Universidade de Aveiro Departamento de Biologia
Ano 2018

RENATO JOSÉ BRAZ MAMEDE

HABITATS BENTÓNICOS DA PLATAFORMA CONTINENTAL PORTUGUESA A NORTE DO CANHÃO DA NAZARÉ: CARACTERIZAÇÃO, MODELAÇÃO E MAPEAMENTO

THE PORTUGUESE CONTINENTAL SHELF HABITATS NORTH OF NAZARÉ CANYON: CHARACTERIZATION, MODELLING AND MAPPING

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Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Biologia, realizada sob a orientação científica do Doutor Victor Quintino, Professor Auxiliar do Departamento de Biologia da Universidade de Aveiro e sob a coorientação científica da Doutora Rosa de Fátima Lopes de Freitas, Investigadora Auxiliar do Departamento de Biologia da Universidade de Aveiro

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Dedico esta trabalho à Márcia pelo suporte e compreensão diários, sem os quais este desfecho não teria sido possível.

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agradecimentos

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palavras-chave

plataforma continental portuguesa; habitats marinhos de substrato móvel; macrofauna bentónica; acústica de feixe simples; interpolação espacial; modelos de distribuição; mapeamento; EUNIS; estado ambiental; valor biológico marinho.

resumo

Os habitats bentónicos são um componente importantíssimo do ambiente marinho, sendo isto particularmente evidente devido ao papel determinante da macrofauna a si associada nas teias alimentares marinhas. A caracterização e mapeamento destes habitats assumem particular relevância no estudo dos ecossistemas marinhos. Este trabalho tinha como objetivos principais combinar métodos de amostragem tradicional e técnicas acústicas de deteção remota, desenvolvendo novas estratégias de modelação e mapeamento, para detalhar e caracterizar os habitats bentónicos e macrofauna associada na secção da plataforma continental portuguesa a norte do canhão da Nazaré. Abrangendo uma área de aproximadamente 7000Km^2, foram obtidos dados sedimentares e de profundidade em 226 amostras coletadas com uma draga, 169 das quais foram utilizadas no estudo da macrofauna. Adicionalmente, mais de 2500Km de transectos acústicos foram adquiridos.

Os dados sedimentares pontuais foram explorados de duas formas: i) usando interpolação espacial com “Empirical Bayesian Kriging”, na produção de mapas dos descritores sedimentares finos%, areia%, cascalho% e curtose, e dos sedimentos classificados de acordo com o sistema MeshAtlantic-Folk; ii) utilizando análises estatísticas univariadas e multivariadas, de modo a relacionar os dados sedimentares com a distribuição espacial da macrofauna.

Os dados acústicos foram adquiridos com o sistema acústico de discriminação de fundos QTC VIEW série V, de forma a serem utilizados em modelos de distribuição de macrofauna bentónica, em substituição dos dados ambientais. Lamentavelmente, não foi possível explorar esta enorme quantidade de dados acústicos obtidos, visto que estes demonstraram estar contaminados pela profundidade, invalidando o seu uso na discriminação dos tipos sedimentares. No entanto, os dados de profundidade obtidos com este sistema permitiram a produção de um mapa batimétrico preciso da área de estudo, sendo utilizado posteriormente como parte dos mapas de variáveis ambientais.

A utilização de diversos métodos de análise estatística univariada e multivariada permitiu o estudo da distribuição espacial de índices biológicos e das comunidades de macrofauna. Modelos de distribuição relacionando a abundância, riqueza específica (ou diversidade alfa) e o índice de diversidade de Shannon-Wiener com parâmetros sedimentares e a profundidade foram desenvolvidos, utilizando diversos tipos de modelos de regressão. Para cada índice biológico, as previsões do modelo mais preciso foram comparadas com as previsões da interpolação espacial realizada diretamente sobre os dados biológicos usando métodos geoestatísticos. Na área de estudo, foram identificadas sete comunidades, sendo desenvolvidos modelos de distribuição de comunidades (CDM, do inglês “communities distribution models”), baseados em modelos de regressão binomial, estudando a relação da presença/ausência de cada comunidade com as variáveis ambientais. Através da combinação dos CDM e dos mapas das variáveis ambientais, foi produzido um mapa que representa a distribuição da comunidade de macrofauna bentónica mais provável. Este mapa combinado foi utilizado na classificação e mapeamento da distribuição dos tipos de habitat EUNIS nível 5 e na avaliação do seu estado ambiental no âmbito da Diretiva Quadro Estratégia Marinha, através da produção de um mapa do valor biológico marinho de tais habitats EUNIS.

Os mapas bentónicos produzidos nesta tese, tanto os ambientais como os biológicos, são importantes ferramentas adequadas a um conjunto de propósitos no contexto da gestão dos ecossistemas marinhos, como a monitorização, controlo de espécies não indígenas, ordenamento espacial e estudos das alterações climáticas.

keywords

Portuguese continental shelf; marine soft-sediment habitats; benthic macrofauna; single-beam acoustics; spatial Interpolation; distribution models; mapping; EUNIS; environmental status; marine biological valuation.

abstract

Benthic habitats are an important component of the marine realm, being this evident by the key role of their associated macrofauna on the marine food webs. Their characterization and mapping assume special relevance in marine ecosystem studies. The main aims of this work were to combine traditional sampling methods with an acoustic remote sensing technique and developing novel modelling approaches, to detail and characterize the benthic habitats and associated macrofauna in the section of the Portuguese continental shelf north of Nazaré canyon. Covering an area of approximately 7000Km^2, baseline sediment data and depth were obtained in 226 grab samples, 169 of which were used to study the macrofauna. Also, acoustic transects were run for more than 2500Km.

The point sediment data were exploited in two ways: i) using spatial interpolation with Empirical Bayesian Kriging, to produce maps of the sediment descriptors fines%, sand%, gravel% and kurtosis, and of the sediment types classified according to the MeshAtlantic-Folk system; ii) using univariate and multivariate statistical analysis, to relate the sediment data with the spatial distribution of the macrofauna.

The acoustic data were collected using the acoustic ground discrimination system QTC VIEW series V, to be used as a surrogate for the environmental data in distribution modelling studies of the benthic macrofauna. Unfortunately, it was not possible to exploit the large amount of acoustic data obtained as it demonstrated to be contaminated by depth, invalidating its use to discriminate sediment types. Nevertheless, the bathymetry data collected with this system allowed to obtain an accurate bathymetric map of the study area, further used as part of the environmental variables layers.

Using a wide range of univariate and multivariate data analysis methods, the spatial distribution of macrofauna indices and communities were studied. Distribution models relating the abundance, species richness (or alpha diversity) and Shannon-Wiener diversity with sedimentary parameters and depth were built, using diverse types of regression models. For each biologic index, the predictions from the most accurate model were compared with the predictions of the direct spatial interpolation of the biological data using geostatistical methods. Seven macrofauna communities were identified in the study area, and communities distribution models (CDM) were built, based on binomial regression models, studying the relation of the presence/absence of each community with respect to the environmental variables. Combining the CDM and the maps of the environmental variables, a map representing the distribution of the most probable benthic macrofauna communities was produced. This overall map was used to classify and map the distribution of level 5 EUNIS habitat types and to evaluate their environmental status in the scope of the Marine Strategy Framework Directive, by producing a Marine Biological Valuation map of such EUNIS habitats.

The benthic maps produced in this work, either the environmental or the biological, are valuable tools suitable for a range of purposes in the context of the marine ecosystem management, such as monitoring, non-indigenous species control, spatial planning or climate change studies.

Contents

List of Figures

List of Tables

Chapter 1. Introduction

1.1 Marine environment value

The oceans contain 97% of the water and cover near three-quarters of the planet. Oxygen production, carbon dioxide sink, fisheries, shipping routes, weather control and water cycle are among the services provided by the marine environment, influencing the climate and the economy worlwide[1,2*]. Despite of this, only a small portion of the ocean ecosystems were adequately studied[3]. Comprised in the larger group of the aquatic ecosystems, the marine environment is characterized by a relatively high salt content in the water and is usually sub-divided in three main groups: the intertidal, the coastal and the oceanic, embracing more than 20 major recognized ecosystems (e.g. salt marshes, coral reefs, deep seamounts, soft shelf sediments; Halpern et al., 2007). Accounting this great importance and the wide variety of anthropogenic and natural threats to the marine realm, several pieces of legislation were developed by the European Commission, of which the Water Framework Directive (WFD; European Commission, 2000), the Marine Strategy Framework Directive (MSFD; European Commission, 2008), the Integrated Maritime Policy for the European Union (European Commission, 2007) and the Maritime Spatial Planning (European Commission, 2014), are some of the most important. Concerning this subject, Portugal revealed the importance that concedes to the Maritime affairs through the creation of the Ocean National Strategy (NOS) in 2006 (NOS 2006-2016), reviewed in 2013 (NOS 2013-2020), where an action plan is presented aiming to promote a sustainable and responsible use of the ocean and coastal areas resources, promoting an economic and social development (Ministério da Defesa Nacional, 2007; Governo de Portugal, 2013).

The work presented in this thesis was carried out in the scope of the MeshAtlantic project. Following the PhD work of Martins (2013) and related papers (Martins et al., 2012a, 2013a, 2013b, 2014; Sampaio et al., 2016), describing the benthic habitats along the whole of the Portuguese continental shelf, this thesis aimed to detail the knowledge about the section located north of the Nazaré Canyon, where the shelf is the widest and the bottom dominated by soft sediments. The sampling resolution in this area was augmented and the data exploited with different statistical methodologies, such as spatial interpolation and regression models.

*The numbers in superscript format are relative to online citations (see webography section).

1.2 Habitat mapping and modelling: basic concepts

In the context of the European nature information system (EUNIS) habitat classification, Davies et al. (2004) defined habitat as “a place where plants or animals normally live, characterized primarily by its physical features (topography, plant or animal physiognomy, soil characteristics, climate, water quality, etc.) and secondarily by the species of plants and animals that live there”, claiming also that almost all EUNIS habitats should also be regarded as biotopes, “areas with particular environmental conditions that are sufficiently uniform to support a characteristic assemblage of organisms”. The MeshAtlantic project defined habitat mapping as “Plotting the distribution and extent of habitats to create a map with complete coverage of the seabed showing distinct boundaries separating adjacent habitats”[4]. Further, species distribution models (SDM) are based in the correlation between the environmental factors and the species presences or abundances, establishing numerical relations between them. This feature allows to predict the species distributions in areas where only environmental data is available (Guisan and Zimmermann, 2000; Austin, 2002; Guisan and Thuiller, 2005; Franklin, 2010). Different terminology has been used for models that predict the spatial distribution of biotic variables. In this thesis was chosen the name that seems at the same time the most comprehensive, widely used and having a straightforward understanding, i.e. species distribution models (SDM) (or just distribution models (DM)).

1.3 Portuguese continental shelf between Porto and Nazaré

The geological continental shelf is defined as “the flat or gently sloping region adjacent to a continent or around an island that extends from the low water line to a depth, generally about 200m, where there is a marked increase in downward slope” (IHO, 2013). This oceanic province presents a wide range of environmental conditions and is considered highly biological productive, when compared to the open ocean. This is mainly due to the nutrient input from terrestrial areas and the penetration of the light in their shallow waters (Yool and Fasham, 2001). The presence of most of the fisheries, hydrocarbon reservoirs and marine touristic areas reveal the great value associated with the continental shelves around the world.

The Portuguese continental shelf is placed in the region of the North-East Atlantic Ocean and, in the scope of the MSFD, integrated in the Bay of Biscay and Iberian Atlantic coast sub-region (European Commission, 2008; EEA, 2017), or in terms of its biogeography in the Lusitanian province (Dinter, 2001). This shelf is situated in a confluence zone being influenced by the cold waters of the North Atlantic and by the warm waters from northern Africa and the Mediterranean Sea (Fiúza, 1983). The western section is characterized by a complex current system and an energetic regime of waves and tides (Fiúza, 1983), stronger between the Portuguese northern border and the Carvoeiro cape (Bettencourt et al., 2004). The Portuguese shelf is marked by the incision of various submarine canyons, of which the Nazaré canyon is the most important (Dias and Nittrouer, 1984). The Nazaré canyon extends for more than 230Km and heading off at 500m from the coast cuts the entire shelf (Oliveira et al., 2007).

The section between the northern border and the Nazaré canyon of the Portuguese shelf presents an average width of 45Km and the shelf-break slope occurs in average at 160m depth (Musellec, 1974). This is a vast area covered approximately by 80% of soft sediments (MAMAOT, 2012). Particularizing to the section between Porto and the Nazaré canyon, the sediment input is done mainly through the Douro River, Ria de Aveiro and the Mondego river. The main contributor to the sediments input is the Douro River, with the Ria de Aveiro estuary contributing modestly to the sediments exported to the shelf (Abrantes and Rocha, 2007). The sediment discharged in this section of the continental shelf was estimated in approximatively $2\times10^6 m^3$ per year (Oliveira et al., 1982). Generally, the sediment dispersion in the northern Portuguese shelf occurs along shore during fair weather, followed by the resuspension of the finer particles in a north-west direction during the stormy months (Dias et al., 2002; Vitorino et al., 2002).

