Universidade de Aveiro Departamento de Biologia
2009

FELIPE MISAEL DA SILVA MORSOLETO

BIODIVERSIDADE NOS RECIFES DE CORAL DO GOLFO DE CÁDIS (NE ATLÂNTICO)

BIODIVERSITY OF COLD-WATER CORAL REEFS IN THE GULF OF CADIZ (NE ATLANTIC)

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Biologia Marinha, realizada sob a orientação científica da Professora Doutora Marina Ribeiro da Cunha, Professora Auxiliar do Departamento de Biologia da Universidade de Aveiro

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o júri

Presidente

Prof. Dr. Victor Manuel dos Santos Quintino
professor auxiliar do Departamento de Biologia da Universidade de Aveiro

Prof.ª Dr.ª Maria Marina Pais Ribeiro da Cunha

professora auxiliar do Departamento de Biologia da Universidade de Aveiro

Doutora Ana Margarida Medrôa de Matos Hilário
investigadora da Centro de Estudos do Ambiente e do Mar

agradecimentos

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palavras-chave

Golfo de Cádis; recifes de coral de profundidade, crostas carbonatadas; oceano profundo; biodiversidade

resumo

Este trabalho foi realizado em vários locais das margens Espanhola e Marroquina no Golfo de Cádis (NE Atlântico), ao longo de uma faixa batimétrica entre os 300 e os 900m caracterizada pela ocorrência extensiva de crostas carbonatadas e recifes de corais pétreos em declínio. Os objectivos principais desse trabalho são: i) compilar informação sobre a biodiversidade da megafauna e do impacto humano na área de estudo através da análise de imagens digitais obtidas durante os mergulhos com o submersível de operação remota e ii) caracterizar, em termos de abundância e biomassa, a composição e a estrutura das comunidades de macroinvertebrados bentónicos associados aos habitats de crostas carbonatadas e recifes de corais através do estudo de amostras de sedimento colhidas com um “boxcore” circular.

Verificou-se que a megafauna associada aos habitats estudados mostra uma grande variedade de organismos sésseis, principalmente esponjas e antozoários, e vágeis, nomeadamente decápodes, cefalópodes e peixes. Foi compilado um atlas com imagens representativas da biodiversidade da megafauna. As imagens recolhidas permitiram ainda verificar a ocorrência de vários tipos de impacto antropogénico nestes habitas profundos, incluindo artes de pesca perdidas, detritos diversos (artefactos de vidro, plástico, metal e têxteis) e efeitos da pesca de arrasto.

Foram ainda identificados 145 taxa de macroinvertebrados bentónicos nas nove amostras de sedimento recolhidas em diversos locais. A comunidade bentónica estudada é constituída maioritariamente por espécies de artrópodes, anelídeos e cnidários, tendo-se verificado uma grande heterogeneidade na composição e estrutura das amostras recolhidas. Em termos de abundância as comunidades são geralmente dominadas por várias espécies de crustáceos enquanto que os cnidários e os equinodermes dominam claramente a biomassa. As amostras estudadas apresentam geralmente uma diversidade (H’: 2.0-3.3) e equitabilidade (J’: 0.740-0.974) elevadas e uma dominância baixa (espécie mais abundante com valores de 10-40% do total). Os valores do índice de Hurlbert ($ES_{(50)}$: 11-33) reflectem a elevada biodiversidade dos habitats estudados.

Este estudo é um contributo para o conhecimento da biodiversidade associada aos recifes de coral de profundidade, habitats de reconhecido valor ecológico e económico que se encontram cada vez mais expostos ao efeito de impactos antropogénicos

keywords

Gulf of Cadiz; cold-water coral reefs; carbonate crusts, deep-sea, biodiversity

abstract

This work was carried out in different locations within the bathymetric range of 300-900m in the Spanish and Moroccan margins of the Gulf of Cadiz (NE Atlantic). This area is characterised by the occurrence of extensive carbonate provinces and mostly dead cold-water coral reefs. The main objectives were: i) to obtain information on the megafaunal biodiversity and human impact in the study area using digital images obtained during ROV (remote operated vehicle) dives, and ii) to characterise, in terms of abundance and biomass, the composition and structure of the benthic macroinvertebrate assemblages associated to the carbonate crust and coral reef habitats using sediment samples collected with a circular boxcore.

The megafauna associated to the studied habitats showed a high variety of sessile organisms, mainly sponges and anthozoans, and swimming organisms (e.g. decapods, cephalopods and fish). Some representative images were compiled in a biodiversity atlas. The images showed that these deep habitats are suffering from the impact of anthropogenic activities. Some examples are the lost fishing gear, different types of litter (glass, plastic, metal and textile) and also trawl marks on the seabed.

From the nine sediment samples that were collected, a total of 145 macroinvertebrate taxa were identified. The benthic assemblages were highly heterogeneous in composition and structure and were represented mainly by arthropods, annelids and cnidarians. The crustaceans usually dominate the assemblages in terms of number of species and individuals but the cnidarian, sponges and echinoderms clearly dominate the biomass. The macroinvertebrate samples show high diversity (H’: 2.0-3.3) and evenness (J’: 0.740-0.974) and low dominance (dominant species representing 10-40% of the total abundance). The Hurlbert’s expected species numbers ($ES_{(50)}$: 11-33) reflect the high biodiversity of the studied habitats.

The high ecologic and economic importance of cold-water coral reefs is presently highly valued by the society. This study documented some aspects of the biodiversity and man’s impact on cold-water corals in the Gulf of Cadiz, therefore contributing to the better knowledge of these deep-sea habitats.

CONTENTS

1. INTRODUCTION

1.1. The Deep-Sea

The deep-sea is the largest ecosystem in the world but less than 1% of its surface has been mapped and studied. The oceans cover 71% of the earth, (61% are in the open sea); 88% of the open sea has depths of more than 1000m, 76% has depths of 3000 - 6000 Km and the maximum depth, 10912m, occurs at the Mariana Trench (Gage and Tyler 1991). The vast extension and great depth make this habitat a challenge to the scientific community and the huge gaps in our knowledge of the biodiversity and functioning of deep-sea ecosystems make almost impossible to predict the effects of man's impact over the years (Gage 1996).

Most of the deep-sea is encompassed by the mesopelagic, bathypelagic and abyssopelagic zones. The mesopelagic zone includes the water masses between 200 and 1000 m; it is characterised by the rapid loss of light; fall in temperature (average values of 4 - 8 ºC), decreased levels of oxygen and nutrients, and increased pressure. The bathypelagic (1000 – 3000m) and abyssopelagic zones (3000-6000m) are characterised by the complete absence of light, and by the decreasing gradients in temperatures, oxygen and nutrients, and increasing pressure. These water masses interact with the seafloor conditioning the benthic environments which are highly heterogeneous, especially at the continental margins where often occur canyons, outcrops, seamounts, cold seeps and a diversity of biogenic habitats including cold-water coral reefs.

Scientists are studying the deep-sea since the 19th century. John Murray (1895) reporting on the data and samples collected during the HMS Challenger expedition (1872 - 1876), divided the animals into three groups based on their life history traits: i) organisms without pelagic larval stage; ii) organisms with pelagic larval stage; iii) organisms that produce large larval supplement. However it was only during the decade of 1960 that there was a significant advance in these studies with the introduction of semi-quantitative (trawls and dredges) and quantitative methods (box cores and mega cores). Today the use of manned submersible and remote operated vehicles (ROV) is becoming very common (Gage 1996). But despite all these technological advances only a negligible part of the deep-sea biodiversity is known (Gage and Tyler 1991). It is estimated that millions of species in the deep-sea are still unknown to scientists. Because of the fragile link of the deep-sea organisms to their habitats, a better knowledge of this ecosystem is of crucial importance to predict the impact of natural an anthropogenic changes and take the necessary actions to its sustainable management.

For early naturalists the deep-sea was a sterile environment: “How could there be life in a dark, cold, highly pressurized and anoxic environment?” In fact, the hydrostatic pressure is an important factor causing stress and leading to the development of the necessary physiological adaptations in the organisms that live in this environment (Ekman 1953). The hydrostatic pressure acting on living organisms, promotes a physiological balance through biochemical reactions. The change in physiological behaviour of species at great depths is more intense when the catalytic reactions involve changes in the volume of reagents. Another important factor is the absence of light that in the deep-sea does not allow photosynthetic organisms to develop. Despite the absence of light, primary production still occurs at great depth where reducing environments, such as hydrothermal vents and cold seeps, favour the existence of high biomass faunal communities fed by microbial mediated chemosynthesis (Van Dover 2000). However, the primary production at coastal and superficial waters remains largely responsible for the food input to the deep-sea.

The high biodiversity of the deep sea continues to be highly debated because of the difficulty in understanding how so many species have evolved and co-exist in the same habitat. The deep-sea fauna is not primitive and it shows many similarities to other species in shallow waters and at high latitudes. During the Mesozoic period there was an increase in temperature of surface waters; at high latitudes, these waters have cooled becoming denser. With the submergence of cold waters at high latitudes the ocean floor became well oxygenated which made possible the occurrence of metazoan life (Tanner 2007). Murray and Renard (1981) suggest that many species might have colonised the deep-sea at higher latitudes when the temperature became isothermic on the ocean floor. This pattern can be seen in many organisms, such as the class Asteroidea represented by hundreds of species in the northern and the southern oceans, decapods, fish and hydrozoans (Murray and Renard 1891).

Important changes occurred during the last glaciation when factors impacting the distribution of the fauna of the oceans led to the differentiation of the ecosystems and their biodiversity (Vinogradova 1997). Today, the theories of biological multi-variably in deep-sea ecosystems are generally accepted and the great paradigm lies in the homogeneity of the species that inhabit this ecosystem (Henry and Roberts 2007).

1.2. Cold-water corals

In certain areas of the deep-sea the variability of the environment leads to high habitat heterogeneity controlling biological patterns and processes at different spatial scales, frequently enhancing the complexity of the food webs and the biodiversity of the faunal assemblages. A common example of these highly heterogeneous habitats is the coral reefs.

1.2.1. Hypotheses of coral mound formation

Carbonate mounds can be considered analogous to carbonate fossils that have arisen in the Paleocene period (Boulvain 2001; Henriet and Guidard 2002). By identifying the factors responsible for coral mound formation it is possible to set a model of the genesis of mounts that represent the accumulation of sediments and how this occurs.

Hypotheses emerged over the years to explain the presence of large swathes of reefs and wide carbonate mound discovered in the North Atlantic Ocean. One of the hypotheses is that the faults draining hydrocarbons from the ocean floor are responsible for the development of coral and carbonate mounds in deep water

(Henriet et al. 1998; Hovland and Risk 2003). These carbonate mounds may be the natural oceanic process of sealing (Hovland 2004), as the ecosystem is in balance with the current conditions of the ocean floor and overlapping water masses (Henriet et al. 1998; Hovland et al. 1998; Hovland and Risk 2003; Masson et al. 2003; Sumida et al. 2004). Another hypothesis is that deep water corals and carbonate mounds were formed by external conditions such as increased temperature and salinity through a process of hydrodynamic turbulence, and high quantities of food in suspension. In areas where these conditions occur, mechanisms of particle fluxes and internal waves favour the development of the corals and associated benthic fauna. As the coral grows, sediment particles are trapped and cemented in the skeleton framework giving rise to the mounds (Freiwald 2002). The tides and waves are important for the transport of food particles to cold-water corals (Frederiksen et al. 1992; White et al. 2005; White 2007).

1.2.2. Biodiversity

Both deep cold-water reefs and shallow tropical coral reefs can be described as a complex three-dimension structured habitat providing numerous niches that may be occupied by many different species (Figure 1). The structural framework of coral reefs serve as refuge and nursery for a diversity of organisms and is especially important for many commercially valuable fish and crustacean species (Bryan and Metaxas 2006).

The sub-habitats in a coral reef include living coral, the spaces between them, the structure of dead corals and sediments around the reefs (Bluhm 2001). Large organisms (other cnidarians, sponges, anemones, starfish, sea urchins) settle on the structure or coral rubble, and smaller species (crustaceans, molluscs polychaetes) live within coral framework, inside the cavities of dead corals or within the sediments associated to the reef (Burgess and Babcock 2005). Large predators such as fish, crabs and lobsters live among the coral thickets. The diversity of animals associated with deep-sea cold-coral reefs is comparable to some tropical coral reefs in shallow water. Clark (2006) mentions about 1300 North Atlantic species found in association with the coral *Lophelia pertusa*

(Scleractinia). Although the diversity of some animal groups is similar in deep and shallow waters other, such as certain types of octocorals, molluscs and fish are much less diverse in *Lophelia* coral reefs than in tropical shallow waters (Cohen et al. 2006).

In living coral reefs, most organisms are found in the vicinity of the reefs, and only a few species seem to live in close association to the corals. All sub-habitats in *Lophelia* coral have been investigated, but the diversity of associated animals is not documented for all (e.g. animals living in coral rubble) (Buhl-Mortensen and Mortensen 2004).

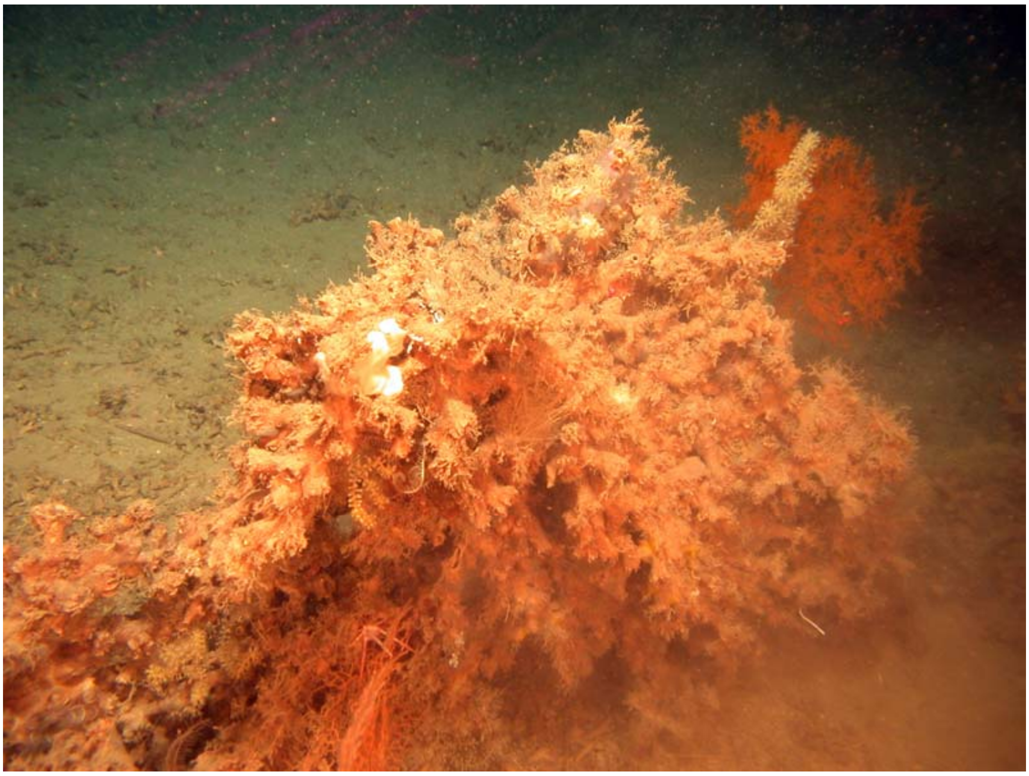


Figure 1 – *Lophelia pertusa* coral formation on Moroccan Margin. There are few living polyps but the skeleton framework is covered by a high diversity of organisms (courtesy of MARUM, Bremen).

