penmarc'h Bank (VH-97, Station 320, 290 m depth)



**Fig. 4.** Bathymetric ranges of 34 Scleractinia in the Bay of Biscay grouped in 100-m-intervals. Coding of bars: *dark grey* = coral sample, *bright grey* = interpolated, *numbers in bars* = frequency of coral samples from the given depth interval