The study about the sediments of the Portuguese continental shelf began in the early 20th century from 1913 to 1940, when eight charts were published named “Cartas Litológicas Submarinas”, covering the entire shelf. Posteriorly, from 1974 to 2005, the SEPLAT project updated the previous study (Moita, 1985; Bizarro, 2010), resulting also in several published works (e.g. Dias and Nittrouer, 1984; Abrantes et al., 2005; Balsinha et al., 2014). It is also important to mention the more recent broad scale work of Martins et al. (2012a), also covering the whole Portuguese shelf. In the study area covered by this thesis, between Porto and Nazaré, several sediment studies were previously conducted (e.g. Dias and Nittrouer, 1984; Abrantes and Rocha, 2007; Martins et al., 2012a; Martins et al., 2012b).

1.4 Acoustic remote sensing in benthic studies

Traditionally, discrete point sediment samplers (e.g. grabs and corers) were used in the ecological studies of the seafloor. The introduction of remote sensing techniques in marine studies permitted the acquisition of continuous data of the seafloor over large areas, representing a significant advance in the knowledge and mapping resolution of benthic habitats. Even so, in situ sampling techniques and others, including image-based methods, photography and video, provide complementary "ground-truth" data and remain an essential part of the benthic habitat studies due to the ambiguity of the remote sensing data (Kenny et al., 2003). Remote sensing techniques, such as aerial photography, (Mast et al., 1997; Nezlin et al., 2007), airborne and satellite imagery (Jobin et al., 2005; Fornes et al., 2006; Knudby et al., 2010; Valle et al., 2015), and acoustic methods (Freitas et al., 2003a; Haris et al., 2012; Cunningham et al., 2013), have been regularly used in ecology works.

The remote sensing of benthic habitats with acoustic methods, when compared to image-based techniques, have the advantage of allowing to map in deeper and turbid waters. Nevertheless, the combination of remote sensing data provided by distinct techniques proved to enhance the ability to discriminate benthic habitats (Walker et al., 2008; Bejarano et al., 2010). Nowadays, a wide variety of acoustic remote sensing techniques are available to map the seafloor: i) side scan sonars (SSS), that provide high-resolution images of wide areas of seabed (Brown et al., 2002; Cochrane and Lafferty, 2002; Sánchez-Carnero et al., 2012); ii) sub-bottom profilers that provide profiles of the upper layers of the seafloor (Yaacob and Mustapa, 2010); iii) single-beam acoustic ground discrimination systems (AGDS, Freitas et al., 2003b; Quintino et al., 2010; Henriques et al., 2015) and iv) multi-beam echosounders (MBES, Smith et al., 2015; Sen et al., 2016), which are the most widely used method given their ability to cover 100% of the seafloor area.

AGDS systems, such as the one used in this study, QTCVIEW series V, have successfully characterized benthic habitats, such as macroalgae (Quintino et al., 2010; Mielck et al., 2014), coral reefs (Riegl and Purkis, 2005; Bejarano et al., 2011) and superficial soft sediments (Freitas et al., 2006; Wolfl et al., 2014). These acoustic devices however do not allow the coverage of 100% of the seafloor, which can be assured by both SSS and MBES. Despite the advantages of such acoustic systems when compared to AGDS, these proved to be a helpful tool to map seafloor habitats, either used alone or complementing other remote sensing techniques (e.g. Riegl and Purkis, 2005; Bejarano et al., 2010; Reshitnyk et al., 2014). Furthermore, the large amount of data collected over the years with AGDS should and have been used in predictive modelling studies (McConnaughey and Syrjala, 2009; van der Kooij et al., 2011). Despite the preference recently given to MBES and SSS as acoustic acquiring techniques, AGDS are still used in mapping and modelling works (among others, Hamouda, 2014; Mielck et al., 2014; Prospere et al., 2016). The ability of swath acoustic systems to ensure 100% coverage of the seafloor requires a significant investment in ship time and data handling, which is a disadvantage of SSS and MBES when compared to single-beam AGDS. Further, the acoustic equipment cost is also lower for AGDS when compared to the others (Brown et al., 2011). A point of interest of some single-beam AGDS systems is the ability to translate the echo signal into data matrices, which then permits to use the acoustic data in multivariate data analysis workflows including modeling and hypothesis testing (Quintino et al., 2010), as in the present work.

The acoustic classification of benthic habitats consists on grouping echoes with similar features (Preston and Collins, 2000). Aboard a vessel, the QTCVIEW is linked to a single-beam echosounder and respective transducer. Different echosounder frequencies can be used by this equipment, generally between 10-200 kHz. The acoustic signal emitted by the echosounder goes through the water column, reflects in the seafloor, and is captured by the transducer. This signal is then transformed in electrical energy and displayed in the computer monitor (Collins and Rhynas, 1998). The acoustic echo captured varies with different substrata characteristics (roughness and density; Watt and Eng, 1999). Some acoustic pulse parameters affect the classification of the seabed, such as: frequency, pulse duration, transmit power, ping rate, transducer and noise (acoustical or electrical). In addition, some survey characteristics could constrain the acquisition of the data, namely the vessel speed, depth and sea state (Collins and Rhynas, 1998). The acoustic pulse parameters and vessel speed could be adjusted to the survey features (e.g. shallow or deep waters) and purposes.

One of the main issues that the marine benthic habitat mapping needs to deal with is the variability of the seafloor. It is well known that the marine benthic habitats can present a high variability in relatively small scales (Chapman et al., 2010), hence the need of methodologies that allow the development of high resolution maps. Thus, many recent studies also used predictive modelling to complement remote sensing, some devoted to the non-living component of the seafloor (Diesing et al., 2009; Huang et al., 2012), others aiming to predict the distribution of the biological component, such as macroalgae (Méléder et al., 2010) or coral reefs (Dolan et al., 2008; Guinan et al., 2009).

Now that it is possible to collect high-resolution environmental data using acoustic survey techniques, appears the need to apply more complex approaches such as SDM to improve our understanding of the marine ecosystems and generate marine benthic habitat maps for management applications. Habitat mapping produced through the combination of traditional, remote sensing and predictive modeling are powerful tools to help managers and stakeholders to make decisions about the benthic habitats, particularly serving as baseline information about habitats and/or species (endangered, rare or economically valuable), that could be the main factors for the establishment of marine protected areas (Gormley et al., 2013). It is so paramount to develop valid and accurate ways to combine the three types of methods, namely due to the nature of the data, continuous or point sample data.

1.5 Macrofauna benthic community studies

The spatial distribution of the marine benthic communities is mainly influenced by abiotic factors such as sediment grain-size and organic matter (e.g. Ellingsen, 2002; Martins et al., 2013a), depth (e.g. Gogina et al., 2010a), energy at the bottom (e.g. Rosenberg, 1995), oxygen (e.g. Hill et al., 2002) and light reaching the seabed (Connor et al., 1997a, 2004; Davies et al., 2004). However, due to the collinearity between these factors, the most commonly sampled (i.e. grain-size and depth) could be used as surrogates to some of the other environmental factors (Austin, 2007; Gogina et al., 2010a).

Several broad-scale community studies conducted around the world, with more incidence in Atlantic and Mediterranean European waters, were conducted since the first decades of the twentieth century, defining a framework for the macrofauna communities (among others, Petersen, 1918; Ford, 1923; Stephen, 1923; Jones, 1950; Thorson, 1957; Pérès and Picard, 1964; Cabioch, 1968; Glémarec, 1973; Cornet et al., 1983) that can be used for comparison by posterior studies. These studies defined several benthic communities, named by the most characterizing species together with the main factors driving their distribution, such as sediment type, depth and geographical location.

In Portugal, the benthic macrofauna knowledge is well developed in some ecosystems, like estuaries (e.g. Marques et al., 1993; Moreira et al., 1993; Rodrigues and Quintino, 1993; Rodrigues et al., 2006), lagoons (e.g. Quintino et al., 1987, 1989), rocky shores (e.g. Saldanha, 1997; Araújo et al., 2005; Bertocci et al., 2012) and sandy beaches (e.g. Gonçalves et al., 2009; Vale et al., 2010), while the submarine canyons (e.g. Curdia et al., 2004; Cunha et al., 2011) and the continental shelf (e.g. Marques and Bellan-Santini, 1993; Freitas et al., 2003a; Henriques et al., 2015) were less known, mainly due to their low accessibility and large extension. Recently, however, several studies were conducted in Atlantic Iberian waters contributing significantly to increasing the current knowledge about the benthic communities in this geographical area (among others, Freitas et al., 2006; Lourido et al., 2010; Martínez and Adarraga, 2011; Galparsoro et al., 2015). Particularly the PhD work of Martins (2013) and related papers describing the benthic macrofauna communities (Martins et al., 2013a), and detailing papers for the mollusks (Martins et al., 2014), polychaetes (Martins et al., 2013b), and crustaceans (Sampaio et al., 2016), contributed greatly to increase current knowledge of the benthic communities of the Portuguese continental shelf.

1.6 Species distribution models (SDM)

Due to the difficulty of obtaining data in the marine environment, especially when compared to the terrestrial, it is common that the ecosystem managers are confronted with sparse species and habitat data. Further, the development of new statistical methods, geographic information system (GIS) tools and the need for more detailed data required for environmental managing, led to the increasing use of SDM. SDM are also known, among other designations, as habitat suitability models, given they describe the suitability of a habitat to support a species (Franklin, 2010). They are based in the assumption that the species and communities distribution, used as response or dependent variables, are mainly driven by environmental factors (explanatory or independent variables, Guisan and Zimmermann, 2000). These models permit the prediction of values of ecological variables (e.g. biomass, abundance, species richness, presence/absence or only presence) in areas where only environmental data is available (Franklin, 2010). Initially developed for the terrestrial realm, these methods have been used in marine modelling to predict the distribution of a wide range of marine biological entities and descriptors, like macroalgae (e.g Young et al., 2015), fish (e.g. Schmiing et al., 2013), fish larvae (e.g. Carassou et al., 2008), corals (e.g. Dolan et al., 2008), polychaetes (e.g. Willems et al., 2008), macrofauna benthic communities (also known as community distribution models, CDM, e.g. Puls et al., 2012; Moritz et al., 2013) and biological parameters of benthic communities (i.e. abundance, species richness or Shannon-Wiener diversity, e.g. Rosa-Filho et al., 2004). Regarding to their applicability in the conservation of the marine ecosystems, SDM have been widely used, namely for studying the impact of climate change in species distributions (e.g. Albouy et al., 2013; Weinert et al., 2016), in risk related with invasive species (e.g. Jones et al., 2013), in the selection of recovery areas for impacted habitats (e.g. Elsäßer et al., 2013), and assisting the decision-making process (e.g. Guisan et al., 2013).

According to Guisan and Zimmermann (2000), ecological predictive modelling is composed by five essential steps: conceptual model, statistical formulation, calibration, predictions and evaluation (Figure 1). The conceptual model is formulated based on an assumption, from previous studies, about the relationship between the biotic entities and the abiotic factors that influence their distribution. This formulation leads namely to the choice of the appropriate sampling design, survey scale and selection of explanatory variables (Guisan and Zimmermann, 2000). Generally, the explanatory variables must honor 3 conditions: i) be potentially explicative; ii) present variation in the study area; ii) be independent or not be excessively correlated with each other, particularly if the study aims a biological interpretation of the results (Mateo et al., 2011).

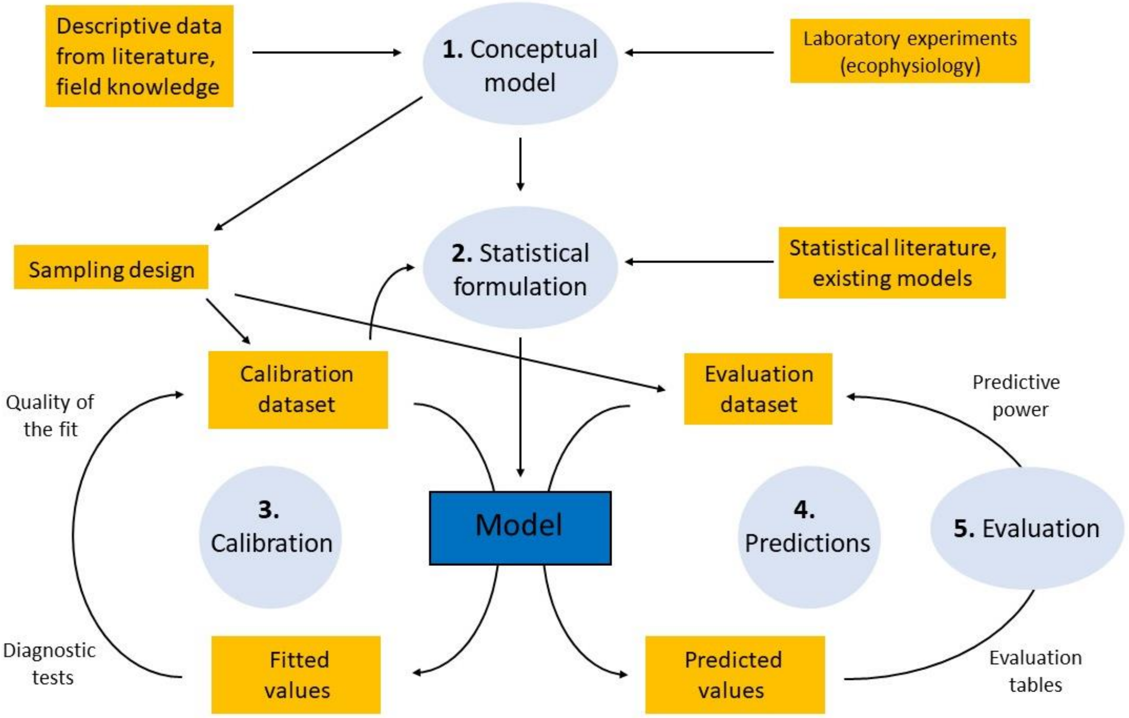


Figure 1. Schematic representation of the steps (1–5) comprised in the predictive model building process, representing the case when two data sets are available, one for fitting and one for evaluating the model (adapted from Guisan and Zimmermann, 2000).