Cold-water and tropical reefs coral share strong similarities in their rate of growth (increase) and destruction (erosion). The same organisms, such as sponges and worms are responsible for both bio-erosion of reefs in shallow and deep water (Bromley 2005). In tropical reefs, there are examples of commensalism or mutual relations between organisms. The commensalisms in deep water coral reefs are related to the competitive and hard coral habitat, but are difficult to observe and occur for short periods of time (Birkeland 1997).

1.2.3. Human impacts

Human impacts on deep cold-water coral reefs are principally caused by fishing activities (Clark 2006). The decrease of fish in shallow water has led to exploitation of the species that inhabit deeper waters. Species such as the granadiers (*Coryphaenoides spp*), orange roughy (*Hoplostethus atlanticus*), redfish (*Sebastes* spp) and oreos (*Pseudocyttus maculatus*, *Allocyttus niger*) suffered drastic decreases in the size of their populations (Kaiser et al. 2000). These fish have low growth rates and are highly vulnerable to overfishing; many live in adjacent waters or in habitats around coral reefs. Some, such as the redfish live among the coral reefs in deep water, both as juveniles and adults (Gianni 2004).

Modern trawlers are designed for fishing over rough terrain or on coral reefs in the sea. The impact of the weight of a trawl with all its chains and other pieces easily crushes the structure of the coral, reducing or completely destroying the habitat reef (Hall-Spencer et al. 2002). Observations show that the fishermen prefer coral reefs because of the high fish abundance in these areas. The increased impact of fishing activities on cold-water coral reefs occurred since the first years after the discovery of these habitats and, in many areas, led to their gradual destruction before conservation measures could be taken (Cryer et al. 2002). In the Tasman Seamounts, the observed reduction of coral fish populations caused concern on the fisheries impact on coral reefs (Nellemann et al. 2008) and in many areas of the European margin, the *Lophelia pertusa* coral reefs and their associated habitats have been reduced to almost 50% of its original size due to overfishing (Van den Hove 2008).

The coral reefs have a low growth rate (0.5 to 2.5 cm per year) and their recovery is difficult which aggravates the problem of the destruction of these habitats (Dullo et al. 2008). Recent research on the areas of reproduction and genetics show that in regions where there was a reduction or destruction of corals, reproduction is not viable anymore. All these factors contribute to the very slow recovery of coral reefs from the action of fishing and explain why, in some cases, it is no longer possible to recover some areas (Hartl and Clark 1997). A striking example are the Tasman Seamounts where affected coral areas were reduced to bare rock inhabited most solely by with sea urchins (Nellemann et al. 2008). With the destruction of these habitats, deep-water fishing begins to be not as profitable as it was before and shows signs of decline (Jennings and Kaiser 1998).

The increasing destruction of coral reefs in deep water has forced governments to create laws to protect this habitat. The coral in Norway, the west coast of Great Britain and now also the Tasman Seamounts are among the protected areas from fisheries (Halpern 2003). But overfishing in the reefs and associated habitats such as seamounts, remains in a disorderly fashion (Krieger 1993). Scientists and governments are aware of the damage caused by these activities that are among the most impactful to the marine environment (Masson et al. 2003). Several animals associated with this habitat are being destroyed before they can be studied, as much of the biodiversity of these sites has never been studied.

Another important impact on marine ecosystems deriving indirectly from man’s activities is ocean acidification. Ocean acidification may have devastating consequences for corals and other marine organisms whose exoskeletons are made of calcium carbonate ($CaCO_3$), a substance that dissolves in acidic conditions. The discovery that ocean waters are acidifying is recent and this process is thought to be enhanced by climate change and by human activities such as extraction of oil, gas, methane hydrates, the mining of polymetallic sulfides, the removal of manganese nodules as well as disposed ammunition and even toxic waste charcoal and plastic wastes (Alvarez-Perez et al. 2005)

1.3. Coral Mounds in the Gulf of Cadiz

The Gulf of Cadiz (located between the Iberian Peninsula and Morocco) is one of the areas in the European margin where extensive carbonate mound provinces and cold-water corals have been frequently recorded (Foubert et al. 2008). The topography provides an optimal condition for coral colonization as it increases the current flow providing a sustained food chain (Roberts et al. 2006). In the Gulf of Cadiz, scleractinian corals are often associated with a variety of topographical and geological features (Foubert et al. 2005) but their occurrence is not confined to high elevations, they also occur in areas of the seabed without ideal topographic features (Hebbeln 2008).

According to some authors, the occurrence of scleractinian corals in deep water is often correlated with areas of seepage where the leaking of hydrocarbons from deep sediment layers (Hovland and Thomsen 1997) caters to local production. Thus, the diapirism and mud volcanism in the Gulf of Cadiz has, or may have had in the past, the potential to boost the development of reefs in this area directly because of the enhanced local production, or indirectly by favouring the bacterial-mediated formation of authigenic carbonates (Somoza et al. 2003; León et al. 2007), an ideal solid foundation of hard substrate for the settlement of scleractinian corals (Figure 2).

Figure 2 – Carbonate formation on Moroccan Margin in Gulf of Cadiz.

The formation of carbonate crusts is related to the low rates of diffusion of fluid ventilation after the eruption of mud, or even periods of inactive mud volcanism (León et al. 2007). But a change in the chemical environment associated with the sedimentary deposit can lead to a partial dissolution of carbonates. The evidence is provided by strong alteration and dissolution of coral fragments collected from several localities in the Gulf of Cadiz (Kopf 2002; Foubert et al. 2008). Therefore, volcanic activity may have a slightly negative influence in the maintenance and development of deep water coral ecosystems in the Gulf of Cadiz. Another negative factor affecting the saturation of aragonite and calcite that may be considered is ocean acidification.

The fossil scleractinian corals are distributed throughout the Gulf of Cadiz between the Spanish and Moroccan margins. Sediment samples collected from the mounds revealed a significant number of corals embedded in the sediment (Foubert et al. 2008). The variety of species of scleractinian coral is high and the most common species are *Lophelia Pertusa, Madrepora oculata, Dendrophyllia alternata* and *Eguchipsammia cornucopia* (Wienberg 2009). Most scleractinian corals were found at depths between 500 and 1000m and may also occur in shallower depths (~280m) along the Moroccan coast (Foubert et al. 2008). However, the records of living scleractinian corals are few and concentrated in the Moroccan margin as shown by several expeditions in the southern Gulf of Cadiz (Wienberg et al. 2009).

The abundant coral fossil record and the almost absence of living colonies in the Gulf of Cadiz suggest that the environmental factors and oceanographic currents (oligotrophic waters, and low tides) in the area are no longer favourable for the development of thriving reefs today (Foubert et al. 2008).The cold-water scleractinian corals require a hard substrate, sufficient food and protection to grow. Therefore, flourishing reefs are found in areas with strong currents where there is little accumulation of sediment and high availability of food (Roberts et al. 2006). In the Gulf of Cadiz, the stratification of the Atlantic water masses and the Mediterranean Outflow water is more dramatic than in the north and upwelling events are restricted to the western Iberian margins (García Lafuente and Ruiz

2007). Therefore the Gulf of Cadiz has a low productivity when compared with the west Iberia or other Atlantic areas at higher latitudes (Behrenfeld et al. 2005).

Recent surveys of sediment samples collected throughout the Gulf of Cadiz indicate that coral reefs in this region developed mostly during the last glaciations (Gonzalez et al. 2009). There is evidence for the hypothesis that flourishing coral ecosystem in the Temperate Atlantic and Mediterranean Sea are restricted to glacial periods, whereas at higher latitudes, the periods of growth of corals occurred during the Holocene and last glaciations (Freiwald et al. 2004). The occurrence of cold-water scleractinian corals in Gulf of Cadiz, however, is not restricted to glacial periods, but environmental changes, especially the increase in sea temperature, may have caused their decline (Wienberg et al. 2009). *Lophelia pertusa* appears to have grown significantly reaching its heyday during the last glacial period in the cold water of the Gulf of Cadiz, when the temperature and marine circulation were more stable. In contrast, *Madrepora oculata* seems to have a wider tolerance to environmental changes and its occurrence was not restricted to the last glacial period while dendrophylliid corals are restricted to relatively stable and warm waters are more frequent in warmer periods (Roberts et al. 2006; Wienberg et al. 2009). Currently, *L. pertusa* is less common than *Madrepora* and their colonies are smaller (Zibrowius 1980; Wienberg et al. 2009). The absence of corals over a period of the Holocene, suggests that important environmental changes occurred at that time, namely higher temperatures and the sudden reduction in current strength of the cold water currents that carry sediment to the deep-water reef corals (Freiwald et al. 2004).

The biodiversity of the faunal assemblages associated to cold-water coral reefs in the Gulf of Cadiz is poorly studied and the data available refer only to the Pen Duick Escarpment (Almeida 2009). The work carried out by Almeida (2009) showed a high biodiversity of this habitat with a total of 293 taxa recorded in the studied area. Arthropoda, Annelida and Cnidaria were the most abundant taxa and the Arthropoda were also the most species-rich group.

1.4. Objectives

Cold-water coral ecosystems are widely distributed along continental margins around the world. Over the past two decades it has been discovered that they occur all along Europe from northern Norway along the Irish margin to the Gulf of Cadiz and into the Mediterranean Sea (Tasker et al. 2002). Whereas off Norway and Ireland thriving cold-water coral ecosystems are quite common, similar vivid communities have only recently been reported from the Mediterranean (Fossa et al. 2002). Up to now there are no records of the existence of thriving cold-water coral reefs in the Gulf of Cadiz. Almost all reports on cold-water coral findings in this region refer to dead scleractinian coral framework and rubble although there are a few records of living colonies too.

This study was carried out to investigate several locations on the extensive carbonate provinces of the Gulf of Cadiz, with a particular focus on the biodiversity associated to carbonate crust and cold-water coral habitats. The biological material for the present work was collected during the cruise 64PE284, carried out in the Gulf of Cadiz onboard the RV *Pelagia* in February-March 2008 This expedition was a contribution to the HERMES project (Hotspot Ecosystem Research along the Margins of the European Seas, integrated project funded within the 6th FRP of the European Union).

The main objective of the present work is to document some aspects of the biodiversity and man’s impact on cold-water corals habitats in the Gulf of Cadiz. The specific objectives are:

I. to compile imagery information on the biodiversity of megafauna and human impact in coral habitats from the analysis of digital photos captured during the ROV Cherokee dives

II. to characterise the composition and structure both in terms of abundance and biomass of the benthic macroinvertebrate assemblages associated with the carbonate and coral habitats from the analysis of box core sediment samples

The results of this work are a contribution to the integrated project HERMIONE (Hotspot Ecosystem Research and Man’s Impact on European Seas, collaborative project funded within the 7th Framework programme of the European Union), which is a follow-up of the above mentioned HERMES project.

2. METHODOLOGY

2.1. STUDY AREA

The Gulf of Cadiz is located west of the Strait of Gibraltar (between Spain and Morocco), on the boundary of the African and Iberian plates, in an area with a complex oceanography and a series of active geological processes.

The Spanish and Moroccan margins of the Gulf of Cadiz are influenced by different water masses (Figure 3) the northern part is influenced mainly by the MOW (Mediterranean Outflow Water), and the south by NACW (North Atlantic Central Water) less saline and cooler (Ambar et al. 2002). In the Gulf of Cadiz the movement of masses of water is complex, and the waters of the Atlantic generally colder (coming from depths of 200 to 1800 m) mingle with the highly salty waters of the Mediterranean. The different water masses interact with the seafloor at different depths and are one of the main responsible for the distribution of sediments along the margins in the Gulf of Cadiz (Gonzalez et al. 2009).

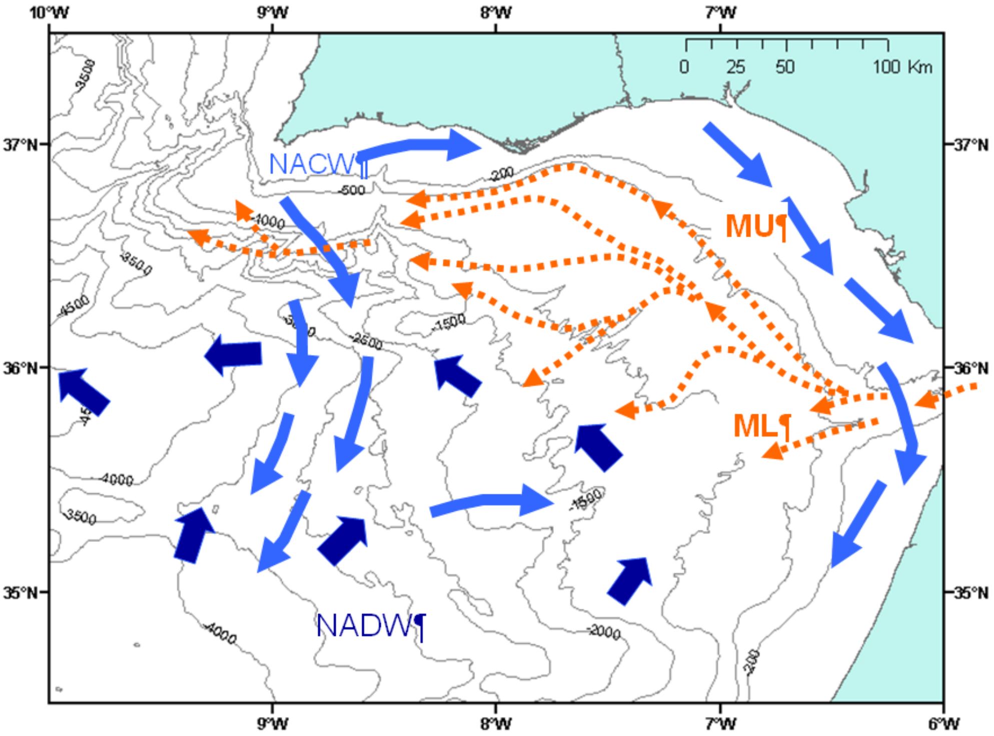


Figure 3 - General circulation patterns in the Gulf of Cadiz (adapted from Hernández-Molina et al., 2006). The present day circulation patterns and the hydrographical conditions in the Gulf of Cadiz are dominated by the exchange of water masses through the Strait of Gibraltar.

The main geodynamic processess include two plate driving mechanisms: i) subduction associated with the formation of the accretionary wedge (not active at present) and ii) oblique collision between Iberia and Nubia that caused thrusting in the Horseshoe Abyssal Plain and dextral wrenching along the SWIM area (active) (Zitellini *et al.* 2009). These processes favour the occurrence of widespread mud volcanism, mud diapirism, and the formation of carbonate mounds and chimney structures related to hydrocarbon-rich fluid venting (Pinheiro et al. 2003; Van Ransbergen, 2005). The mud volcanoes and their adjacent habitats, such as carbonate crusts and cold-water coral reefs, sustain highly diverse biological assemblages (Rodrigues et al. 2008; Almeida 2009).

During the 64PE284 cruise (Hebbeln et al. 2008) the study areas focused on carbonate provinces, at depths between 300 and 1000m in the Spanish and Moroccan margins in the Gulf of Cadiz and also on the Coral Patch Seamount, West off the Gulf of Cadiz (Figure 4). As mud volcanism is widespread in the area some of the video observations and samples were carried out in the vicinity or at the flanks and crater of mud volcanoes (eg. Pipoca, Mercator and Meknès).

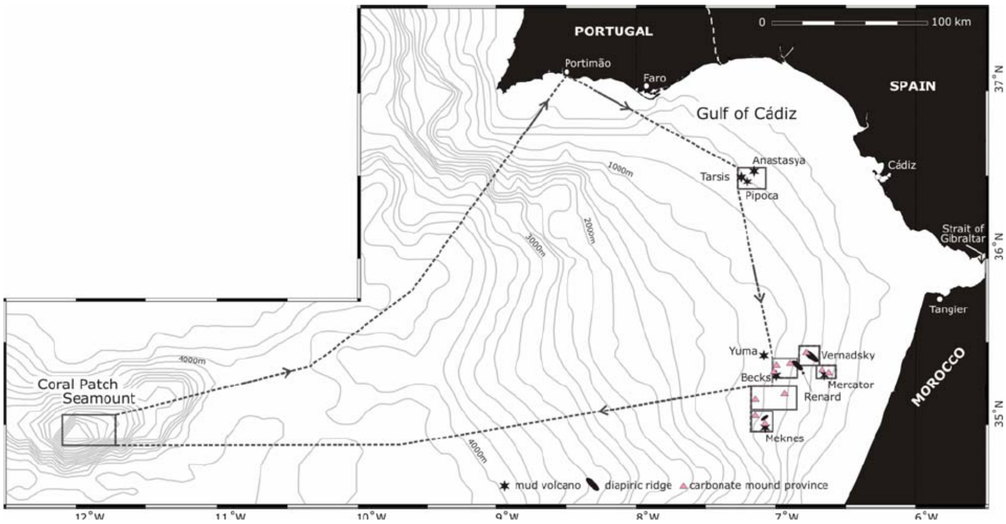


Figure 4 - Carbonate provinces in the Spanish and Moroccan margins in Gulf of Cadiz, with the location of the different areas sampled during the cruise 64PE284. From Hebbeln (2008)**.**

Detailed bathymetric maps of the study areas in the Spanish margin (Figure 5), the Moroccan margin (Figure 6) and Coral Patch Seamount (Figure 7) are shown below.

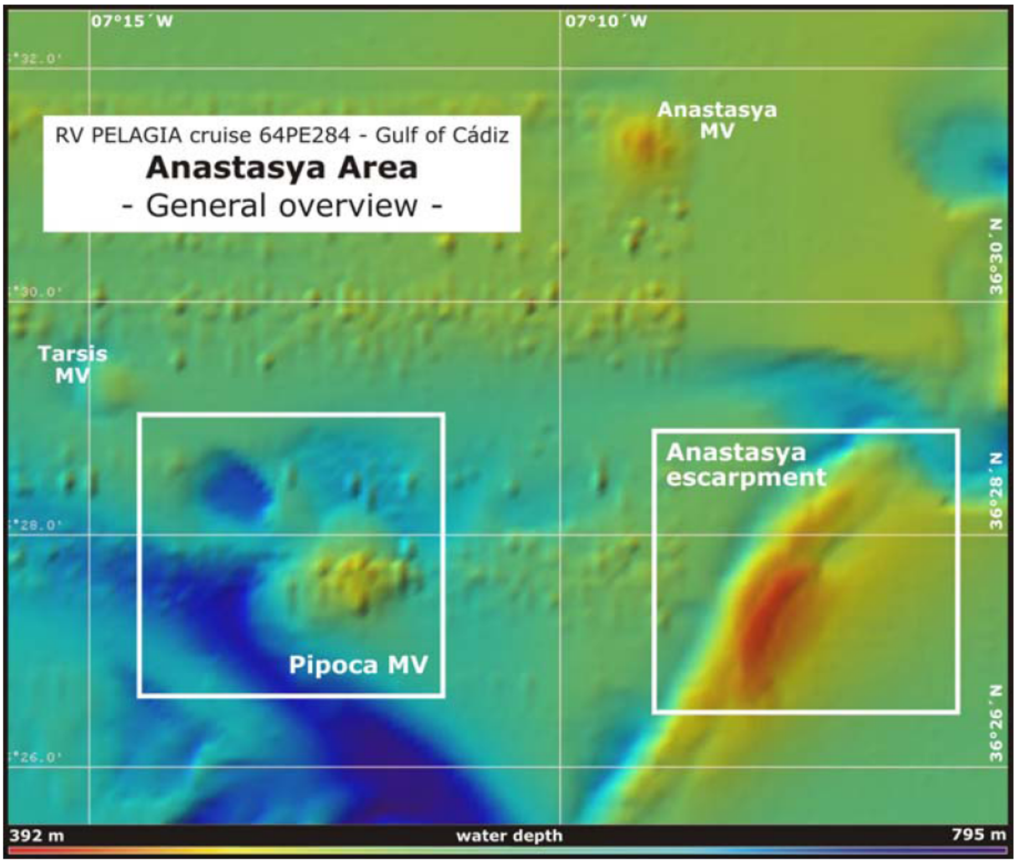


Figure 5 – The study areas Pipoca mud volcano and Anastasya escarpment in the Spanish margin, Gulf of Cadiz. From Hebbeln (2008).

2.2. SAMPLING

Video surveys

The ROV Cherokee (Figure 8) was used for the video survey of the selected study areas. The Cherokee is a commercially available, midsize inspection class ROV, manufactured by Sub-Atlantic, Aberdeen adapted and enhanced for scientific purposes. During the cruise 64PE284, the system was operated by MARUM and FIELAX pilots/technicians. The ROV Cherokee is 1000m depth rated, but due to several “cut offs” and terminations of the umbilical supply cable, only a diving depth of 850m was guaranteed during this cruise. Four video cameras are mounted on the ROV for observation and navigational purposes. A colour video zoom camera (720x576 lines), a modified digital Nikon still camera (3.2 Megapixel) with associated flash light and two mini video cameras for the overview to the front and back areas of the vehicle. For scientific sampling and experiments, a small hydraulical manipulator system is used.

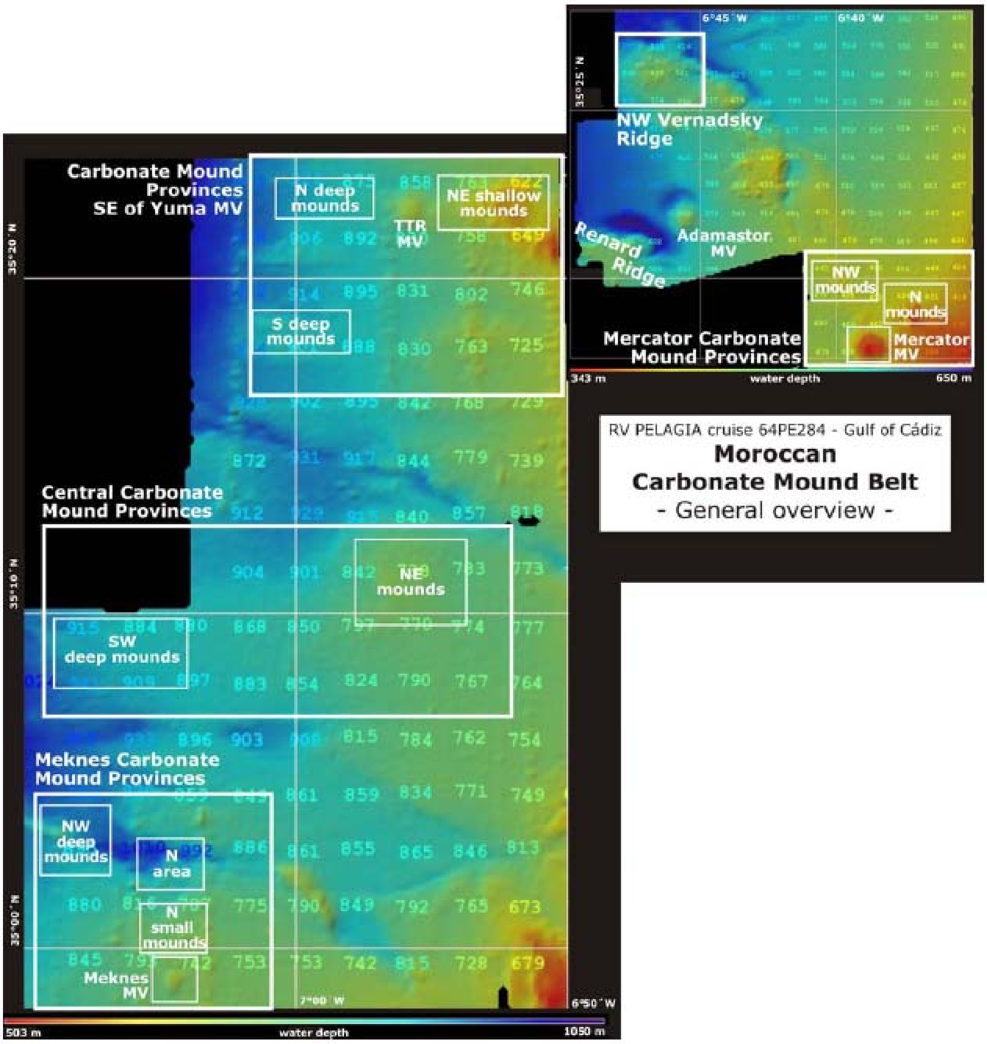


Figure 6 – The study areas in the Moroccan Carbonate Mound (CM) Belt. Mercator CM Province, CM province SE of Yuma Mv, Central CM and Meknès CM Province. From Hebbeln (2008).

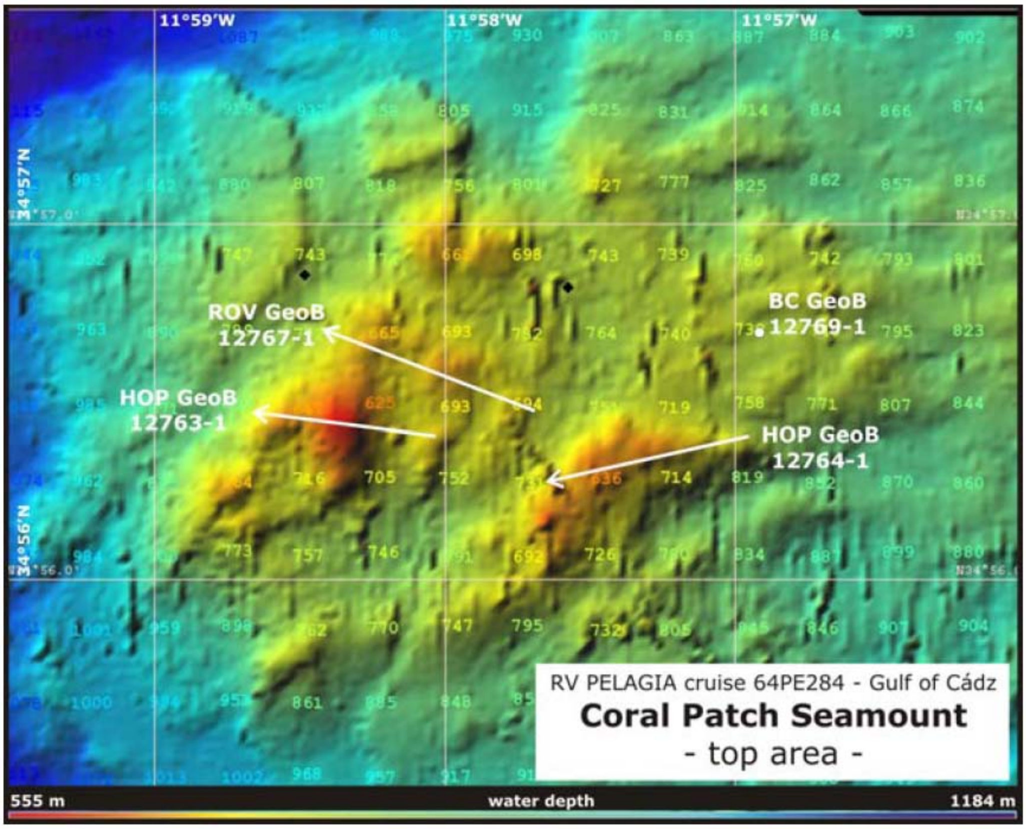


Figure 7 – The study area in the Coral Patch Seamount. From (Hebbeln 2008).