In the statistical formulation, the method used to predict is selected within the wide variety of available methods. Linear regression (LR, e.g. Rosa-Filho et al., 2004), generalized linear models (GLM, e.g. Gogina et al., 2010b; Moritz et al., 2013), generalized additive models (GAM, e.g. Quattrocchi et al., 2016), maximum entropy (MaxEnt, e.g. Ashford et al., 2014; Yuan et al., 2015), multivariate adaptive regression splines (MARS, e.g. Meißner and Darr, 2009) and bioclimatic envelope (BIOCLIM, e.g. Ward, 2007), are some examples of the statistical tools used in SDM. Their use is mainly dependent of the data type of the response variable, for example for continuous data LR could be used, for counts (integer positive) a GLM or GAM model using a Poisson distribution are suitable, for presence/absence (logistic regression) a GLM or GAM with a binomial distribution (Zuur et al., 2009), whilst for presence-only data the options could be the MaxEnt or BIOCLIM (Reiss et al., 2015). The methods used in this thesis are included in the regression methods and they were the LR, GLM, additive modelling (AM) and GAM. The GLM and GAM consist of three steps: i) select the suitable statistical distribution; ii) specify the systematic part in terms of explanatory variables; iii) define the relationship (or link) between the explanatory and response variables (Zuur et al., 2009). The LR and AM have the statistical distribution and the link predefined, Gaussian and identity, respectively, and so the only concern is the choice of the systematic part. When the data studied do not present a linear relationship, the additive modeling (AM and GAM) is a good alternative to the LR and GLM (Zuur et al., 2007).

The calibration part of a modelling work consists in the adjustment of the mathematical model, which includes the selection of the explanatory variables (Guisan and Zimmermann, 2000). Several approaches are available to perform the model selection, its choice depending on the work aims. Nevertheless, the searching for parsimonious models is very important for the increase of the accuracy and predictive power. In the case that the study aim includes to find which environmental factors are driving the biological response, it is very important to account for the collinearity between the explanatory variables (Guisan and Zimmermann, 2000; Franklin, 2010; Zuur et al., 2010).

The model predictions output depends on the measurement scale of the response variable. If the response is a continuous variable (e.g. abundance, biomass, species richness), then the predictions are given in that biotic factor scale of values. If the response is of presence/absence type, then the attribute predicted is the probability of occurrence of that biotic entity (Guisan and Zimmermann, 2000; Franklin, 2010).

Finally, the model evaluation could be made in two different ways: i) on the training (or calibration) data using cross-validation, Jack-knife or bootstrap techniques; or ii) on the test dataset by comparing the predicted to the observed values, needing for this that the data were previously divided in training and test (or evaluation) data. The latter case is the most advisable, avoiding the overestimation of the model predictive power (Franklin, 2010). If the response variable is continuous, a large set of measures of fit are available: proportion of the deviance explained (R^2), root mean square error (RMSE), mean absolute error (MAE), among others. If the predictions are given as a probability of occurrence, then a threshold-independent method, like the area under the ROC curve method (AUC), should be used (Guisan and Zimmermann, 2000).

In spatial distribution studies, the spatial autocorrelation (SAC) should be accounted for. The fundamental idea behind geostatistics was invoked by Tobler (1970) as the first law in geography: “Everything is related to everything, but near things are more related than distant things”, meaning that the observations are spatially autocorrelated. This feature of spatial data could be both a problem and an opportunity. The problem exists because the autocorrelation of the model residuals can lead to an increase of type errors I (falsely rejecting the null hypothesis of no effect, Dormann et al., 2007). One way to fix this is to create an explanatory autocovariate that will be added to the model. An autocovariate is a variable that captures the spatial autocorrelation, intending to explain, in the case of a biological variable, some endogenous processes as the dispersal limitations, interspecific interactions or contagious population growth (Dormann et al., 2007). The SAC could be an opportunity permitting to directly interpolate the data, both environmental or biological.

As one of the major applications of the SDM, the production of maps relative to the biological responses is a very important stage. For this, it is also important to have maps representing the environmental explanatory variables. One way to obtain them is through geostatistical methods, producing continuous surfaces using spatial interpolation of point data. Geostatistics have been employed in several scientific fields, Environmental Sciences and Ecology being among the counting top ten (Zhou et al., 2007). Interpolation methods are divided in two types, deterministic and geostatistical, using only mathematical or mathematical and statistical methods, respectively. The most frequently used interpolation methods are the inverse distance weighting (IDW), deterministic, and ordinary kriging (OK) or ordinary co-kriging (OCK), geostatistical (Li and Heap, 2014). Recently, was developed and implemented in ArcGIS 10.1 the Empirical Bayesian Kriging that proved to be a reliable automatic interpolator (Krivoruchko, 2012). In a GIS, using the results from a SDM, these environmental layers could be combined to obtain the final species distribution map. These interpolation techniques could also be used to directly interpolate species distributions (Franklin, 2010), their use being known in the marine realm (Monestiez et al., 2006; Sundermeyer et al., 2006).

1.7 European Nature Information System (EUNIS) habitat classification

To catalogue the wide range of marine habitats various classification systems were developed around the world, namely in the United States (Allee et al., 2000; Madden and Grossman, 2004), Canada (Roff and Taylor, 2000), Australia (among others, Ferns and Hough, 2000; Banks and Skilleter, 2002), Caribbean (for coral reefs, Mumby and Harborne, 1999) and Britain and Ireland (Connor et al., 1997a, 1997b, 2004).

Aiming to offer a comprehensive and common reference of all European habitats, the EUNIS was developed (Davies et al., 2004; Evans, 2012). In brief, the marine section of the 2004 version of the EUNIS classification results from a revision made by the Environmental European Agency (EEA, Davies and Moss, 2004), based on the classification system for Britain and Ireland (Connor et al., 2004), following also propositions received from OSPAR (2004). The current EUNIS version results from an update in 2007 of the 2004 version, that consisted in adding some new habitats and revising the hierarchical structure[5]. Presenting a hierarchical structure, the classification is done firstly concerning the physical environment. For the marine realm, habitats are classified from the more generic level (e.g. Level A - Marine habitats) to the more specific, corresponding to a habitat level 3 or 4 (e.g. A5.34: Infralittoral fine mud), depending on the substrata (3 for rock and 4 for soft sediments). The physical factors used to build the levels are: i) the light reaching the seafloor and bathymetry, used to define the biological zonation (e.g. infralittoral); ii) substrate type, used to separate between rock and soft sediment, and within the latter the various sediments types, classified using the Folk scale modified in the scope of the MeshAtlantic project (Mata Chacón et al., 2013); iii) kinetic energy of the seafloor, used only on rock substrata to define the energy levels of the bottom (low, medium or high). Then, when available, biological information is added obtaining an EUNIS habitat of level 4 or 5 depending again of the substrata (e.g. A5.341: *Cerastoderma edule* with *Abra nitida* in infralittoral mud)[6].

Proving its value as a classification tool, EUNIS has been applied in the framework of diverse marine mapping projects, namely MeshAtlantic, EUSeaMap and BALANCE (Al-Hamdani and Reker, 2007; Coltman et al., 2008; Cameron and Askew, 2011; Henriques et al., 2015; Vasquez et al., 2015), in the definition of areas to include in the NATURA 2000 network[7] or to be used in the environmental status (ES) assessment in the scope of the Marine Strategy Framework Directive (MSFD, European Commission, 2017). Also, in the scope of the MeshAtlantic project, Vasquez et al. (2015) created several broad-scale GIS layers for environmental factors (i.e. seabed substrate, biological zones and levels of energy at seabed), used in the EUNIS habitat classification. This lead to a EUNIS seafloor habitat map of level 3 and 4, comprising the continental shelves of Ireland, Bay of Biscay, Iberian Peninsula and Azores. Further, EUNIS habitat maps presenting biological information, achieving levels of classification 4 and 5, have been produced for more restricted areas (Monteiro et al., 2013; Galparsoro et al., 2015; Henriques et al., 2015).

In 2012, the workshop "Using EUNIS Habitat Classification for Benthic Mapping in European Seas", identified the challenges for the future development of EUNIS, being these classified in five categories: i) structure and hierarchy; ii) biology; iii) terminology; iv) mapping; v) future development (Galparsoro, 2012). An overview of the themes discussed in that workshop is offered in Galparsoro et al. (2012). More recently, Evans et al. (2016) proposed a revision for the marine section of EUNIS, including a revision of the EUNIS structure, that the level 2 of the marine section should be based on biological zone and substrate type. This proposal was not followed in the current work.

1.8 Marine Strategy Framework Directive (MSFD)

The European MSFD (European Commission, 2008) establishes that every member state should act, aiming to achieve or maintain the Good Environmental Status (GES) in the Community's marine environment until the year 2020. For the GES evaluation, eleven quality descriptors were set. Later, the European Commission (2010) determined the environmental criteria, accompanied by related indicators, that are relevant for each descriptor. Recently, this decision of the European Union was repealed by a new document where new criteria and methodological standards on GES of marine waters were established (European Commission, 2017). The implementation of the MSFD for national marine waters have to be done with compliance with a defined schedule[8] (European Commission, 2008): i) by 2012, member states had to make an initial assessment, define what GES means and establish environmental targets to achieve GES until 2020 for their waters; ii) by 2014, based on the initial assessment, establish the monitoring program for the ongoing assessment; iii) by 2015/2016, development and implementation of a program of measures needed to achieve the GES until 2020; iv) from 2018 to 2021, review and prepare the second cycle[8]. With concerns to the Portuguese waters, the tasks defined until 2016 were completed (MAMAOT, 2012; Dupont et al., 2014; MAM, 2014) and analyzed in Cavallo et al. (2018).

The data used in this thesis are suitable to use directly in GES evaluation methods of the descriptors 1 (biological diversity) and 6 (sediment integrity) (Cochrane et al., 2010; Rice et al., 2010; Galparsoro et al., 2015), being also suitable, indirectly, for the remaining descriptors (European Commission, 2011; Galparsoro et al., 2015). For the GES evaluation, it is required to compare the results achieved with baseline (or reference) conditions (Cochrane et al., 2010; Rice et al., 2010).

For the biological diversity descriptor, the GES meaning determined by Portugal (see MAMAOT, 2012) resulted from the merging of the GES defined in the MSFD as the "biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions" (European Commission, 2008) and the definition of the Convention on Biological Diversity as "variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" (CBD Secretariat, 1992). For the GES evaluation of this descriptor, marine biological valuation (MBV, Derous, 2007), using diverse taxonomic ecossytem components, was applied in the initial assessment, in the Basque country, Spain (Borja et al., 2011, Pascual et al., 2011) and in Portugal (MAMAOT, 2012). The MBV was defined as "the intrinsic value of marine biodiversity, without reference to anthropogenic use", permitting the production of biological valuation maps (BVM's) showing this intrinsic value for subzones within the study area (Derous, 2007; Derous et al., 2007a). More recently, the MBV was also obtained for all the Portuguese continental shelf combining a range of taxonomic groups (Gomes et al., 2018).

According to the European Commission (2008), for the descriptor 6, the GES is achieved if the “seafloor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected”. Benthic fauna is considered the component of the marine ecosystems indicated to use in the GES assessment of the seafloor integrity (Rice et al., 2010). A wide variety of benthic assessment methods are available to evaluate the GES related to the seafloor integrity (Borja et al., 2009). Amongst the most used are the AZTI Marine Biotic Index (AMBI, Borja et al., 2000) and the multimeric AMBI (M-AMBI, Borja et al., 2004; Muxika et al., 2007), developed for and used in the Water Framework Directive (WFD, European Commission, 2000). These indices were also used in the initial assessments of the Bay of Biscay and Iberian Atlantic coast sub-region, more precisely for the Basque and Portuguese waters (Borja et al., 2011; MAMAOT, 2012).

Although acknowledging that the assessment should be comprehensive, integrating different types of data, in this thesis the indicators were assessed through the available sediment and macrofauna data alone.