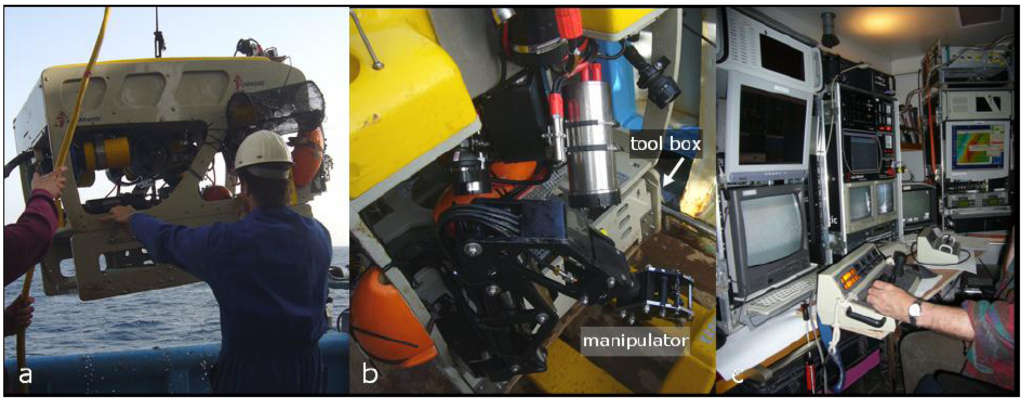
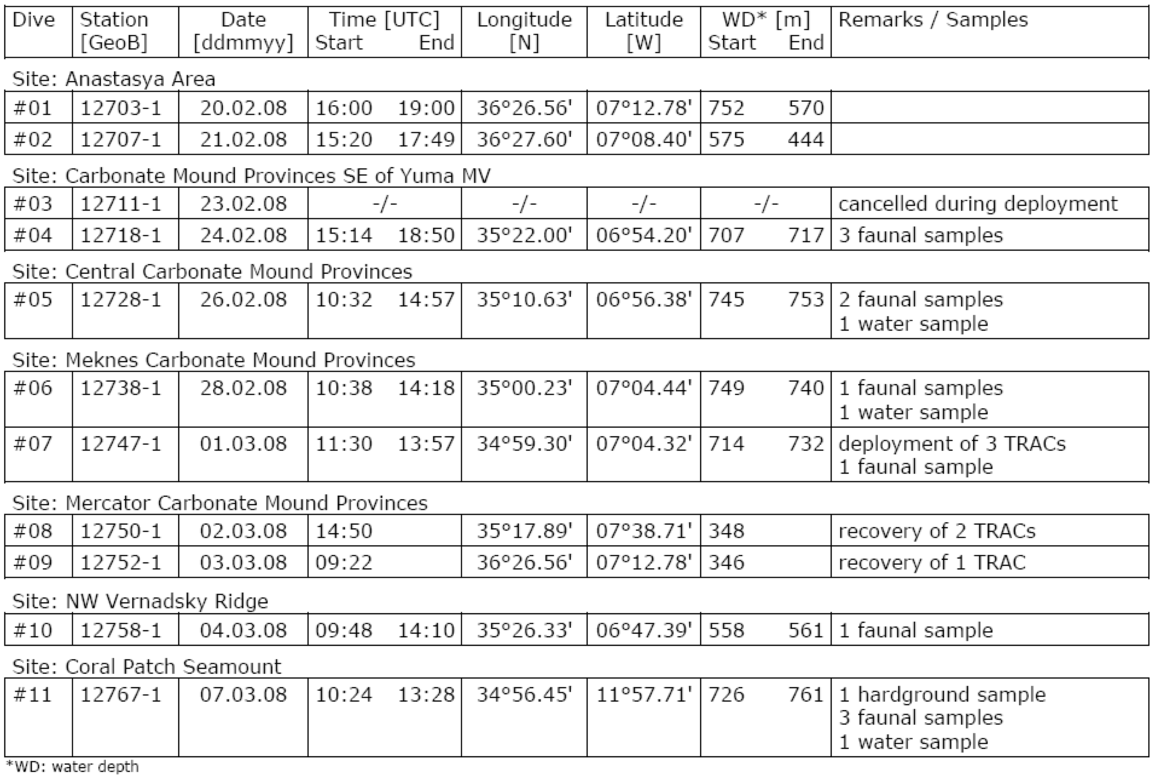


Figure 8 - The ROV Cherokee used for the video surveys of the study sites. a) ROV; b) camera and tool system; c) control system with several display and recording devices. From Hebbeln (2008)**.**

During the cruise 64PE284 eleven dives were carried out: two in the Spanish margin; eight in the Moroccan margin and one in the Coral Patch Seamount (Table 1). Because Dive #03 was cancelled and Dives #08 and #10 were used solely for the recovery of colonization experiments, only the remaining eight dives were used for the analysis. Time tagged photo frames were taken during the dives and occasionally faunal samples were also collected (Table 1). The photo frames were carefully examined and the megafauna present was identified with the highest possible taxonomical resolution. For the most conspicuous taxa, selected photos and a list of records were compiled in an Atlas. The visual records of anthropogenic impacts were listed and categorised into litter, lost fishing gear and trawl marks.

Table 1 - Metadada of the eleven dives carried out during the cruise 64PE284 in the Gulf of Cadiz. From Hebbeln (2008)**.**



Dive	Station [GeoB]	Date [ddmmyy]	Time [UTC]		Longitude [N]	Latitude [W]	WD* [m]		Remarks / Samples
			Start	End			Start	End	
Site: Anastasya Area									
#01	12703-1	20.02.08	16:00	19:00	36°26.56'	07°12.78'	752	570	
#02	12707-1	21.02.08	15:20	17:49	36°27.60'	07°08.40'	575	444	
Site: Carbonate Mound Provinces SE of Yuma MV									
#03	12711-1	23.02.08	-/-		-/-	-/-	-/-		cancelled during deployment
#04	12718-1	24.02.08	15:14	18:50	35°22.00'	06°54.20'	707	717	3 faunal samples
Site: Central Carbonate Mound Provinces									
#05	12728-1	26.02.08	10:32	14:57	35°10.63'	06°56.38'	745	753	2 faunal samples 1 water sample
Site: Meknes Carbonate Mound Provinces									
#06	12738-1	28.02.08	10:38	14:18	35°00.23'	07°04.44'	749	740	1 faunal samples 1 water sample
#07	12747-1	01.03.08	11:30	13:57	34°59.30'	07°04.32'	714	732	deployment of 3 TRACs 1 faunal sample
Site: Mercator Carbonate Mound Provinces									
#08	12750-1	02.03.08	14:50		35°17.89'	07°38.71'	348		recovery of 2 TRACs
#09	12752-1	03.03.08	09:22		36°26.56'	07°12.78'	346		recovery of 1 TRAC
Site: NW Vernadsky Ridge									
#10	12758-1	04.03.08	09:48	14:10	35°26.33'	06°47.39'	558	561	1 faunal sample
Site: Coral Patch Seamount									
#11	12767-1	07.03.08	10:24	13:28	34°56.45'	11°57.71'	726	761	1 hardground sample 3 faunal samples 1 water sample

*WD: water depth

Macrofauna

A NIOZ TV-guided box-corer was used for the collection of surface sediment during the cruise 64PE284. The TV camera was mounted on the side of the box (Figure 9) enabling a targeted sampling of the seabed. The box-corer has a barrel-like shape with a diameter of 50 cm and a length of 55 cm.

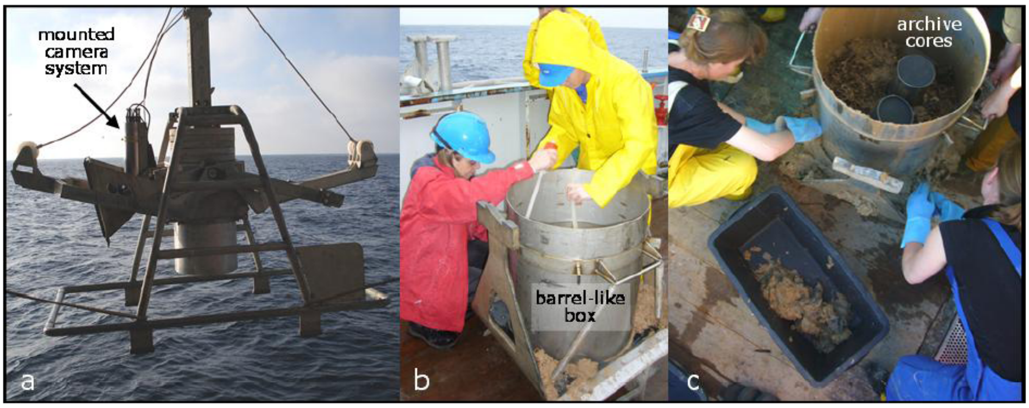


Figure 9 – a) TV-guided box corer; b) rinsing water for fauna sampling; c) sub-sampling of the box corer. From Hebbeln (2008).

The TV-guided box corer was deployed at a total of 14 stations. Nine deployments were successful, although three of them were tilted or disturbed and therefore standard sampling was not possible (Table 2). After the collection of the box-core, the water on the sediment was filtered and the surface of the box was photographed and described. All conspicuous organisms in the surface of the sediment were picked and immediately fixed in 96% ethanol. Biological material was retrieved from the nine successful deployments. One fourth of the box core surface was used for macrofaunal sampling (A= 0.049m^2). The upper 25-30 cm of the sediment were collected and the washed through a sieve column (2, 1 and 0.5mm mesh sizes). The fauna in the two coarser fractions was sorted and kept in 96% ethanol to enable genetic barcoding. The finer fraction (0.5 to 1 mm) of the sieved sediments was also kept in 96% ethanol but it was stained with rose Bengal and was sorted later under a stereoscopic microscope. The faunal samples collected during the ROV dives (Table 1) were also kept in 96% ethanol for further analysis.

In the laboratory the organisms were sorted into families and their biomass (fresh weight) was weighted to the nearest 0.0001g. Later the specimens were examined under a stereoscopic microscope and whenever possible identified to species level. After the taxonomic identification, the organisms will be curated and deposited in the Biological Research Collection of the University of Aveiro, in the Department of Biology and will be available for further studies.

Table 2 – Metadata of the successful box-core deployments during the cruise 64PE284 that were used for macrofaunal analysis. From Hebbeln 2008). Lp: *Lophelia pertusa*; Mo: *Madrepora oculata,* Dc: *Dendrophyllia cornigera;* Car: *Caryophylla*

Station [GeoB]	**Date** [ddmmyy]	**Time** [UTC]	**Latitude** [N]	**Longitude** [W]	**Depth** [m]	**Rec** [cm]	**Remarks**	**Area**
12705-1	21/02/08	09:26	36°27.60	07°12.33	525	>55	brown hemipelagic sediments overlying grey mud breccia with abundant mud clasts	Pipoca MV W summit
12706-1	21/02/08	11:19	36°26.81	07°12.70	702	~15	disturbed sample; brown mud with coral fragments overlying grey mud breccia	Pipoca MV S flank
12712-1	23/02/08	16:31	35°22.27	06°54.20	733	0-18	tilted sample; light olive brown mud with abundant fragments of Lp, Mo and Dc	CMP SE of Yuma MV NE shallow mounds
12721-1	25/02/08	09:12	35°18.59	06°59.94	868	29-38	brown muddy clayoverlying grysh brown clay, few fragments of Mo and Lp	CMP SE of Yuma MV S deep mounds
12722-1	25/02/08	11:38	35°18.63	07°00.99	907	42-45	surface with sponges and framework of Lp, Mo and Car; brown muddy clay overlying light olive brown clay with shell and coral fragments throughout	CMP SE of Yuma MV S deep mounds
12729-1	26/02/08	17:10	35°10.83	06°56.53	754	33-45	surface with Lp and Mo framework overgrwown by Car Brown muddy clay overlying greyish brown clay; coral fragments throughout	Central CMP NE mounds
12739-1	28/02/08	16:34	35°00.01	07°04.47	736	55	surface with Lp framework with Car; brown sandy mud overlying greyish brown muddy clay; coral fragments throughout	Meknès CMP N mounds
12748-1	01/03/08	16:27	35°58.85	07°04.39	722	33-41	surface with clasts and shells; greyish brown sandy clay overlying grey sandy clay; shells, clasts and crusts throughout	Meknès MV
12759-1	04/03/08	16:57	35°26.57	06°46.78	524	47-55	light olive brown to brown muddy/sandy clay; shells and Mo, Dc and Dd fragments throughout	Vernadsky Ridge NW area

2.3. DATA ANALYSIS

Data analysis of the macrofaunal quantitative samples (box-core) was performed using the statistic package Primer V.5 (Clarke & Warwick 2001). The biodiversity was assessed by diversity (Shannon-Wiener H'), and equitability (Pielou J') indices, Hulbert (1971) expected species richness ($ES_{(n)}$) and k-dominance curves. Shannon-Wiener diversity index assumes that individuals are randomly sampled from an "indefinitely large" population and that all species are represented in the sample (Magurran, 1988); its values depend on the sample size. Pielou´s evenness index (J') assumes that all species in the community are accounted for in the sample (Magurran 1988), and it varies from 0 to 1.0 (with 1.0 representing a situation where all species are equally abundant. k-dominance curves consist of plotting the cumulative ranked abundances (y-axis) against species (x-axis) that are ordered by decreasing abundances in a logarithmic scale (Lambshead *et al*. 1983). The shape and position of the curve allow the interpretation of community structure. Communities dominated by a small number of species have a high value of y-axis intersection point. Curves with a long "tail" indicate a large quantity of rare species in the community.

3. RESULTS

Megafauna observations

The information compiled from the digital photo frames obtained during the ROV dives was compiled into an Atlas (not included in this thesis) organized by the different megafaunal groups. Information and selected images of bioturbation marks and anthropogenic impacts is also reported. For the construction of the Atlas a total of 958 frames were analysed, from which the 404 photos that best characterized the different habitats were selected. The number of taxa identified during each dive was recorded (the average duration of a dive was about 3 hours). Some selected images are shown in Annex I.

Very few and small colonies of living scleractinians were observed and most of the coral areas consisted of dead coral framework or coral rubble. Most megafaunal species associated to these areas were anthozoans that showed a huge diversity of forms. Among those the most frequently observed were *Chelidonisis aurantiaca* and *Isidella elongata*. Sponges also showed a large diversity and decapod crustaceans were also quite frequent, especially the large crab *Paromola couvieri*. Among the fish, most species were observed during the dive at the Coral Patch Seamount; in the other areas the most common species associated with corals was *Helicolenus* sp.

During the dives there were also frequent observations of human impact on the sea floor. These were mostly trawl marks, lost fishing gear and a diversity of litter (metal tools, cans, bottles, plastic, clothes, etc.). Megafauna and human impact observations in each of the eight dives that were analysed are summarised in Table 3.

Table 3 – Summary of the records of megafauna (number of taxa or morphotypes), bioturbation and man's impact on the studied areas. The records were obtained from photo frames obtained during the ROV Cherokee dives. SM: Spanish margin; MM: Moroccan margin; CPS: Coral Patch Seamount.

Area	**SM**	**SM**	**MM**	**MM**	**MM**	**MM**	**MM**	**CPS**
Depth	570-752	444-575	707-717	745-753	749-740	714-732	558-561	726-761
Dive	#01	#02	#04	#05	#06	#07	#10	#11
Megafauna								
Porifera	3	3	4	6	4	1	0	1
Cnidaria	5	5	7	14	9	3	3	2
Mollusca	0	0	0	0	1	0	0	0
Arthropoda	2	2	0	2	2	1	3	3
Echinodermata	3	3	1	3	2	1	2	2
Brachiopoda	0	0	0	0	0	0	1	1
Fish	0	2	3	4	3	3	3	7
Bioturbation								
Burrows			X	X	X	X	X	
Mounds					X	X	X	
Trails			X	X	X	X		
Impacts								
Trawl marks	X	X					X	
Lost gear	X	X					X	X
Litter			X	X	X		X	X

Macrofauna assemblages

A total of 145 taxa were identified from which 116 in the nine box core samples. The complete species list is given in Annex 2 where the 46 new records for the coral reefs in the Gulf of Cadiz are also marked. The organisms identified are mainly distributed among the taxonomic groups Arthropoda, Annelida and Cnidaria.

The variability in abundance and species richness in all samples (including the occasional ones taken during ROV dives) are shown in Figure 10 and Table 4. The number of species in each box core varied between 11 and 17 in the Spanish margin (samples 12705, 12706) and between 15 and 36 in the Moroccan margins (Figure 10; Table 4). No successful box-cores were taken in the Coral Patch

Seamount. The most specious groups were either the crustaceans or the polychaetes, followed by cnidarians and echinoderms. Molluscs and sponges were also recorded in some samples.

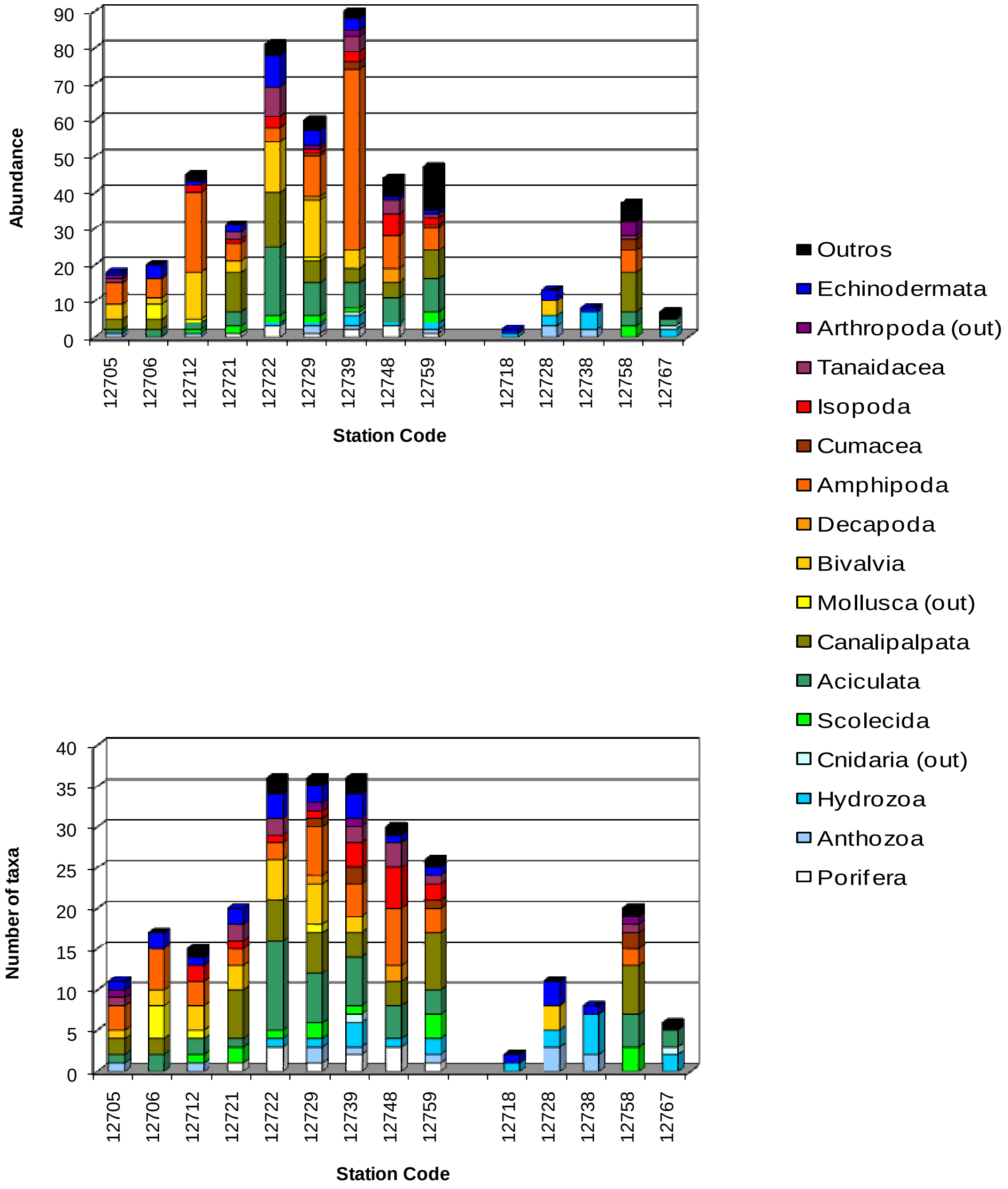


Figure 10 - Abundance (top) and taxa richness (bottom) of all stations. ROV stations (not quantitative) are shown in the right side.

Table 4 - Number of taxa (S), total individuals per station (N), Shannon-Wiener diversity index (H´) and Pielou equitability index (J´) estimated for all quantitative samples (box-core).

Station code	S	N	H'(loge)	J'
12705	11	18	2.274	0.948
12706	17	20	2.761	0.974
12712	15	45	2.024	0.747
12721	21	32	2.810	0.923
12722	36	81	3.258	0.909
12729	36	60	3.320	0.926
12739	36	90	2.653	0.740
12748	30	44	3.250	0.955
12759	26	47	2.850	0.874

The rarefaction curve (Figure 11) plotted with the pooled data from all box cores shows the high biodiversity of the coral reef associated assemblages in the Gulf of Cadiz with a Hurlbert's expected number of species for a sample of 400 individuals equal to 115 (ES(400) = 115).

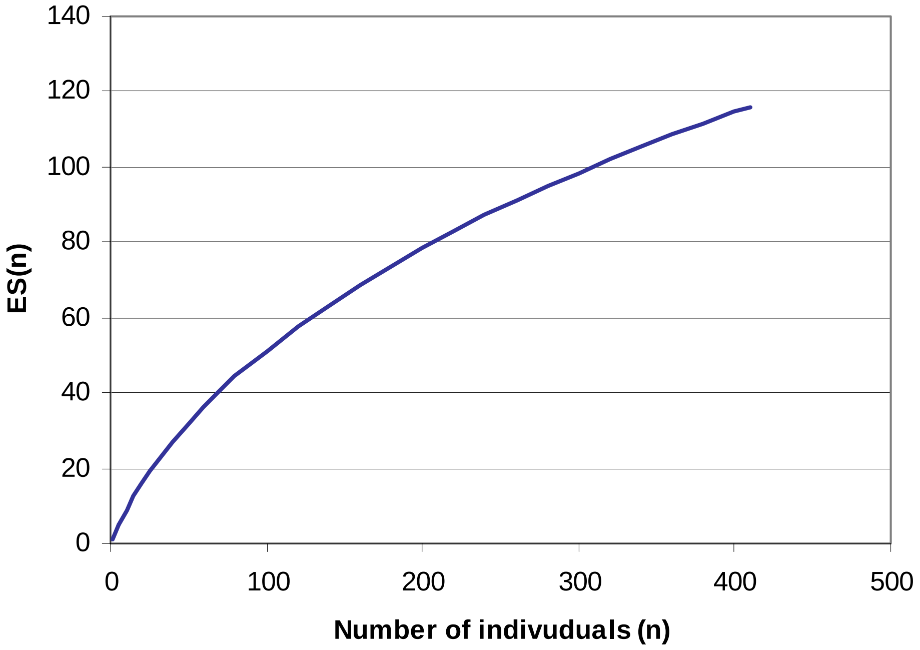


Figure 11 - Rarefaction curve for the pooled box-core data. ES(n) is the Hurlbert's expected number of species for a given number of individuals in the sample (n)**.**

The number of individuals collected in each box core sample (Table 4; Figure 11) varied between 18 and 20 in the Spanish margin but it was much higher in the Moroccan samples (32 to 90 individuals per sample). The samples collected with the ROV, yielded a low number of individuals because mostly only the sessile organisms are collected by this type of sampling. The average densities of the macrofauna were estimated as 376.9±30.56 ind.m^{-2} for the Spanish margin (two samples) and 1085.5±152.82 ind.m^{-2} for the Moroccan margin (seven samples). For these estimates modular sessile organisms such as the Porifera, Hydrozoa, and Anthozoa were excluded because of the difficulty in discriminating and counting individual organisms.

The structure of the assemblages showed a high heterogeneity among the collected samples (Figure 10) with polychaetes (e.g. samples 12721 and 12722), crustaceans (eg. samples 12712 and 12739) or even bivalves (sample 12729) being the most dominant organisms in different samples. The overall most abundant taxa in the samples are listed in Table 5.

Table 5 - List of the overall dominant species in the quantitative samples (total of nine samples), including their abundance (total number of individuals collected), frequency of occurrence (number of samples where they were present) and percentual contribution for the total number of individuals collected. AMP: Amphipoda; SIP: Sipuncula; BIV: Bivalvia; POL: Polychaeta; OPH: Ophiuridea; TAN: Tanaidacea.

	Taxa	**Abundance**	**Occurrence**	**Contribution (%)**
AMP	*Notopoma* sp	49	2	11.2
AMP	Amphipoda sp.	25	4	5.7
SIP	Sipuncula und.	24	6	5.5
BIV	*Bentharca asperula*	22	5	5.0
BIV	*Limopsis aurata*	15	5	3.4
POL	*Pholoides dorsopapillatus*	12	5	2.7
POL	*Prionospio* sp.	12	2	2.7
AMP	*Harpinia* sp.	12	7	2.7
OPH	*Amphipholis* squamata	12	5	2.7
POL	*Lysippides* cf. *fragilis*	11	5	2.5
TAN	cf. *Leptognathia*	11	3	2.5

The Shannon-Wiener diversity values (Table 4) varied between 2.02 and 3.32 and the evenness was usually higher than 0.9 except in three samples (12712, 12739 and 12759). The k-dominance curves (Figure 12) confirm the results obtained with the H’ and J’ indexes showing the low dominance and high diversity in the different assemblages. The first dominant species in each sample always accounted for no more than 10 to 40% of the total abundance.

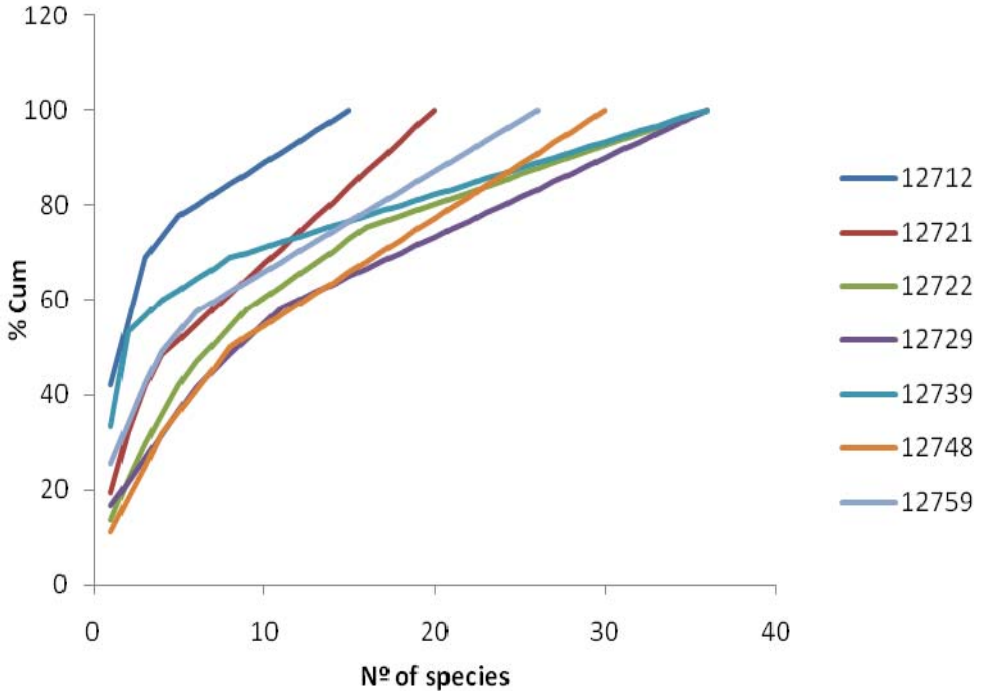


Figure 12 - k-dominance curves between the 7 samples from the Moroccan margin.

For the analysis of the biomass, large sessile organisms such as sponges and cnidarians showed biomass estimates that are one order of magnitude higher than the smaller macrofaunal groups and therefore they were kept separately (Figure 13). The biomass community structure of the smaller macrofauna is very different from the abundance community structure already described above the dominant groups in terms of biomass are the echinoderms and bivalves (and not the crustaceans and polychaetes) and the heterogeneity among samples is higher when the biomass of the different groups (instead of their abundance) is considered (Figure 14).