1.9 Aims

The main aims of this thesis were dependent of diverse tasks. To achieve these aims, the results and discussion of the present thesis were structured by data types, namely environmental, acoustic and biologic. The following tasks (i) and aims (ii, iii and iv) were pursued:

i. Sampling and processing:

- Obtain sediments and macrofauna samples and acquire acoustic data, on the Portuguese continental shelf north of the Nazaré canyon;

- Process the different samples and data types, including the sediment grain-size analysis, identification of the benthic macrofauna and post-processing of the acoustic data, to produce data matrices that could be used in the statistical data analysis;

- Use different software for data analysis, namely PRIMER v6 with the add-on PERMANOVA$^+$ (Clarke and Gorley, 2006; Anderson et al., 2008a), the R environment v3.2.5

(R Core Team, 2016), the geographic information system ArcGIS v10.2 (ESRI, 2013) and the acoustic post-processing software QTC IMPACT^{TM} v3.40 (QTC IMPACT, 2004).

ii. Environmental data:

- Characterize the superficial sediments within the study area using the sediment point samples;

- Produce maps of depth and some sedimentary parameters (i.e. fines, sand and gravel contents, and kurtosis);

- Based on the combination of the layers of fines, sand and gravel contents, produce a map with the sediment classified trough the modified Folk-MeshAtlantic classification system adopted by the MeshAtlantic project.

iii. Acoustic data:

- Characterize the inherent variability of the acoustic data collected with a single-beam AGDS, pursuing their use as an explanatory variable in the species distribution modelling (SDM) developed in this thesis;

- Describe the benthic seascape based on the data collected with the AGDS QTC View Series V.

iv. Biological data:

- Study the spatial structure of the benthic community parameters abundance, species richness and the Shannon-Wiener diversity index;

- Develop distribution models (DM) of the biological variables abundance, species richness and Shannon-Wiener diversity, using various regression methods and studying their relationship with environmental variables. Find the more accurate model for each biologic variable and compare the DM predictions with those obtained from the direct interpolation of the biological data;

- Identify the benthic macrofauna communities in the study area, describing them in terms of their biologic descriptors and associated physical environment;

- Develop communities distribution models (CDM), based on binomial models, to study the presence/absence of each community with respect to the environmental variables. Further, using the results obtained in the CDM, produce a map representing the distribution of the most probable benthic communities throughout the study area;

- Classify the habitats in the study area using the EUNIS habitat classification up to level 5, including the production of a map containing biological information and evaluate the challenges of applying this classification system to the study area;
- In the scope of the MSFD, and solely based on the sediment and benthic macrofauna data, evaluate the environmental status (ES) of the benthic habitats within the study area, as a contribute to the future evaluations required for the Portuguese waters.

Chapter 2. Material and Methods

2.1 Study area and sampling

The study area embraces a portion of the Portuguese continental shelf from Nazaré to Porto (Figure 2), between 9 and 154 meters depth. This area is comprised in the North-east Atlantic Ocean region, subregion of the Bay of Biscay and Iberian Coast (EEA, 2017; European Commission, 2008). The total area covered was approximately 7000 Km^2, extending 165 Km along the north-south direction (Lat 39˚42'20''N to 41˚11'31''N) (cf. Figure 2). In the present thesis, data from three surveys were included: i) two in the scope of the MeshAtlantic project held in 2010 and 2011; ii) another from a previous survey carried out in the project ACOSHELF and held in 2007/08. The MeshAtlantic surveys were conducted in the vessel “Mytilus” of the Spanish National Research Council (CSIC), whilst the ACOSHELF campaign was undertaken on board of the vessel “Noruega” of the Portuguese Institute of the Sea and Atmosphere (IPMA).

A total of 226 samples were obtained for sediment grain-size analysis of which 169 for the macrofauna (cf. Figure 2). The samples were obtained using a $0.1m^2$ Smith-McIntyre grab (Figure 3A). The coordinates and depth of each sampling site were recorded. At each site, two grab samples were collected, one for the sediment grain-size analysis and the other for macrofauna. On board, these two samples were submitted to a visual quality control and rejected for low quantity of sediment and when discrepancies between the samples existed. Concerning the grain-size analysis, a portion of the grab content was stored in 0.5L plastic boxes, whereas for the macrofauna the whole sediment present in the grab was sieved on board in a 1mm mesh size. The material retained was fixed in stabilized formalin (4%), stained with rose Bengal.

Acoustic data were collected using the AGDS QTC VIEW Series IV and V (ACOSHELF and MeshAtlantic surveys, respectively), connected to a 50 kHz echosounder Hondex 7300II, with the transducer mounted in the side of the vessel (Figure 3B). The acoustic system also contains a laptop for data acquisition, storage and visualization, and a Differential Global Position System (DGPS) to acquire the coordinates, which was logged continuously along with the acoustic data and depth, permitting the post-processing of the acoustic data in a GIS.

The echosounder base settings are shown in Table 1. The MeshAtlantic 2010 and ACOSHELF surveys include 39 transects perpendicular to the coast with length ranging from 22 to 49 km, making a total of 1798 km (1210 and 588 Km, respectively). The 2010 transects distanced apart from 3 to 8 Km and were positioned between the survey lines of the ACOSHELF, which distanced apart from 10 to 15 Km (cf. Figure 2). In turn, the acoustic survey of 2011 was conducted around “Pedra da Galega” rock outcrop, comprising 24 x 11 acoustic transects placed parallel and perpendicular from each other, distanced apart approximately 0.6 and 1.8 km (cf. Figure 2). Ranging from 14 to 34 km, a total of approximately 716 Km of acoustic transects were carried out in 2011. The sediment sampling sites were positioned to overlap the acoustic transects, aiming to comprehend the whole range of benthic habitats from this area.

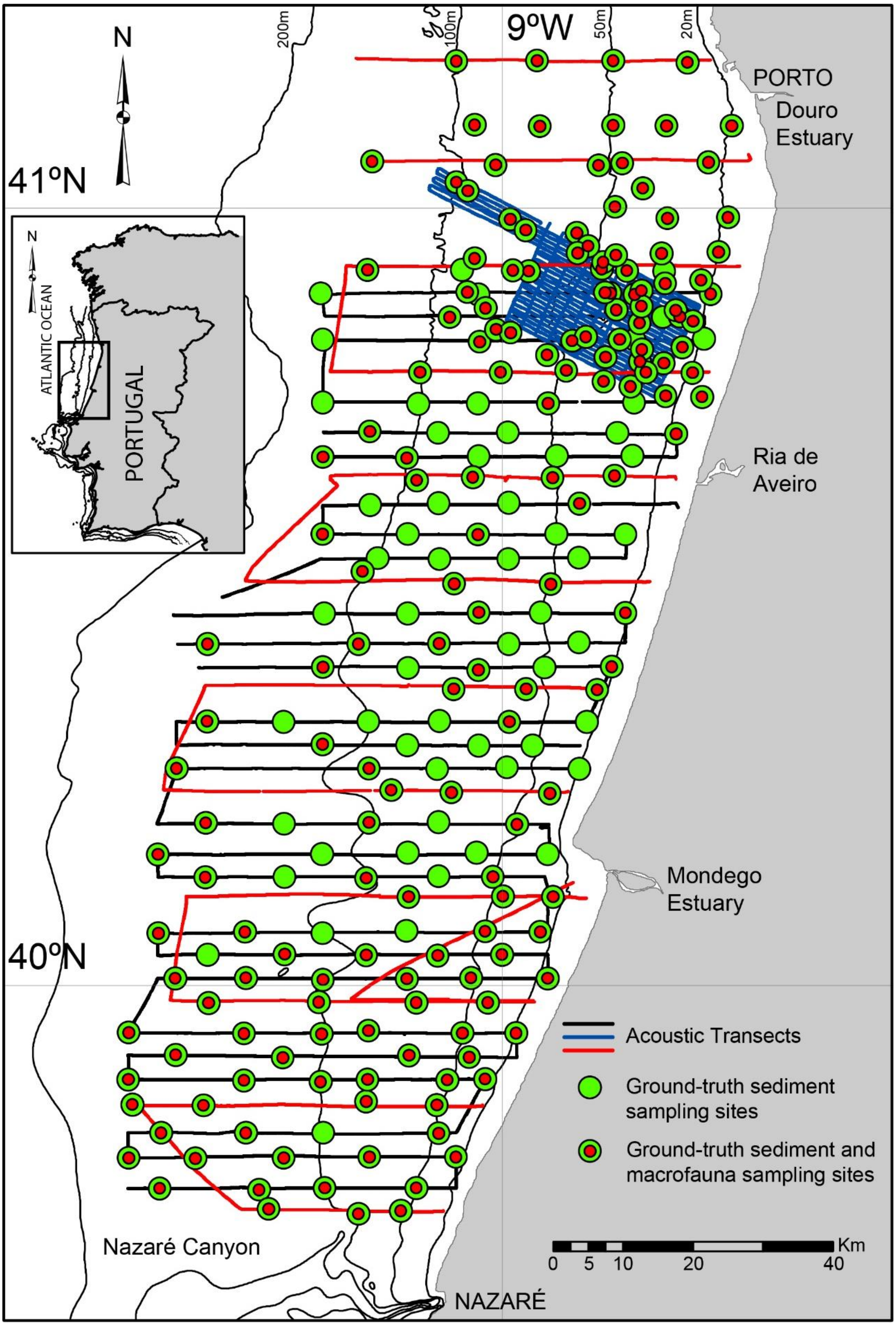


Figure 2. Survey area showing the positioning of the acoustic transects (survey lines: black – MeshAtlantic 2010; blue – MeshAtlantic 2011; red – ACOSHELF 2007/08), ground-truth sediment (green circles) and macrofauna sampling sites (red circles).

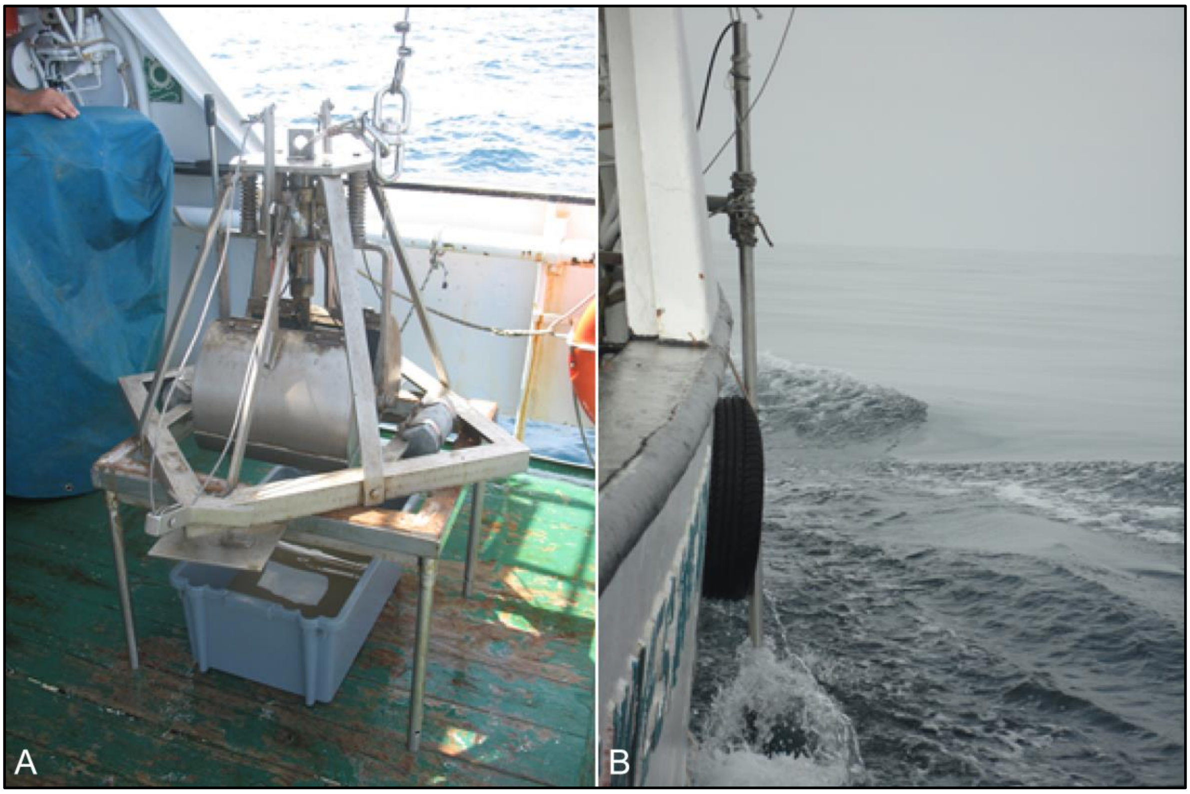


Figure 3. A. Smith-McIntyre grab; B. Transducer mounted in the side of the survey vessel Mytilus.

Table 1. Base settings for the echo-sounder.

	Parameter	Setting
Echo-sounder	Transmit power	600 Watt
	Pulse duration	265 µs
	Ping rate	7 per second
	Beam width	28°

2.2 Laboratory analysis

2.2.1 Sediments

The sediment grain-size was analyzed in the laboratory by wet- and dry-sieving, through the following steps described in Quintino et al. (1989):

i. Washing the sediments with freshwater;

ii. Chemical destruction of organic matter with hydrogen peroxide (H_2O_2), using successively increasing concentrations: 30, 65 and 130 volume strength;

iii. Drying the sample until obtention of a constant weight (48 hours), determining the total dry weight (P1);

iv. Chemical dispersion of the sediment with tetra-sodium pyrophosphate (30g/l);

v. Wet sieving through a 63 µm mesh screen;

vi. Drying the material retained on the 63 µm sieve until obtaining a constant weight (48 hours), determining in this way the dry weight of the material retained in the 63 µm mesh (P2);

vii. Calculation of the dry weight of the fraction under 63 µm by the difference of P1-P2;

viii. Dry mechanical sieving of the fraction P2 using a battery of sieves with mesh size ranging from 125 µm (4Φ) to 4 mm (-2Φ), at 1Φ intervals (Φ = $-\log_2$ dimension of the particle expressed in mm);

All grain-size fractions were expressed as a percentage of the total sediment dry weight.

2.2.2 Acoustic data (Post-processing)

The pressure waves received by the transducer were translated into full wave forms (fwf) by the QTC VIEW Series V and loaded to the post-processing software QTC IMPACT^{TM} (v3.40). This software described each echo in 166 variables, corresponding to the full features vectors file (FFV file). The acoustic data were quality controlled in QTC IMPACT using depth and position descriptors, allowing suppressing data with erroneous registers for any of these two descriptors. Two different methods to exploit the acoustic data were used in this thesis: i) statistical analysis using the FFV files extracted directly from the QTC IMPACT; ii) manual cluster analysis by the QTC IMPACT using the three principal axes of a PCA.

Firstly, to translate the echo signal into data matrices aiming to use them in multivariate analysis and modelling works, the final FFV file was output by QTC IMPACT in ASCII format and converted to CSV format using the Microsoft® Windows® net-software application converter (v1.0.8.45), created using a Microsoft® Visual® c#2005 developing tool (Quintino et al., 2010). The CSV files can be opened and saved in Microsoft® Office Excel®, allowing to export the acoustic data matrix to GIS as well as other data analysis software. Three variables were only represented by the values 0 or 1 and were eliminated from the final analysis. The acoustic survey lines as well as the ground-truth sites were mapped using ArcGIS (v10.2). Also, using this software, the acoustic data enveloping the ground-truth sampling site was organized into sections of 125, 250, 500, 750 or 1000 meters long. These sections were positioned over the acoustic survey in a way to keep the ground-truth site as close as possible to the middle point of the central section. For each ground-truth site, 5 replicates of such acoustic sections were set (Figure 4). Depending on the length of the acoustic sections, the mean number of echoes per section ranged from 10 to 75. These echoes, described by a total of 163 variables were the basic acoustic information characterizing each ground-truth site. The value of each variable per replicate acoustic section corresponded to the mean over the respective number of echoes. Five acoustic data matrices representing the ground-truth sediment sites were prepared. The matrices differed on the length of the acoustic sections considered for the integration of the echoes data (125, 250, 500, 750 or 1000 meters). In this part of the analysis, only data from the MeshAtlantic 2010 survey was used, and included 121 sediment grain-size ground-truth sites. Therefore, with 5 acoustic replicate sections per site, the acoustic matrices presented a final size of 605 samples x 163 variables.

In the second method, the acoustic data from the MeshAtlantic survey of 2010, was analyzed by manual clustering, aiming to form groups of echoes, corresponding each cluster to an acoustic class (QTC VIEW Series V, 2004). The final FFV file was submitted to a PCA, reducing the 166 variables into 3 principal axes, named Q-values (Q1, Q2 and Q3, Collins and McConnaughey, 1998). Then a CSV file with the classification for each record and the probability (p-value) of the record belonging to its class was downloaded from QTC IMPACT. Additionally, aiming to refine the analysis, from this file were selected the records that presented p-values > 90%. Finally, the spatial distribution of the acoustic classes for both files (with all records and with only the records presenting a p-value > 90%) were separately charted and visually analyzed in ArcGIS v.10.2.

The acoustic datasets of the MeshAtlantic 2011 and ACOSHELF, together with the MeshAtlantic 2010, were used to obtain the bathymetry layer.

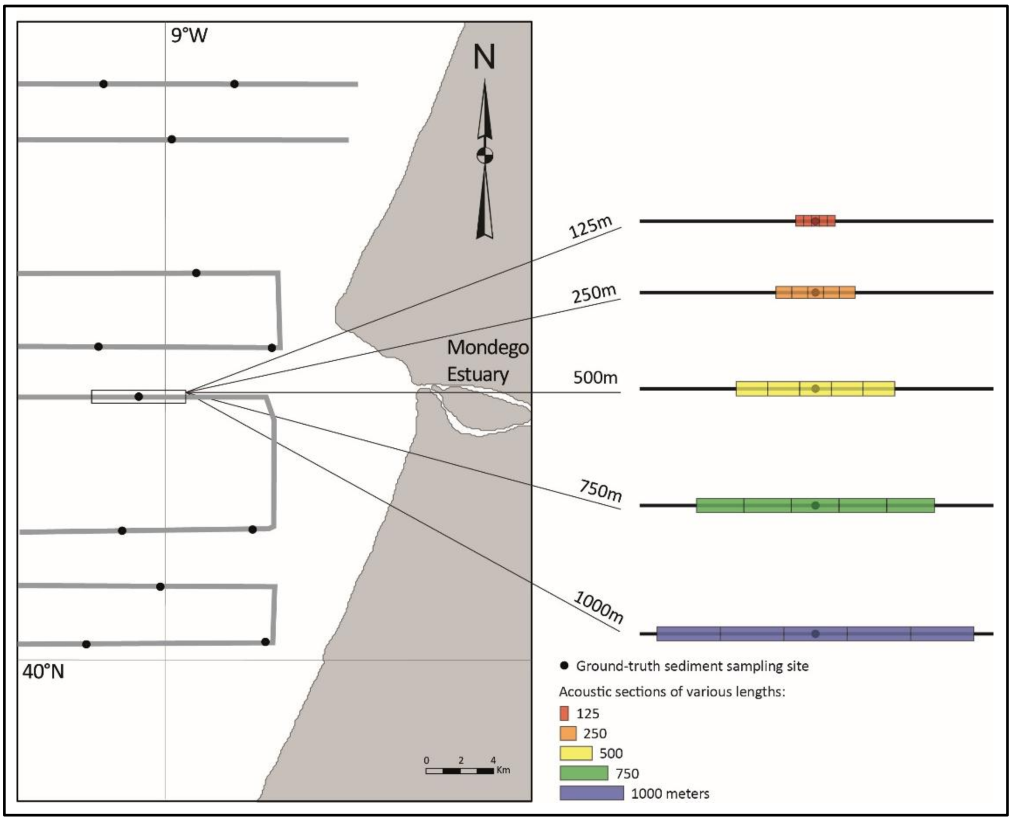


Figure 4. Schematic representation of the sediment ground-truth site (black circle) and the acoustic sections of various lengths (rectangles, five replicates per ground-truth site), placed on the acoustic survey transects (grey lines). The middle acoustic section envelops the ground-truth site. The acoustic data for testing the null hypotheses described in the section 2.4.2 was integrated considering five spatial steps: 125, 250, 500, 750 and 1000meters.

2.2.3 Macrofauna

In the laboratory, sediment macrofauna samples were individually and abundantly washed over a 0.5mm sieve. Hereafter, the specimens were hand sorted, separated by large macrofauna groups and stored in 70% ethylic alcohol. Using a stereomicroscope and an optical microscope, the macroinvertebrates were identified to species level, whenever possible, according to internal identification keys and recommended bibliography (among many others, for annelids: Fauvel, 1923, 1927; Campoy, 1982; Fauchald, 1982; George and Hartmann-Schröder, 1985; Holthe, 1986; O'Connor, 1987; Pleijel and Dales, 1991; Chambers and Muir, 1997; San Martín, 2003; Viéitez et al., 2004; Garwood, 2007; Ravara, 2010; Mortimer et al., 2011; for crustaceans: Chevreux and Fage, 1925; Bouvier, 1940; Tattersall and Tattersall, 1951; Allen, 1967; Naylor, 1972; Lincoln, 1979; Bellan-Santini et al., 1982, 1989, 1993; Holdich and Jones, 1983; Mauchline, 1984; Ingle, 1993; for mollusks: Tebble, 1976; Graham, 1988; Thompson, 1988; Macedo et al., 1999; for echinoderms: Southward and Campbell, 2006; and for macrofauna in general: Hayward and Ryland, 1995). Due to several reasons, some taxa are excluded from the final macrofauna data matrix, namely the Copepods due to their pelagic nature and Nematoda related to the reported differential patterns compared to the macrofauna (Vanaverbeke et al., 2011). The identification quality was assessed by experienced colleagues and using the World Register of Marine Species (WoRMS Editorial Board, 2015), the species authority and accepted name were confirmed, as such the classification to higher taxonomic categories.

2.3 Data analysis

2.3.1 Environmental data

2.3.1.1 Sediment analysis

Using Gradistat (v4.0, Blott and Pye, 2001), several sediment parameters were calculated per sample: median value (P50, expressed in ϕ units); fines or mud (< 0.063 mm), sand (0.063 – 2 mm) and gravel (> 2 mm) contents (expressed in % of the total); sorting and kurtosis, the latter determined using the method of moments described in Krumbein and Pettijohn (1938) calculated logarithmically. Hereafter, the sediment was classified: i) using the median value, according to the Wentworth scale (Table 2, Doeglas, 1968); ii) using the mud, sand and gravel contents, through the modified Folk classification system developed in the scope of the MeshAtlantic project (Mata Chacón et al., 2013), hereafter named the Folk-MeshAtlantic system (Figure 5).

Table 2. Sediment classification using the Wentworth scale (Doeglas, 1968).

Median value (ϕ)	Sediment classification
< (-1)	Fine gravel
(-1) – 0	Very coarse sand
0 – 1	Coarse sand
1 – 2	Medium sand
2 – 3	Fine sand
3 – 4	Very fine sand
> 4	Mud

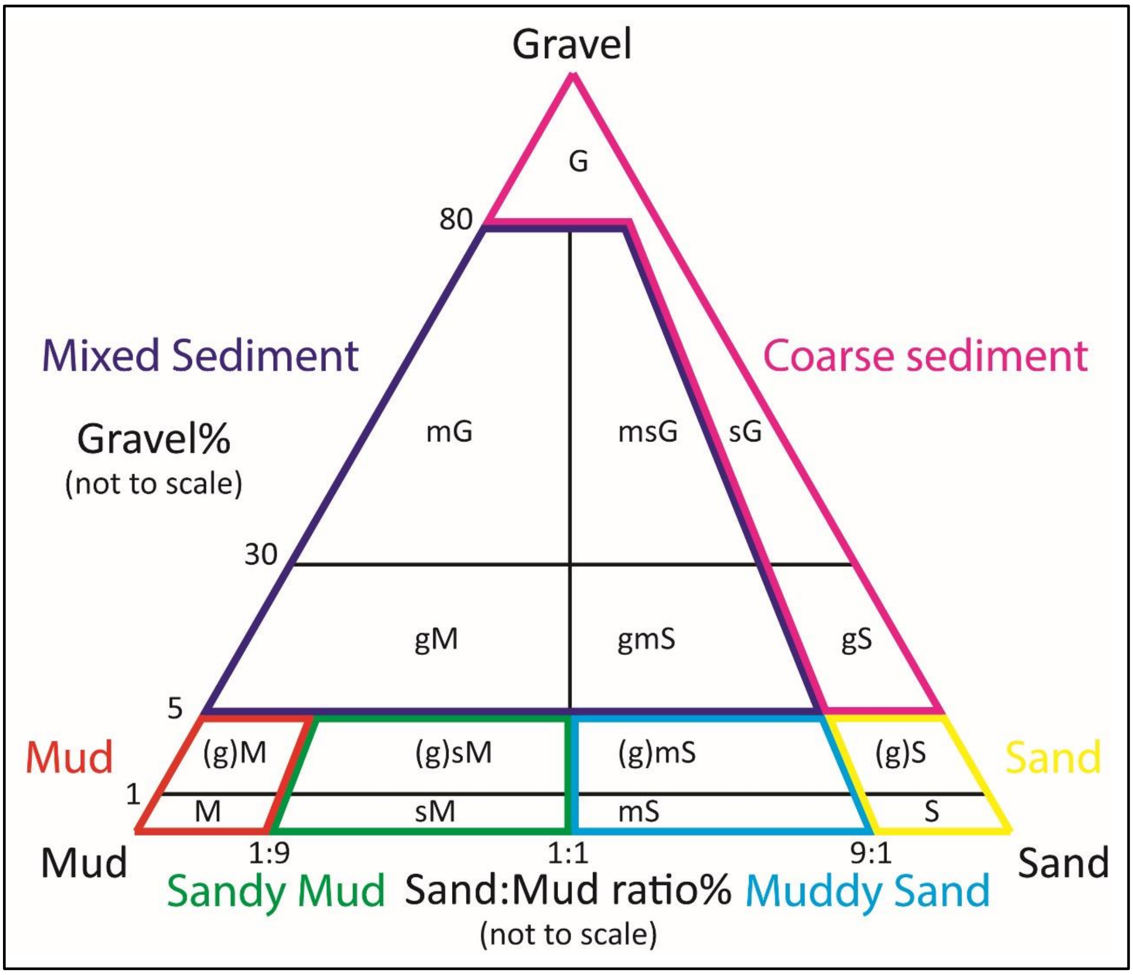


Figure 5. Folk-MeshAtlantic system for the classification of sediment types (adapted from Mata Chacón et al., 2013)**.**

2.3.1.2 Environmental data spatial interpolation

Spatial interpolations of depth, sediment fractions (mud, sand and gravel contents) and kurtosis were made. In the case of depth, because the data were collected using different acoustic systems, the accordance between them was confirmed previously. In this case, data from both the acoustic transects and sediment point samples were used (see Figure 2), while in the case of the sediment parameters, the data from the 226 sediment samples were used (see Figure 2). Suitable transformations were made for each variable, namely: i) square root for bathymetry; ii) fourth root for sediment sample kurtosis; iii) additive log-ratio (alr) transformation recommended for compositional data (Eq. 1 and 2, Odeh et al., 2003), to fines, sand and gravel contents (after adding a very small value to fines and gravel contents, i.e. 0.0001, to account for zero values). Compositional data are defined as those that contain only relative part of the information, being parts of some whole. Their sum is always a constant, often 100% (Pawlowsky-Glahn and Egozcue, 2006).