The average biomass of the sessile taxa was estimated as 57.69±57.65g_{FW}.m^2 for the Spanish margin and 347.0±223.72$g_{FW.}$$m^{-2}$ for the Moroccan margin. For the smaller macrofaunal groups the values were 97.9±88.39g_{FW}.m^{-2} for the Spanish margin and 34.9±12.64g_{FW}.m^{-2} for the Moroccan margin.

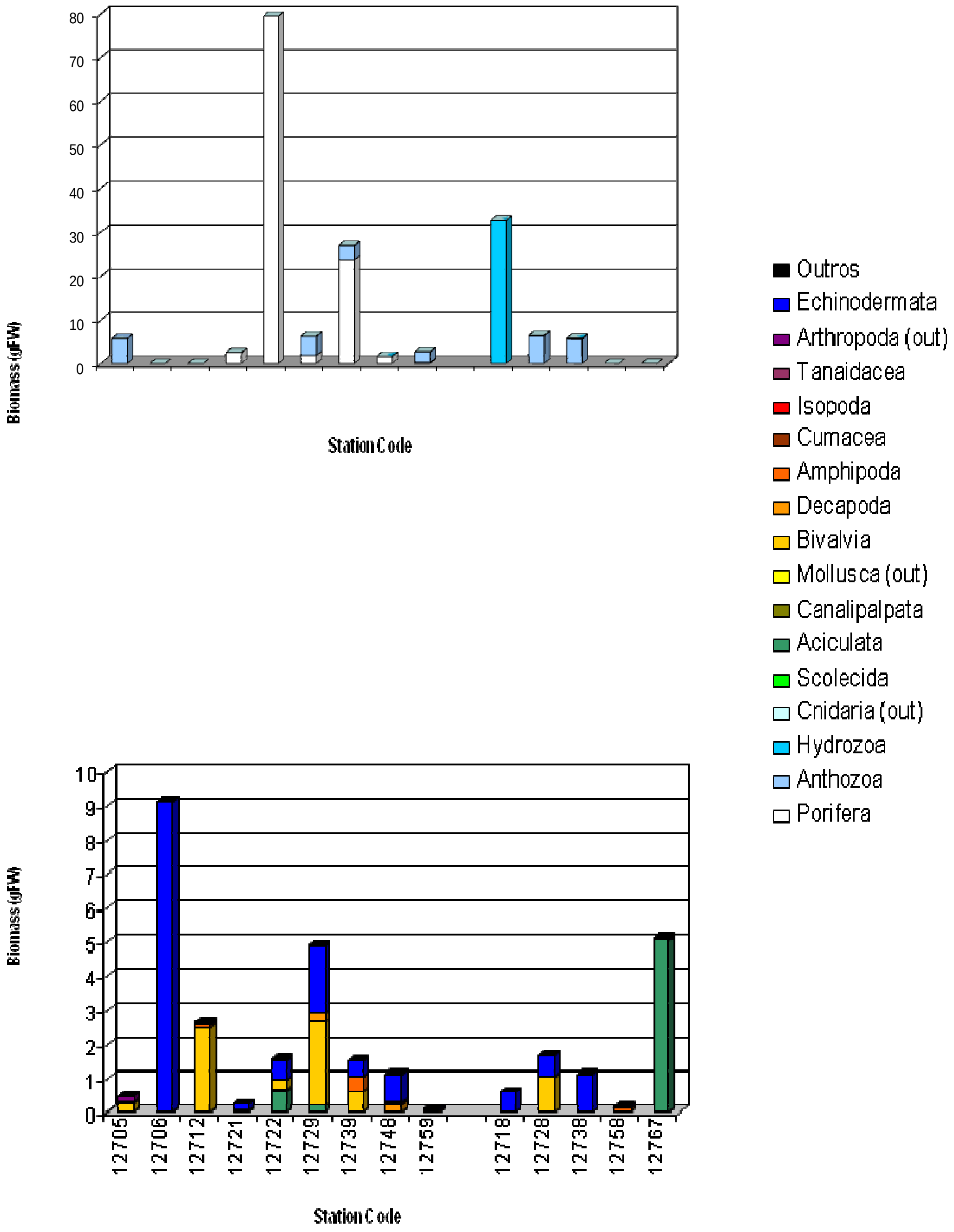


Figure 11 - Biomass of the different taxa (fresh weight) for all stations. ROV stations are shown in the right side. Sessile organisms are shown separately (top) as they represent biomasses one order of magnitude higher than the smaller macrofauna.

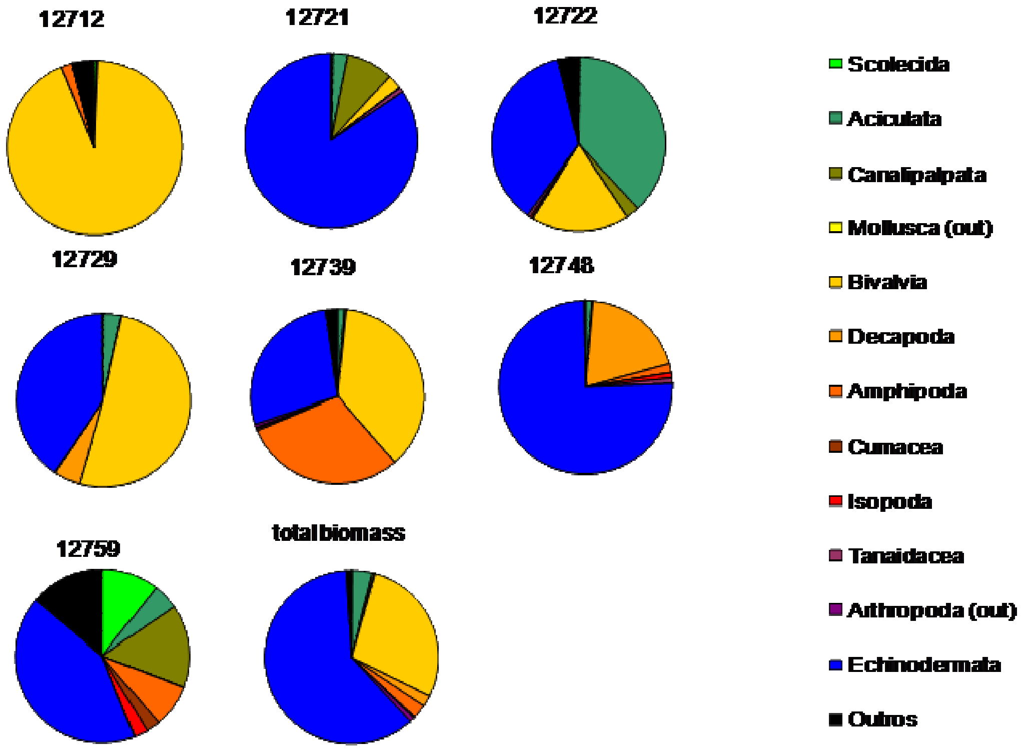


Figure 14 – Community structure of the macrofaunal samples in terms of biomass. Large sessile animals such as sponges and cnidarians were not considered.

4. DISCUSSION

This work contributed with a first effort to compile visual information on the composition of megafaunal assemblages in the Carbonate Mound Provinces of the Gulf of Cadiz. Once the verification of the identifications by specialist taxonomists will be made, the Atlas that was compiled from the photo frames taken with the ROV will be a extremely helpful tool in future work in this region and in the characterization of cold-water coral habitats. The record of traces of man's impact on the seafloor is also an important contribution as it can be a powerful outreach instrument and a call for attention on the conservation and management needs of deep-sea ecosystems.

A total of 145 macrobenthic invertebrates were identified in the samples collected during the cruise 64PE284 in the carbonate mound provinces along the Spanish and Moroccan margins of the Gulf of Cadiz. From the taxa listed, approximately one third are new records of species for carbonate and cold-water coral habitats in this region. Considering that only nine quantitative samples (accounting for a total area of 0.44m^2) and five occasional ROV samples were analysed, these results are indicative that our knowledge of the biodiversity of these habitats is far from complete. Arthropoda, Annelida and Cnidaria were the major taxonomic groups represented in the samples. A previous study carried out in the Pen Duick Escarpment (Gulf of Cadiz) also indicates these groups as the most representative among the samples analyzed (Almeida 2009)

The scleractinian assemblages of the Gulf of Cadiz share many similarities with the ones from the northeast Atlantic margin, where carbonate mounds have been identified as the ideal substrate for the development of coral reefs (Roberts 2003). These carbonate mounds are often dominated by the settlement of *Lophelia pertusa*. As shown by previous studies (Wheeler et al. 2007), *Lophelia pertusa* prefer the deeper areas, with higher concentration of food particles, to grow. The highest concentrations of *Lophelia pertusa* were found in the stations 12739 and 12748, both in carbonates mounds deeper than 700 m.

The carbonate mounds and fossil coral reefs that occur in the Gulf of Cadiz are highly suitable for the settlement of sessile animals such as sponges cnidarians and crinoids. The coral framework also operates as a shelter for animals of various species crustaceans, mollusks and polychaetes as already noticed by Almeida (2009). One of the polychaetes found living in the coral framework in this study was *Eunice norvegicus*. This polychaete has been referred to have a symbiotic relationship with the coral (Costello, 2005) and to have a cleaning function of the skeletons of corals and their fragments (Reed 2006). In the present study a high abundance and taxa richness was observed especially in the samples that yielded coral framework in the surface of the sediments (12722 and 12729 from the Central Carbonate Mounds; 12739 and 12748 from the carbonates mounds around Meknes mud volcano). Whereas the highly diverse and abundant samples from the Moroccan margin were collected in carbonate mounds, the two samples from the Spanish margin were collected from mud volcanoes and showed a much lower abundance and taxa richness. It is likely that coral and carbonate areas in the Spanish margin may also yield abundant and rich macrofaunal assemblages.

The results of this study can be compared with those of a similar study carried out in the Pen Duick Escarpment (Almeida 2009, Table 7). The communities associated with the coral reefs are similar in the Moroccan margin and the Pen Duick Escarpment, and both studies have a similar number of expected species ($ES_{(200)}$=80). Values of species richness, abundance and biomass were very variable between the studied stations. The high variability in the assemblages studied in the Moroccan margin has also been found in the study of the Pen Duick Escarpment where the samples were also heterogeneous and yielded different assemblages with low dominance and high diversity. For further comparisons with other studies more samples would be necessary once the number of samples and sampled area in this study were very small (nine sample representing less than 0.5 m^2). Despite this, the results obtained in this study contribute the knowledge of this poorly studied region of the NE Atlantic Ocean.

Table 3 – Comparison of the studies on cold-water coral from the Gulf of Cadiz. St: number of stations

Locality	St.	Area (m^2)	Method	Taxa	Depth (m)	
Pen Duick Escarpment	83	----	Box-core	293	227 -682	Almeida 2009
Pen Duick Escarpment	41	2.01	Box-core	93	227 -678	Almeida 2009
Carbonate Provinces	9	----	Box-core	145	520-907	This study

Final remarks

A major difficulty encountered in this work was the small amount of material available for the research. Only few samples could be analyzed and the data obtained was not sufficient for a detailed study and interpretation. The variability in the results did not allow inferring on which factors control the diversity in the cold-water coral reefs in the Gulf of Cadiz.

It is however possible to conclude that coral reefs and carbonate mounds in the Moroccan margin of the Gulf of Cadiz largely contribute to the diversity found in this region since they provide hard substrate and shelter that are essential for the establishment of a wealth of benthic organisms. The destruction of scleractinean corals by anthropogenic activities can result in an important loss of habitat and biodiversity. Because of their slow growth rate, corals are at serious risk of collapse in the upcoming years and with them an unimaginable chain of species that might never be studied.

With the present studies in the deep Gulf of Cadiz is still difficult to quantify the species that inhabit this region, but the rate of new records reported in each study suggests that this is an area with a surprisingly high biodiversity. Further studies in the Gulf of Cadiz should allow discoveries of more new species and the understanding of the dynamics of its populations.

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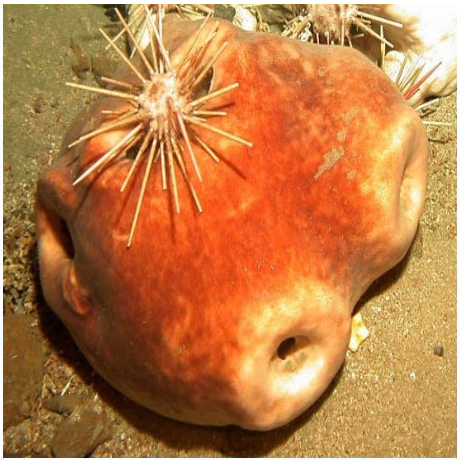
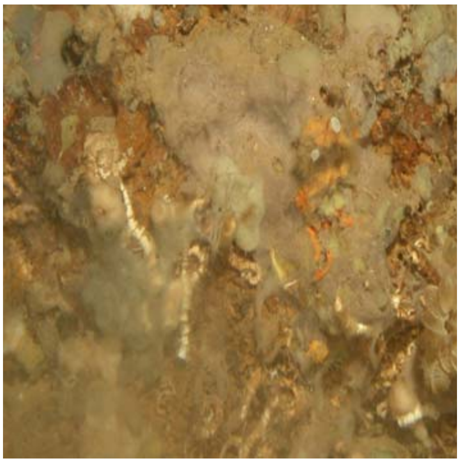
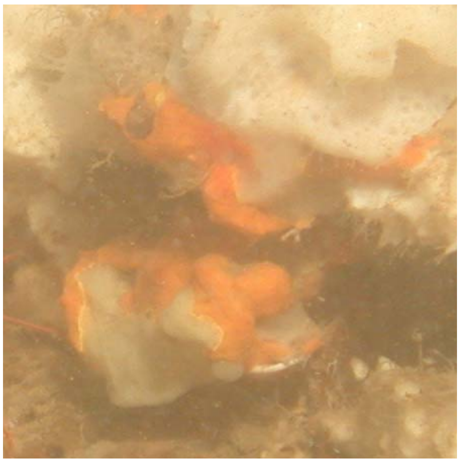
ANNEX I