Eq. 1. $$\mathbf{S1} = \mathbf{ln}\left(\frac{\mathbf{gravel\ content}}{\mathbf{mud\ content}}\right)$$

Eq. 2. $$\mathbf{S2} = \mathbf{ln}\left(\frac{\mathbf{sand\ content}}{\mathbf{mud\ content}}\right)$$

For the spatial interpolation of the environmental data, a tool incorporated in ArcGIS 10.2 was selected, the Empirical Bayesian Kriging (EBK), a straightforward and robust kriging method (Krivoruchko, 2012). The best interpolation was achieved using the results of a leave-one-out cross-validation analyzing the following parameters: i) Root Mean Square Error (RMSE, Eq.3), that measures the difference between the predicted and the measured values; ii) Average Standard Error (ASE, Eq.4), showing the average of the prediction standard errors; iii) Root Mean Square Standardized Error (RMSSE, Eq.5), that is essentially a ratio between the previously mentioned parameters, evaluating if the prediction standard errors are valid.

Eq. 3. $$\mathbf{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{Z}(s_i) - z(s_i)\right)}{n}}$$

Eq. 4. $$\mathbf{ASE} = \sqrt{\frac{\sum_{i=1}^{n}\hat{\sigma}^2(s_i)}{n}}$$

Eq. 5. $$\mathbf{RMSSE} = \sqrt{\frac{\sum_{i=1}^{n}\left[\left(\hat{Z}(s_i) - z(s_i)\right)/\hat{\sigma}^2(s_i)\right]^2}{n}}$$

Legend – n: number of samples; $\hat{Z}(s_i)$: predicted values; $z(s_i)$: observed values; $\hat{\sigma}^2(s_i)$: prediction standard errors.

For a good estimation of the variability by the predictions, the RMSE and ASE should present close values, whilst to consider that the prediction standard errors are valid, the RMSSE should be close to one[9]. Through an intensive trial and error approach, if these assumptions were observed, when changing the EBK parameters only caused very small changes in the cross-validation results, it was considered that the best models were achieved[10]. Further, visual examinations of the predictions layers were performed as an additional and necessary quality control method to the interpolated layers, as suggested by Li and Heap (2014).

Finally, the spatial interpolation results were exported as raster surfaces with 0.0027 decimal degrees (approximately 250m) resolution. Then, each variable was back transformed to the original scale of values. The predicted values of bathymetry and kurtosis were back transformed squaring them (x^2) and raised to the fourth power (x^4), respectively, whilst in the case of the fines, sand and gravel contents the predictions were back transformed using the alr back transformation (Eq. 6, 7 and 8), subtracting 0.0001 to fines and gravel contents. The raster layers were delimited by hand to be as close as possible to the sampling sites.

Eq. 6. $$\boldsymbol{G}\textbf{ravel content} = \frac{\mathbf{e}^{\mathbf{S1}}}{(\mathbf{1}+\ \mathbf{e}^{\mathbf{S1}}+\mathbf{e}^{\mathbf{S2}})}$$

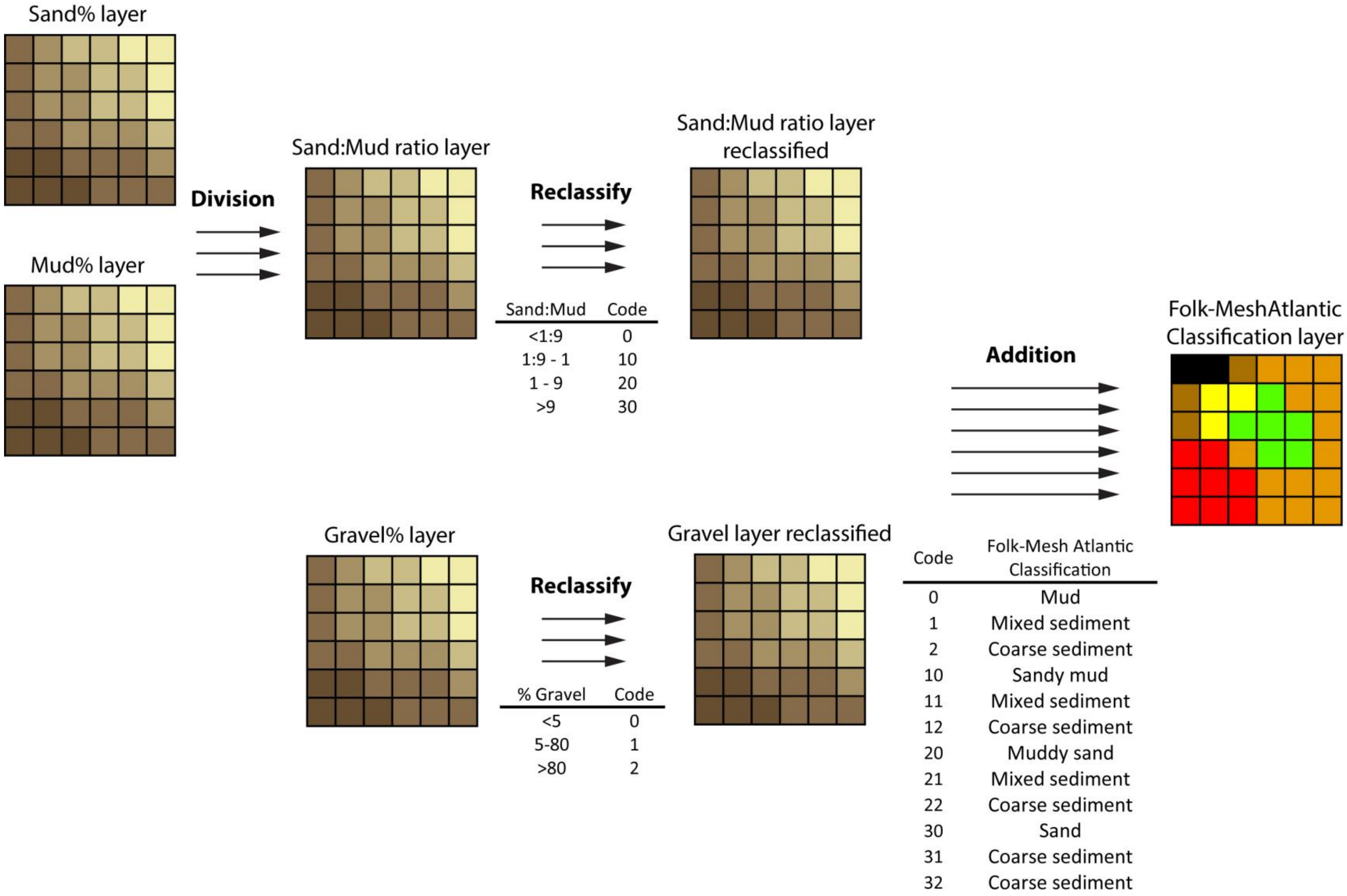
Eq. 7. $$\textbf{Sand content} = \frac{\mathbf{e}^{\mathbf{S2}}}{(\mathbf{1}+\ \mathbf{e}^{\mathbf{S1}}+\mathbf{e}^{\mathbf{S2}})}$$

Eq. 8. $$\textbf{Mud content} = \frac{\mathbf{1}}{(\mathbf{1}+\ \mathbf{e}^{\mathbf{S1}}+\mathbf{e}^{\mathbf{S2}})}$$

Legend – S1 and S2: sediment compositional variables calculated in Eq. 1 and 2.

2.3.1.3 Sedimentary map presenting the Folk-MeshAtlantic system

The raster layers relative to the three sediment parameters contents (i.e. mud, sand and gravel contents) were combined to produce a continuous layer according to the Folk-MeshAtlantic sediment classification system (cf. Figure 5). The raster calculator and reclassify included in the spatial analyst toolbox in ArcGIS (v.10.2) was used for this. The workflow is presented in Figure 6.



Sand:Mud	Code
<1:9	0
1:9 - 1	10
1 - 9	20
>9	30

% Gravel	Code
<5	0
5-80	1
>80	2

Code	Folk-Mesh Atlantic Classification
0	Mud
1	Mixed sediment
2	Coarse sediment
10	Sandy mud
11	Mixed sediment
12	Coarse sediment
20	Muddy sand
21	Mixed sediment
22	Coarse sediment
30	Sand
31	Coarse sediment
32	Coarse sediment

Figure 6. Schematic representation of the workflow to produce the sediment map, classified accordingly to the Folk-MeshAtlantic system.

2.3.2 Acoustic data

2.3.2.1 Acoustic variability study

The aims of this section were to characterize the superficial sediments within the study area and the inherent variability of the acoustic data collected with a single-beam AGDS, assuming that acoustic echoes obtained on the same seafloor portion will show some degree of variability. Such variability should occur due to inconsistencies in measurement values of the AGDS system, as well as to spatial heterogeneity of the seafloor. A strategy to circumvent such variability would be to run the acoustic survey lines more than once, and so increase the amount of acoustic information to be used to relate to the sediment grain-size ground-truth data. Because this was not possible in this work, we assume that along-track averaging of the single-beam acoustic data could be a way to diminish the variability. The purpose of the work was then to perform such along-track averaging over different spatial scales and answer the questions:

1. Which spatial step should be used to integrate single-beam acoustic data in order to minimize the within site replicates variability, 125, 250, 500, 750 or 1000m?

2. Will such spatial step also maximize the variability among the sites?

3. Once the acoustic data is organized in groups according to the sediment types, which spatial step should be used to integrate the acoustic data in order to maximize the variance among groups, 125, 250, 500, 750 or 1000m?

The acoustic data matrices presenting the 163 FFV were analyzed, using the software PRIMER v6 (Clarke and Gorley, 2006). Pseudo-F values for the PERMANOVA (permutational multivariate analysis of variance, Anderson et al., 2008a) main tests and the t-statistic for the pairwise comparisons were evaluated in terms of statistical significance, the null hypothesis being rejected at $p \leq 0.05$. Three null hypotheses were tested, the workflow schematically presented in Figure 7:

$H_0$1: The Euclidean distance within site replicates is not significantly different when the acoustic data are integrated at various spatial steps (125, 250, 500, 750, and 1000 meter blocks).

This null hypothesis was tested using a one-factor model with the spatial integration step as fixed factor, with five levels (125, 250, 500, 750, and 1000 meter sections). Each ground-truth site was represented by five replicates, corresponding to the 5 acoustic sections per site.

$H_0$2: No significant differences exist among sites when the acoustic data are integrated at various spatial steps (125, 250, 500, 750, and 1000 meter blocks).

Each acoustic data matrix representing each spatial integration step was run in a one-factor model, using sites as a random factor. This allowed obtaining the main test pseudo-F values for each spatial integration step. The spatial steps were further compared in a two-factor model, using the spatial steps fixed and crossed with sites, random (cf. Figure 7).

$H_0$3: No significant differences exist between the acoustic groups representing the sediment types when the acoustic data are integrated at various spatial steps (125, 250, 500, 750, and 1000 meter blocks).

In this analysis, the acoustic data were restricted to the middle acoustic section, enveloping the sediment ground-truth sample (121 samples x 163 variables, cf. Figure 7). Each acoustic matrix, representing the various spatial step sizes, was tested separately using a one-factor model with the sediment type as fixed factor, and the levels mud, very fine, fine, medium, coarse, and very coarse sand and fine gravel. This allowed obtaining the main test pseudo-F values for each spatial integration step. As in the previous null hypothesis, the spatial step sizes were further compared in a two-factor model with sediment types and spatial steps as fixed and crossed factors (cf. Figure 7).

The main result of these analyses, namely the spatial step that should be used to integrate the acoustic data, was applied in the hypothesis test described in the next section (2.3.2.2).

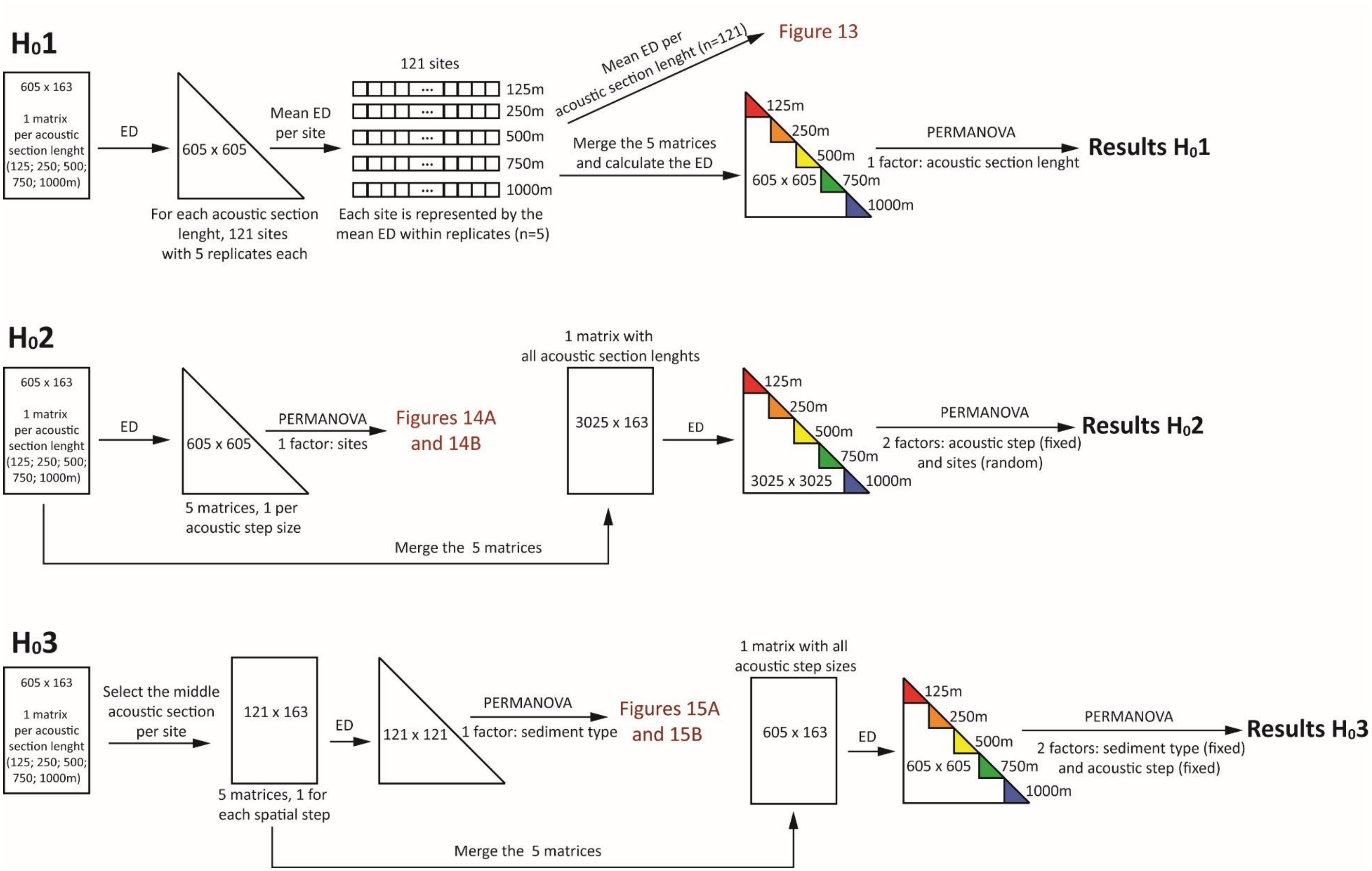


Figure 7. Schematic representation of the workflow involved in the testing of the various null hypotheses. ED = Euclidean distance.

2.3.2.2 Acoustic diversity pattern and depth

The acoustic transects presenting the acoustic classes and the grain-size sampling sites presenting the sediment types accordingly to the Wentworth scale were compared using ArcGIS (v10.2). The matching between the acoustic classes resulted from the manual clustering and the sediment types, was visually evaluated. For this analysis, 130 sediment samples were used (of the total 137), because seven of them do not coincide with the acoustic transects.

The acoustic diversity pattern analysis suggested that the acoustic data was contaminated by depth. To clarify this issue, the acoustic data matrix, corresponding to the 250 meter sections, was submitted to hypothesis testing with PERMANOVA (Anderson et al., 2008a). To visualize the multivariate patterns, the acoustic data matrix was also submitted to an ordination method, non-metric multidimensional scaling (NMDS), with the depth and the sediment types superimposed. The NMDS diagrams contain stress values that indicate the mismatch between the distances of the samples in the Euclidean matrix and in the ordination diagram. Stress values < 0.1 mean that the diagram representation is accurate (Clarke and Warwick, 2001). The null hypothesis tested was:

H_0: No significant differences exist between the acoustic groups representing the depth classes.

In this null hypothesis, the acoustic matrix was only represented by the middle acoustic sample enveloping the ground-truth site (121 samples x 163 variables). This acoustic matrix was tested using a one-factor model with depth as fixed factor, with the levels < 30, 30 - 50, 50 - 70, 70 - 90, 90 - 110, 110 – 130 and > 150 m.

2.3.3 Macrofauna

2.3.3.1 Environmental data exploration and statistical analysis framework

This section used the data from the 169 macrofauna samples. Various environmental variables were available to relate to the benthic macrofauna spatial patterns, such as: i) continuous sediment parameters, namely fines%, sand%, gravel%, kurtosis and sorting; ii) sediment classified following the Folk-MeshAtlantic classification system and the Wentworth classification; iii) depth. However, as explained below, not all these variables were used in all the sections of this thesis. Whenever possible, the environmental data was used untransformed.

In the modelling selection (present in sections 2.3.3.3, 2.3.3.5 and 2.3.3.6), priority was given to continuous data, and as such, the sediment types from the Folk-MeshAtlantic and Wentworth classifications were excluded. Given the main objective of the modelling work was to assess the environmental variables significantly related to the benthic communities, collinearity between predictors was a major problem. To deal with it, some theoretical and statistical based criteria were followed. First, sand% was excluded given its complementary value to fines% and gravel%, which normally influence the macrofauna in 'opposite' ways. Also, skewed distributions of environmental data are not advised for some methods (Zuur et al., 2007; Anderson et al., 2008a), hence some environmental variables were transformed. Whenever necessary, fourth root transformations were applied to fines%, gravel%, kurtosis and sorting. The transformed variables were renamed adding '4throot' in the subscript after the name of each variable (e.g. fines%$_{4throot}$). Further, scatterplots and Spearman correlation between the environmental variables were produced and evaluated. Finally, the variance inflation factor (VIF) values were assessed with a strict threshold of three. Variables presenting higher VIF values were removed sequentially, until every variable present a value lower than three. Despite fines%$_{4throot}$ presented a VIF value of 3.1, it was decided to keep it given the well-documented influence of fines on benthic communities. The explanatory variables used in the models were: fines%$_{4throot}$, gravel%$_{4throot}$, kurtosis$_{4throot}$ and depth. Despite of the different scales of the covariates it was not necessary to standardize them (or normalize in PERMANOVA+ for PRIMER (v6)) because all the methods used in these models deal with this issue (Zuur et al., 2007; Anderson et al., 2008a).

In all regression models of sections 2.3.3.3 and 2.3.3.6, a backward stepwise selection was performed. Only the significant terms ($p < 0.05$) remained in the final models. First, the model with all variables was fitted and the non-significant term with highest p-value was excluded. This process was repeated until only significant explanatory variables remained. Due to the spatial autocorrelation between the model residuals, a spatial autocovariate was added to some models.

These methods were all developed with the statistical packages R (v3.2.5, R Core Team, 2016) and PRIMER (v6.1.11, Clarke and Gorley, 2006) with the add-on PERMANOVA+ (v1.0.1, Anderson et al., 2008a).

2.3.3.2 Macrofauna abundance and diversity patterns

The phyla identified were described through the relative (% of the total) abundance and species richness. Further, the most abundant and frequent taxa were identified and described. Abundance, alpha diversity and the Shannon-Wiener index per sampling site were calculated and their spatial distribution were charted using ArcGIS (v10.2). The study of the relationship between these macrofauna indices and some environmental variables included: i) scatterplots of each of the three macrofauna indices and fines%, gravel% and depth, to which was added a LOESS smother to aid the interpretation; ii) box-and-whisker plots representing the abundance, alpha diversity and Shannon-Wiener diversity per sediment class of the Wentworth sediment scale.

2.3.3.3 Macrofauna abundance and diversity distribution models (DM)

For the biodiversity indices models, the response variables used were the abundance, alpha diversity and Shannon-Wiener diversity index (H’, $\log_2$) per site. The matrix with all the sampling sites, presenting also the environmental variables, was divided randomly in training and testing datasets with a ratio of 0.7 to 0.3. The resulting matrices are composed of 118 and 51 sampling sites, respectively.

With the training dataset an exploration analysis was performed, aiming to evaluate the relationship between the response and the explanatory variables (fines%$_{\text{4throot}}$, gravel%$_{\text{4throot}}$, kurtosis$_{\text{4throot}}$ and depth). For this, scatterplots were used to which a smoothing curve was added to facilitate the interpretation. For abundance and alpha diversity both GLM and GAM were assessed, using in both cases appropriate distributions for overdispersed counting data, namely quasi-Poisson and negative binomial. The overdispersion was previously assessed using a Poisson model (Zuur et al., 2009). For the modelling of the Shannon-Wiener index, the LR, additive modelling (AM), GLM and GAM were used, the latter two with the Gamma distribution. For all indices, in the additive modelling (i.e. AM and GAM), the model selection was performed with the R package ‘mgcv’, using penalized regression splines with the default parameters. Also, aiming to maintain an ecological interpretation of the models, the degrees of freedom of the smoothing parameters were limited to four (Wood and Augustin, 2002). The model predictions for the test datasets were calculated using the model formulas obtained with the training dataset.

Spatial autocorrelation was assessed using the model residuals, Pearson for quasi-Poisson, negative binomial and gamma distribution, and standardized residuals to multiple linear regression models. Hence, for each model, the spatial correlation of model residuals was evaluated using the p-value of the Moran’s I test under the null hypothesis that no spatial correlation was present among model residuals. For models presenting p-values < 0.05, it was considered that the spatial independence rule was not fulfilled. In the case of the abundance, every model showed spatial dependence of the residuals, hence a spatial correlation structure was added using an autocovariate, calculated using the function autocov_dist of the R package ‘spdep’. Once more, for these models, the spatial autocorrelation of the residuals was evaluated using the p-value of the Moran’s I test. Finally, only spatially independent models were analyzed, except for the case of abundance where the accuracy assessment was only possible using a model showing spatial dependence of the residuals, because an autocovariate for the test dataset was not produced.

Additionally, with the training dataset in ArcGIS (v10.2), these three biological indices were, separately, spatial interpolated using the same methodology described in the section 2.3.1.2 (i.e. EBK), resulting in raster layers for each of them. Then, for each biological parameter, the test dataset sampling sites, were superimposed to these EBK layers. Finally, the predicted values of the test dataset were extracted from these spatial interpolation layers.

All model performances were assessed through their prediction accuracy in terms of coefficient of determination (R^2), and their prediction error in terms of the root mean squared error (NRMSE, normalized to the different scales of data) of the linear regression between the observed and fitted values.

2.3.3.4 Multivariate analysis

The macrofauna abundance matrix was square root transformed to decrease the importance of the most abundant species, followed by the calculation of the Bray-Curtis similarity matrix between sites. This matrix was submitted to classification and ordination methods in the software PRIMER (v6, Clarke and Gorley, 2006), using hierarchical agglomerative clustering with the group-average algorithm (UPGMA), NMDS and Principal coordinates analysis (PCO). This will help to find natural agglomerations of samples, meaning that, the samples within a group are more similar among them, than with samples belonging to other groups (Clarke and Warwick, 2001). These agglomerations were named macrofauna affinity groups, communities, assemblages or biocenosis. From the classification analysis, three sampling sites appeared isolated and were excluded from the subsequent analysis. The macrofauna affinity groups were characterized using environmental variables and mean values for a set of biological indices, namely abundance, alpha diversity, Margalef richness, Pielou’s evenness, Shannon-Wiener index, Simpson index, total species richness, beta diversity within the group, number of exclusive species and their characteristic species. Beta or turnover diversity, which corresponds to the species replacement along the community (Whitaker, 1960), was calculated through the ratio between the total number of species of a given community and the mean alpha diversity of their sites. The most characteristic species were obtained using the product between the constancy and fidelity for each species in a community. Constancy corresponds to the frequency expressed as percentage of a species in a community (Dajoz, 1996), while fidelity is the ratio between the constancy of a species in a community and the sum of that species in all communities (Retière, 1979). The species were classified in terms of: i) constancy, as constant ($C > 50.0\%$), common ($50.0 \geq C > 25.0\%$), occasional (25.0 ≥ C > 12.5%) and rare (C ≤ 12.5%); ii) fidelity, into elective (F > 90.0%), preferential (90 ≥ F ≥ 66.6%), indifferent (66.6 ≥ F > 33.3%), accessory (33.3 ≥ F > 10%) and accidental (F ≤ 10%). Succession of species along the assemblages were obtained using a reduced matrix with only the species that contribute at least 5% of the total abundance in one sampling site. The spatial distribution of the benthic communities was charted in ArcGIS (v10.2) and used as response variables in the community distribution models (CDM) presented in this thesis.

2.3.3.5 Relationship between environmental and multivariate macrofauna data

The environmental variables used in this section were fines$\%_{4throot}$, gravel$\%_{4throot}$, kurtosis$_{4throot}$ and depth. Redundancy analysis (RDA, also known as multivariate multiple regression) was performed using the distance based linear models (DISTLM) and distance-based redundancy analysis (dbRDA) routines in PERMANOVA+ for PRIMER (Anderson et al., 2008a). While the DISTLM provides a quantitative measure, performing tests for the variation explained by each explanatory variable, dbRDA permits the visualization of the fitted model in the multi-dimensional space (Anderson et al., 2008a). The model was built using the BEST selection procedure based on the Akaike Information criterion (AIC). BEST evaluates the value of the selection criterion for all the combinations of the explanatory variables (Anderson et al., 2008a). Marginal and sequential tests were performed, which included only one explanatory variable at a time and all variables sequentially, respectively.