Selected images from dive surveys of the studied areas

Porifera





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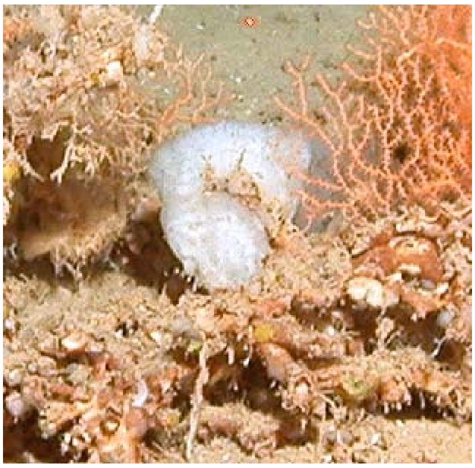
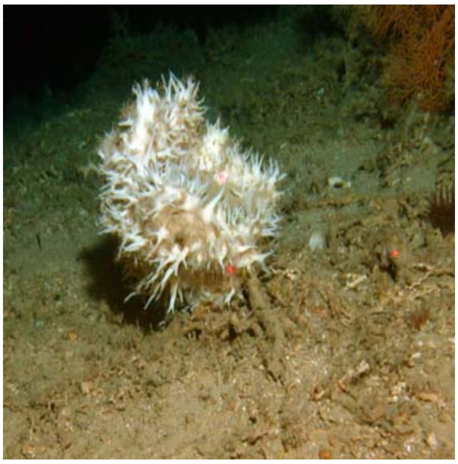


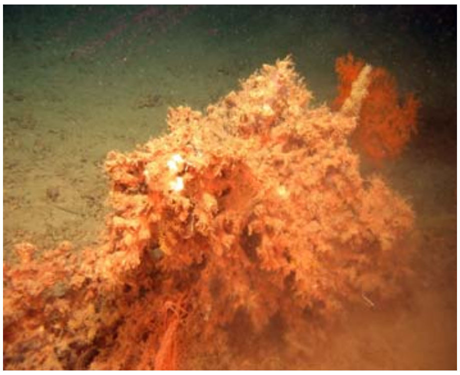
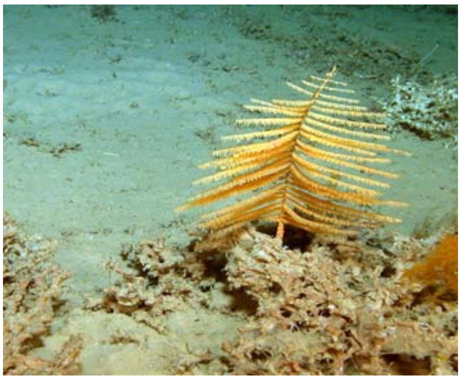


Cnidaria





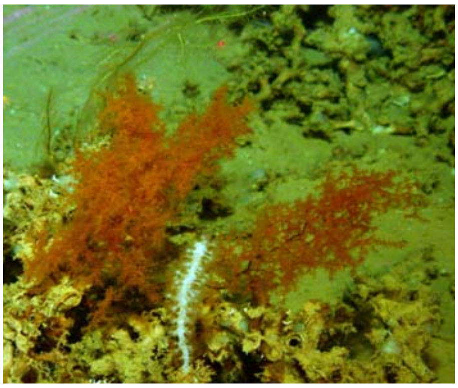
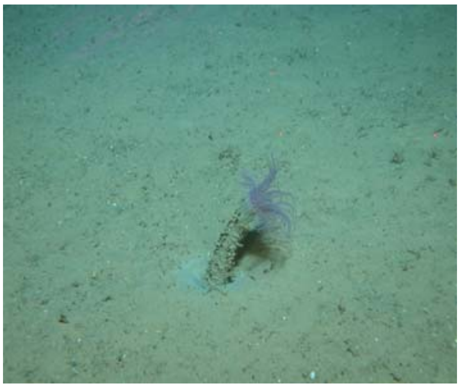
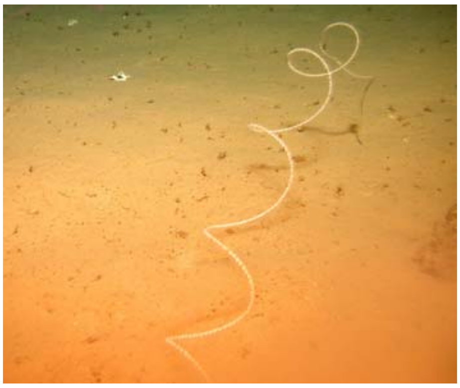
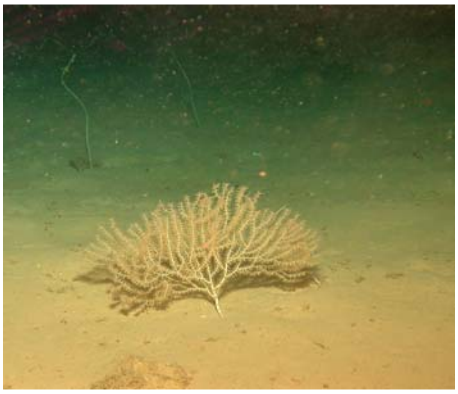


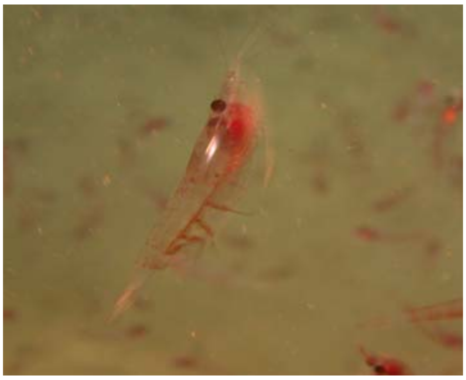
Cnidaria

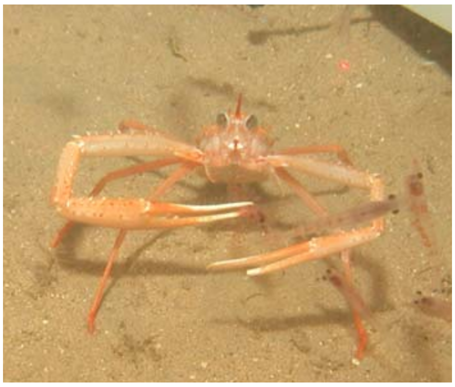




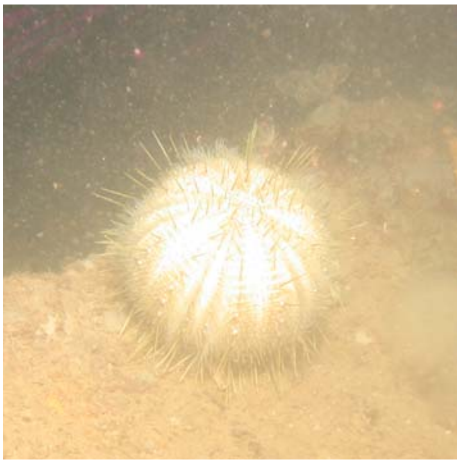





Arthropoda

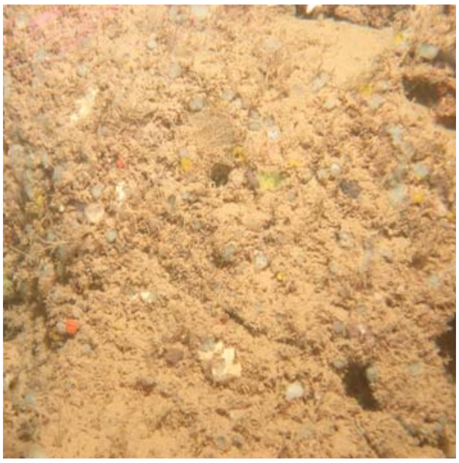




Echinodermata

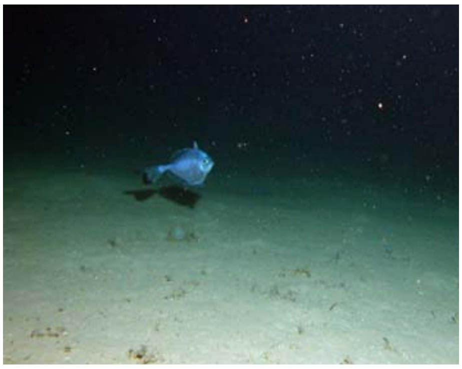
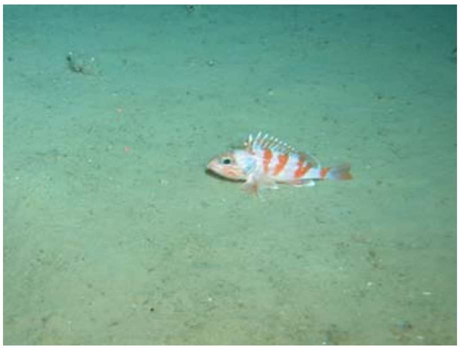
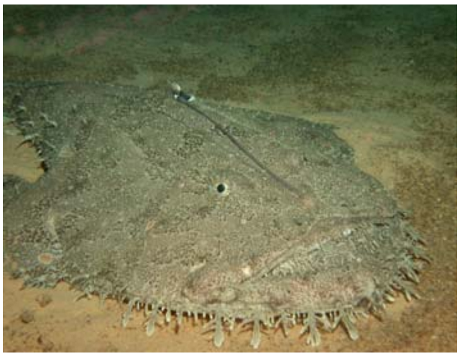


Brachiopoda



Chordata



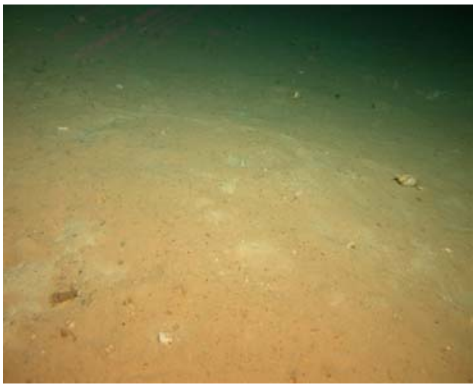
Bioturbation

Burrow Cluster

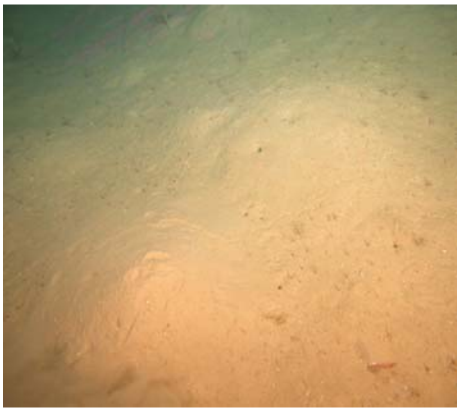
Paired Burrow

Oblique Burrow

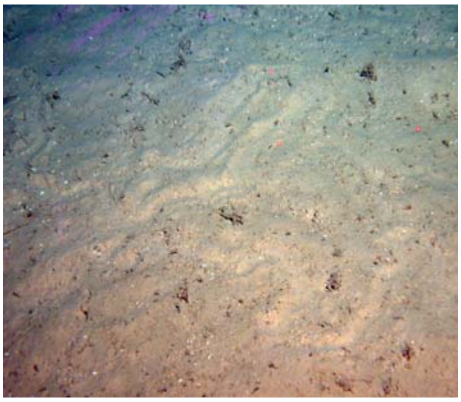
Small Mound



Large Mound

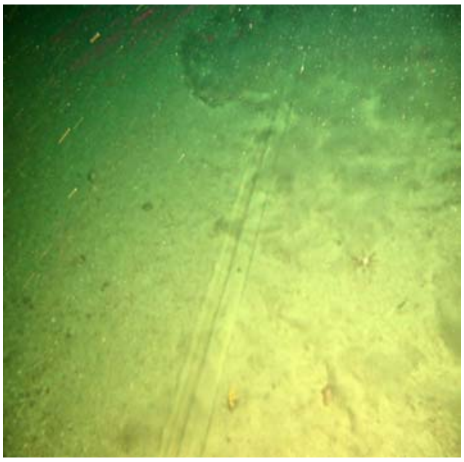


Elongate Depression



Anthropogenic Impacts

Trawling mark



Lost fishing line

Litter

ANNEX II

LIST OF THE TAXA IDENTIFIED IN ALL SAMPLES

Phyllum PORIFERA Grant, 1836

Porifera undetermined (several species)

Class Hexactinellida Schmidt, 1870

SubClass Hexasterophora Schulze 1886

Order Hexactinosida Schrammen 1912

Family Aphrocallistidae Gray 1867

Genus *Aphrocallistes* Gray 1858

Aphrocallistes sp

Phyllum CNIDARIA Hatscheck, 1888

Class Anthozoa Ehrenberg, 1834

SubClass Hexacorallia Haeckel, 1866)

Order Scleractinia Bourne, 1900

Family Flabellidae (Bourne, 1905)

Genus *Flabellum* Lesson 1832

Flabellum sp SubClass Octocorallia Haeckel, 1866

SubClass Octocorallia Haeckel, 1866

Order Alcyonacea

Family Clavulariidae Hickson, 1894

Clavularia sp

Order Gorgonacea Lamouroux, 1816

Family Paramuceidae Bayer, 1956

Sp1

Sp2

SubOrder Calcaxonia

Family Isididae Lamouroux, 1812)

Genus *Chelidonisis* Studer, 1890

Chelidonisis aurantiaca Studer 1890

Class Hydrozoa Owen,1843

SubClass Hydroidolina Collins & Marques, 2004

Order Anthoathecatae Cornellius, 1992

Family cf. Stylasteridae

cf Stylasteridae ***ndetermined ****

SubOrder Filifera Kühn, 1913

Family Eudendriidae L. Agassiz, 1862

Genus *Eudendrium* Ehrenberg, 1834

Eudendrium **sp**

Order Leptothecata Cornelius, 1992

SubOrder Conica Broch, 1910

Family Lafoeidae Hincks, 1868

Genus *Acryptolaria* Norman, 1875

Acryptolaria conferta Allman, 1877

Genus *Cryptolaria* Busk, 1857

Cryptolaria pectinata Allman, 1888

Genus *Zygophylax* Quelch, 1885

Zygophylax biarmata Billard, 1905

Genus *Kirchenpaueria* Jickeli, 1883

Kirchenpaueria pinnata Linnaeus, 1758 *

Family Sertulariidae Lamouroux, 1812

Genus *Serturella* Ellisia Westendorp, 1843

Sertularella gayi (Lamouroux, 1821)

SubOrder Proboscoida Broch, 1910

Family Campanulariidae Johnston, 1836

Genus *Campanularia* Lamarck, 1816

Campanularia hincksii Alder, 1856

Genus *Clytia* Lamouroux, 1812

Clytia linearis Thorneley, 1900

Class Scyphozoa Götte, 1887

Order Coronatae Vanhöffen, 1892

Family Nausithoidae Bigelow, 1913

Genus *Nausithoe* Kölliker, 1853

Nausithoe **Phylum Sipuncula** Rafinesque, 1814

Phylum Sipuncula Rafinesque, 1814

Class Sipunculidae

Order Golfingiida

Sipuncula Undetermined

Phylum Annelida Lamarck, 1809

Class Polychaeta Grube, 1850

Order Capitellida

Family Capitellidae Grube 1862

Capitellidae undetermined

Capitellidae Sp1

Notomastus sp

Family Maldanidae Malmgren 1867

Maldanidae Undetermined

Maldanidae sp1

Maldanidae sp2

Order Orbiniida

Family Orbiniidae Hartman 1942

Genus *Leitoscoloplos* Day 1977

Leitoscoloplos mammosus Mackie 1987

Family Paraonidae Cerruti 1909

Paraonidae undetermined

Paraonidae sp1

cf. Aricidea fragilis mediterranea Laubier & Ramos 1974

Aricidae simonae

Order Amphinomida

Family Amphinomidae Lamark 1818

Pareurythoe borealis Sars 1862

Order Eunicida

SuperFamily Eunicea

Family Eunicidae Savigny, 1818

Genus *Eunice* Cuvier 1817

Eunice dubitatus Fauchald 1974

Eunice norvegica Linnaeus 1767

Genus Lysidice Lamark 1818

Lysidice ninetta Audouin & Milne-Edwards

Family Lumbrineridae Malmgren 1867

Genus *Lumbrineriopsis* Orensanz 1973

Lumbrineriopsis paradoxa Saint-Joseph 1888

Family Onuphidae Kinberg 1865

Genus ***Paradiopatra***

Paradiopatra hispanica Amoureux 1972

Order Terebellida Rouse & Fauchald, 1997

Family Ampharetidae Malmgren, 1866

Ampharetidae Undetermined

SubFamily Ampharetinae

cf. Eclysippe Eliason 1955

Genus *Lysippides* Hessle 1917

cf.Lysippides fragilis Wollebaeck 1912

Family Sabellariidae

Genus *Phalacrostemma* Marenzeller 1895

Phalacrostemma sp1

Order Spionida Rouse & Fauchald, 1997

SubOrder Chaetopteriformia

Family Chaetopteridae

Spiochaetopterus sp Sars 1853

SubOrder Spioniformia

Family Poecilochaetidae

Genus *Poecilochaetus* Claparéde 1875

Poecilochaetus sp

Family Magelonidae

Genus *Magelona*

Magelona wilsoni Glémarec 1966

Family Spionidae G.O. Sars 1872

Genus *Prionospio* Malmgren 1867

Prionospio sp

Genus ***Scolelepis***

Scolelepis sp

Genus *Spiophanes* Grube 1860

Spiophanes sp

SubOrder Cirratuliformia

Family Cirratulidae Ryckholt, 1851

Cirratulidae undetermined

Dodecaceria sp

Order Flabelligerida

Family Flabelligeridae

Flabelligeridae undetermined

Order Fauveliopsida

Family Fauveliopsidae

Genus *Fauveliopsis*

Fauveliopsis sp

Order Phyllodocida

SubOrder Glyceriformia

Family Glyceridae Grube 1850

Genus *Glycera* Savigny 1818

Glycera tesselata Grube 1840

Family Goniadidae Kinberg 1866

Goniadidae sp

SubOrder Phyllodociformia

Family Phyllodocidae

SubFamily Phyllodocinae Williams 1851

Genus *Phyllodoce* Savigny 1818

cf. Phyllodoce maculate Linnaeus 1767

Phyllodoce madeirensis Langerhans 1880

SubOrder Nereidiformia

Family Hesionidae Sars 1862

Leocatres atlanticus Mc Intosh 1885

Family Syllidae Grube 1850

SubFamily Exogoninae Langerhans 1879

Genus *Exogone* Orsted 1845

Exogone sp

Genus *Sphaerosyllis* Claparede 1863

cf. Sphaerosyllis pirifera Claparede 1868

SubFamily Syllinae Grube 1850

Genus *Haplosyllis* Langerhans 1879

Haplosyllis spongicola

Family Pilargidae Saint-Joseph 1899

Genus *Synelmis* Chamberlin 1919

Synelmis sp

SubFamily Eusyllinae Malaquin 1893

Genus *Pionosyllis* Malmgren 1867

Pionosyllis enigmatica Wesenberg Lund 1950

SubOrder Phyllodocida incertae sedis

Family Nephtyidae

cf. Aglaophamus elamellata

SuperFamily Aphroditoidea

Family Pholoidae Kinberg 1857

Pholoides dorsopapillatus

Family Sigalionidae Kinberg 1856

Sigalionidae undetermined

SubFamily Polynoidae Kinberg 1856

Genus *Harmothoe* Kinberg 1856

cf. Harmothoe evei Kirkegaard 1980

Genus *Subadyte* Pettibone 1969

Subadyte pellucida Ehlers 1864

Order Oweniida

Family Oweniidae

Genus *Galathowenia* Kirkegaard 1959

Galathowenia oculata Zachs 1922

Order Sabellida

Family Sabellidae

Sabellidae undetermined

Family Siboglinidae

Genus *Siboglinum* Caullery 1914

Siboglinum sp

Phylum Arthropoda

Class Pycnogonida *Latreille 1810*

Pycnogonida undetermined

Class Malacostraca

Order Mysida Haworth 1825

Mysida undetermined

Order Decapoda Latreille 1803

Family Alpheidae Rafinesque 1815

Genus Alpheus Weber 1795

Alpheus sp

Family Cymonomidae Bouvier 1897

Genus *Cymonomus* Milne-Edwards 1881

Cymonomus granulatus Norman 1873

Family Galatheidae

Genus *Munida* Leach 1820

cf. Munida Intermedia

Order Euphausiacea

Euphausiacea undetermined

Order Amphipoda Latreille 1816

Amphipoda undetermined

Amphipoda undetermined spA

Amphipoda undetermined spB

SubOrder Gammaridea Latreille 1802

InfraOrder Gammarida Latreille

- Family Ampeliscidae Costa 1857
    - Genus *Ampelisca* Kroyer 1842
        - cf. ***Ampelisca dalmatina Karaman 1975***
    - Genus *Haploops* Liljeborg 1856
        - ***Haploops proxima Chevreux 1919***
- Family Amphilochidae Boeck 1871
    - Genus *Gitana* Boeck 1871
        - ***Gitana sp***
- Family Isaeidae Dana 1853
    - Genus *Gammaropsis* Liljeborg 1855
        - ***cf. Gammaropsis sp***
- Family Phoxocephalidae Sars 1891
    - Genus *Harpinia* Boeck 1876
        - ***Harpinia sp***
- Family Iphimediidae boeck 1871
    - Genus *Iphimedia* Rathke 1843
        - ***cf. Iphimedia obesa Rathke 1843***
- Family Ischyroceridae Stebbing 1899
        - ***Ischyroceridae undetermined***
    - Genus *Notopoma*
        - ***Notopoma sp***
- Family Lysianassidae Dana 1849
        - ***Lysianassidae undetermined sp A***
- Family Carangoliopsidae Bousfield 1977
    - Genus *Carangoliopsis*
        - ***Carangoliopsis spinulosa*** Ledoyer 1970
- Family Melitidae Bousfield 1973
    - Genus *Eriopisa* Wrzesniovsky 1890
        - ***Eriopisa elongata*** Bruzelius 1859

SuperFamily Eusiroidea Bousfield 1979

- Family Eusiridae Stebbing 1888
    - Genus *Eusirus* Kroyer 1845
        - ***Eusirus longipes*** Boeck 1861

SubOrder Corophiidea
  InfraOrder Corophiida
    Family Aoridae Walker 1908
        Aoridae undetermined
  InfraOrder Caprellida Leach 1814
   SuperFamily Caprelloidea Leach 1814
    Family Caprellidae Leach 1814
      Genus *Liropus* Mayer 1890
        Liropus elongata Mayer 1890
  SubOrder Hyperiidea Milne Edwards 1830
  InfraOrder Physocephalata Bowman & Gruner 1973
   SuperFamily Phronimoidea Rafinesque 1815
    Family Hyperiidae H. Milne Edwards 1830
      Genus *Euthemisto* Bovallius 1887
        Euthemisto sp
  InfraOrder Physosomata Pirlot 1929
   SuperFamily Scinoidea Stebbing 1888
    Family Proscinidae
      Genus *Euprimno*
        Euprimno macropus
Order Cumacea Kroyer 1846
        Cumacea undetermined
    Family Nannastacidae Bate 1866
      Genus *Campylaspis* G.O. Sars 1865
        Campyilaspis sp
        Campylaspis undetermined
    Family Leuconidae Sars 1878
      Genus *Leucon* Kroyer 1846
        Leucon sp
        ***Leucon* undetermined**
Order Isopoda Latreille 1817
  SubOrder Asellota Latreille 1802
   SuperFamily Janiroidea Sars 1897
    Family Paramunnidae Vanhoffen 1914
      Genus *Pleurogonium* G.O. Sars 1864
        Pleurogonium pulchrum Hansen 1916

Family Desmosomatidae G.O. Sars 1897

Genus *Chelator* Hessler 1970

Chelator sp

Genus *Eugerdella* Kussakin 1965

Eugerdella sp

Family Munnidae Sars 1897

Genus *Munna* Kroyer 1839

Munna sp

Family Munnopsidae Lilljeborg 1864

SubFamily Eurycopinae Hansen 1916

Genus E*urycope* Sars 1864

Eurycope sp

Genus *Disconectes* Wilson & Hessler 1981

Disconectes sp

SubFamily Ilyarachninae Hansen 1916

Genus *Ilyarachna* Sars 1870

Ilyarachna sp

Family Thambematidae Stebbing 1913

Genus *Thambema* Stebbing 1912

Thambema sp

SubOrder Cymothoida Wagele 1989

SuperFamily Anthuroidea Leach 1914

Family cf. Leptanthuridae Poore 2001

cf. Leptanthuridae undetermined

Order Tanaidacea Dana 1849

SubOrder Apseudomorpha Sieg 1980

SuperFamily Apseudoidea Leach 1814

Family Apseudidae

Genus *Apseudes*

Apseudos sp 016

Apseudos sp 017

Apseudos sp 019

Family Sphyrapidae Gutu 1980

SubFamily Pseudosphyrapinae

Genus *Sphyrapus* Sars 1882

Sphyrapus sp

Sphyrapus malleolus Norman & Stebbing 1886

SubOrder Tanaidomorpha Sieg 1980

SuperFamily Paratanaoidea Lang 1949

Family Tanaellidae Larsen & Wilson 2002

Genus *Tanaella* Norman & Stebbing 1886

Tanaella unguicillata Norman & Stebbing 1886

Family cf. Typhlotanaidae Sieg 1986

cf. Typhlotanaidae Undetermined

Family Pseudotanaidae Sieg 1976

Pseudotanaidae sp

Family Leptognathiidae Lang 1976

SubFamily Leptognathiinae Sieg 1973

Genus *Leptognathia* sars 1882

cf. Leptognathia sp

Phylum Mollusca Linnaeus 1758

Class Aplacophora

Aplacophora undetermined

Class Polyplacophora Gray 1821

Polyplacophora undetermined

Class Gastropoda Cuvier 1795

Order Hypsogastropoda

Family Rissoidae Gray 1847

Genus *Alvania* Risso 1826

Alvania sp

Family Eulimidae Philippi 1853

Eulimidae undetermined

Class Bivalvia Linnaeus 1758

Order Arcoida Stoliczka 1871

Family Arcidae Lamark 1809

Genus *Bathyarca* Kobelt 1891

Bathyarca philippiana Nyst 1848

Genus *Bentharca* Verril & Bush 1898

Bentharca asperula Dall 1881

Family Limopsidae Dall 1895

Genus *Limopsis* Sassi 1827

Limopsis aurita Brocchi 1814

Limopsis aurita juvenil

Order Mytiloida Ferussac 1822

Family Mytilidae Rafinesque 1815

Genus *Dacrydium* Torell 1859

Dacrydium balgimi Salas & Gofas 1997

Order Nuculoida

SuperFamily Nuculoidea

Family Nuculidae Gray 1824

Nuculidae undetermined

Nuculidae sp1

Genus *Ennucula* Iredale 1931

Ennucula aegeensis Forbes 1844

Order Pteriomorpha

SuperFamily Limoidae

Family Limidae Rafinesque 1815

Genus *Lima* Bruguière 1797

Lima sp

Order Ostreoida Walker 1978

SuperFamily Pectinoidea Rafinesque 1815

Family Pectinidae Rafinesque 1815

Genus *Delectopecten* stewart 1930

Delectopecten vitreus Gmelin 1791

Phylum Echinodermata Bruguière 1791

Class Crinoidea Miller 1821

Order Comatulida A.H. Clark

SuperFamily Mariametracea A.H. Clark 1909

Family Himerometridae A.H. Clark 1907

Genus *Antedon*

Antedon sp

Class Asteroidae de Blainville 1830

Asteroidae undetermined

Class Ophiuroidea Gray 1840

Ophiuroidea undetermined

Order Ophiurida Muller & Troschel 1840

Family Amphiuridae Ljungman 1867

Genus *Amphipholis*

Amphipholis squamata Delle Chiaje 1828

Genus *Amphiura* Forbes 1843

Amphiura sp

Family Amphilepididae Matsumoto 1915

Genus *Amphilepis* Ljungman 1867

Amphilepis ingolfiana Mortensen 1933

Class Echinoidea Leske 1778

Order Cidaroida

Family Cidaridae

Cidaridae undetermined

Order Spatangoida

Family Brissidae

Genus *Brissopsis* L. Agassiz & Desor 1847

Brissopsis lyrifera Forbes 1841

Phyllum Brachiopoda Duméril 1806

Brachiopoda sp1

Class Rhynchonellata

Order Terebratulida

Family Terebratulidae Gray 1840

Genus *Gryphus* Megerle von Muhlfeld 1811

Gryphus vitreus Born 1778

Phylum Chordata Bateson 1885

Class Ascidiacea Nielsen 1995

Ascidiacea undetermined