2.3.3.6 Community distribution models (CDM)

To relate the environmental variables with the presence of the macrofauna communities, the presence/absence of a given community per site was used as the response variable in binomial models. For each community, a binomial GLM for presence/absence was performed assuming a clog-log link function. The spatial distribution of the model residuals was evaluated using the p-value of the Moran's I test under the null hypothesis that no spatial correlation was present among model residuals. Some of the models presented evidence of spatial correlation between the residuals (p-values < 0.05), namely the models for the communities identified as A3, B1, C1 and C2. This was handled by adding a spatial correlation structure to the model through an autocovariate, calculated using the function autocov_dist of the R package 'spdep'. Once more, for these models, the spatial autocorrelation of the residuals was evaluated using the p-value of the Moran's I test. For every model, non-significant p-values were obtained, revealing that the spatial autocorrelation could now be neglected.

Using the pROC package for R, the models performances were evaluated through the area under the ROC curve (AUC) method. The AUC value represents the probability that a randomly chosen presence has a higher probability of occurrence than a randomly chosen absence. The models accuracy was evaluated as high (AUC ≥ 0.9), moderate (0.9 ≥ AUC > 0.7) and low (0.7 ≥ AUC > 0.5) (Swets, 1988).

Using the spatial analyst toolbox included in ArcGis 10.2, maps revealing the probability of presence of each macrofauna group were produced. The obtained seven maps were superimposed, achieving a unique map presenting the spatial distribution of the most probable community through the study area. The observed spatial distribution of the macrofauna communities was superimposed to this predictive map, aiming to assess the coincidence between them.

2.3.3.7 EUNIS habitat classification assessment

Habitats in the study area were classified according to EUNIS, up to level 5, through a bottom up approach. Firstly, to each sampling site a habitat type level 4 was attributed, being then evaluated their distribution by each macrofauna community. For this, in addition to the sedimentary and macrofauna data used previously, a layer produced in the scope of the MeshAtlantic project was also used (Vasquez et al., 2015), to extract the necessary information relative to the biological zones attributed to each site (i.e. infralittoral, circalittoral and deep-circalittoral zones). This layer used the percentage of light (400 - 700 nm) intensity reaching the seafloor to delimitate the boundary between the infra and circalittoral zones, using the cut-line of 1%. The limit boundary between circalittoral and deep circalittoral was defined as the ratio of 2.53 between the wave length and depth (Vasquez et al., 2015).

A map with the EUNIS habitat classification up to the level 5 was produced for the study area. For this, four data layers were used: i) layer of the biological zonation (described above); ii) a superficial sediments layer of the Portuguese shelf developed in the scope of the MeshAtlantic project; iii) layer representing the kinetic energy at the seafloor; iv) the map presenting the most probable macrofauna communities (described previously in section 2.3.3.5). With regards to the sediment layer, this was developed based in historical and some sampling point data, using also the sediment data used in this thesis (Mata Chacón et al., 2013). The wave-induced energy layer on the seabed (resolution 0.05˚), expressed as kinetic energy (N/m^2), was produced by the Marine, Environmental and Technology Center (MARETEC[11]). This layer was computed using the WAVEWATCH (WW3) model results (IST wave Forecast for the Portuguese Coast[12]), being used to determine the different seafloor energy levels (i.e. low, moderate and high). To limit the influence of extreme events, a layer of the 90th percentile was used. The threshold used for the energy levels were defined following Monteiro et al. (2015). The four layers were combined using the spatial analyst toolbox of ArcGIS (v10.2), resulting in the habitats map in the study area, classified according to EUNIS, up to level 5. Further, the area of each habitat class was calculated considering the adequate projection coordinate system for this area, the ETRS89 PT-TM06.

2.3.3.8 Contributions to the environmental status (ES) assessment in the scope of the Marine Strategy Framework Directive (MSFD)

The assessment of the ES in the scope of the MSFD was realized using three indicators belonging to two descriptors (Table 3). The methodological approach used followed that proposed by Borja et al. (2011) but using just the macrofauna data to assess the ES. For each indicator, the ecological quality ratio (EQR) was calculated, resulting from the comparison of the results obtained with reference conditions, whenever possible. The EQR value ranges from 0 (low) to 1 (high) and when not established, the thresholds used was: 0 – 0.2 as ‘bad status’;

0.21 – 0.4 as ‘poor status’; 0.41 – 0.6 as ‘moderate status’; 0.61 – 0.8 as ‘good status’ and 0.81 – 1 as ‘high status’, as suggested by Borja et al. (2004).

Table 3. Qualitative descriptors, criteria and indicators used in the present work, selected based on that indicated by the European Commission (2017) for the ES assessment in the scope of the MSFD.

Descriptor	Criteria	Indicator
D1. Biological Diversity	D1C6. Condition of the habitat type	a) Condition of the typical species and communities
D6. Sea-floor integrity	D6C5. Condition of benthic community	a) Presence of particularly sensitive and/or tolerant species
		b) Multi-metric index assessing benthic community condition and functionality, such as species diversity and richness, proportion of opportunistic to sensitive species

With regards to the criteria of the descriptor 1 (Biological diversity), the assessment evaluation was done using the marine biological valuation (MBV) described in detail by Derous (2007) and Derous et al. (2007b). MBV aims to quantify the biological value of each subzone using all the information available. Previously to the assessment, the area must be divided into subzones, then the valuation is achieved by answering relevant biological questions incorporating several components of the biodiversity coupled to the proposed valuation criteria (see Table 4, Derous, 2007; Derous et al., 2007b). For this, the sampling sites were divided in subzones represented by the EUNIS habitats level 5 obtained previously, following the recommendation of previous studies to use ecological meaningful subdivisions (Laffoley et al., 2000; Derous 2007). The MBV assessment questions (Table 4) were selected based upon previous studies (Derous et al., 2007b; Pascual et al., 2011; Van Hoey et al., 2014) and their suitability for this study. For the selection of dominant or rare species, the threshold of present in > or < than 5% of samples was set, respectively, following Derous et al. (2007b). The classification of the species in habitat-forming (HF) and ecological important (EI) species is based on the lists present in Derous (2007) and as appendix of Pascual et al. (2011). The complete list of the species identified in this thesis is presented in the Appendix I. The MBV is not completely free of subjectivity, namely in the choice of the questions and in the choice of the HF and EI species. To obtain the final score for each question by subzone, first a value per sampling site was attributed, then the mean of the sampling sites within each subzone was calculated. Due to the lack of reference values for the study area, it was impossible to use quantitative scoring, thus the solution was a semi-quantitative scoring system (very low [1], low [2], medium [3], high [4] and very high [5]) for each question and subzone. The boundaries for each class were defined based on probability quantiles. It is acknowledged that it is important the assessment of the reliability of the MBV results. For example, in Derous et al. (2007b) the reliability of the data was obtained based on the number of questions answered and number of sampling sites by subzone. It is important to notice that because all questions were answered by subzone, consequently larger subzones would present higher reliability values. Hence, due to the useless of this result, the reliability was not obtained for the MBV. Finally, in ArcGIS 10.2, the MBV through the study area was mapped.

For the assessment of descriptor 6 (Sea-floor integrity), the AMBI (Borja et al., 2000) and the M-AMBI (Borja et al., 2004; Muxika et al., 2007) were used, calculated with the software AMBI (v5.0)[13]. AMBI is a widely-used index developed in the scope of the Water Framework Directive (WFD) and is calculated based on the proportion of sensitive/opportunistic species previously classified in five ecological groups (EG, Borja et al., 2004). The AMBI is presented in a continuous scale ranging from 0 (not disturbed) to 6 (extremely disturbed or 7 in azoic conditions) corresponding to a perturbation gradient. In turn, the M-AMBI combine the AMBI, the species richness and the Shannon-Wiener diversity. The M-AMBI thresholds used were that achieved in the intercalibration assessment realized by Borja et al. (2007): $0 \leq \text{Bad} \leq 0.20 < \text{Poor} \leq 0.38 < \text{Moderate} \leq 0.53 < \text{Good} \leq 0.77 < \text{High} \leq 1$. The M-AMBI value represents directly the EQR.

Table 4. Questions assessed in the evaluation of the MBV.

	Questions assessed
Q1	Is the abundance of dominant species high?
Q2	Are there many rare species?
Q3	Is the abundance of rare species high?
Q4	Are there the presence of many habitat-forming species?
Q5	Is the abundance of habitat-forming species high?
Q6	Are there the presence of many ecological important species?
Q7	Is the abundance of ecological important species high?
Q8	Is the α-diversity high?

Chapter 3. Results

3.1 Environmental data spatial interpolation

3.1.1 Empirical Bayesian Kriging cross-validation

The cross-validation results of the Empirical Bayesian Kriging (EBK) of the environmental data are presented in Table 5 and Figure 8. For each variable, the root mean squared error (RMSE) and average squared error (ASE) presented very similar values (cf. Table 5), revealing that the variability was correctly assessed by the predictions. Further, the root mean squared standardized error (RMSSE) values are very close to one (cf. Table 5), mean that the prediction standard errors are valid. In Figure 8A, it is shown that a very good prediction power was achieved in the case of the bathymetry square root, revealed by the cloud of points very close to the 1:1 line.

Table 5. Results of the Empirical Bayesian Kriging (EBK) cross-validation. S1 and S2 = Sediment parameters transformed under the additive log-ratio (alr) transformation; RMSE = Root mean squared error; ASE = Average squared error; RMSSE = Root mean squared standardized error.

Variable	Parameter	EBK
Bathymetry (square root)	RMSE	0.03355
	ASE	0.03362
	RMSSE	0.9935
S1	RMSE	5.142
	ASE	5.219
	RMSSE	1.004
S2	RMSE	1.926
	ASE	1.916
	RMSSE	1.000
Kurtosis (fourth root)	RMSE	0.298
	ASE	0.290
	RMSEE	0.999

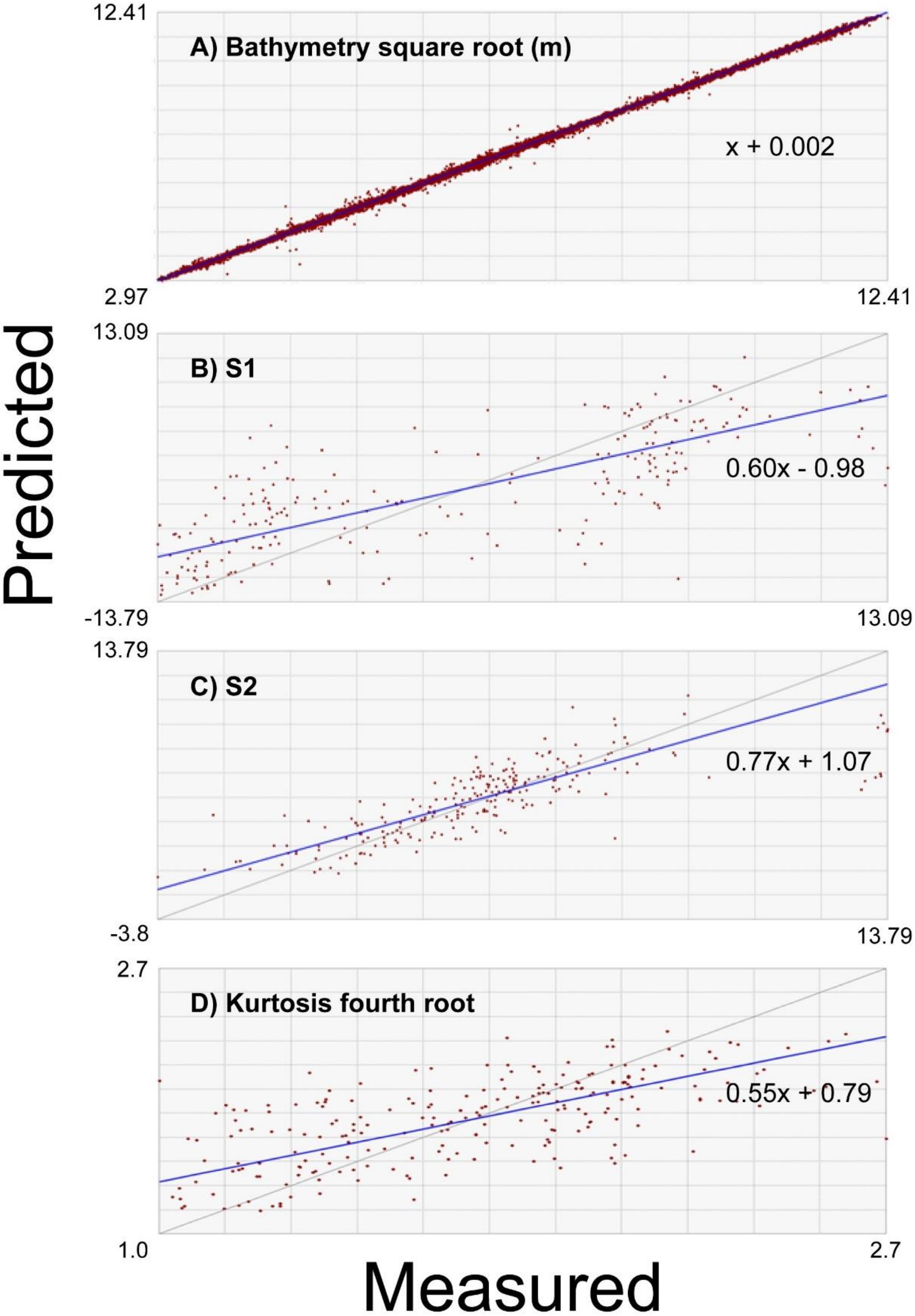


Figure 8. Scatterplot of the Empirical Bayesian Kriging cross-validation. Gray line – 1:1 line; Blue line – fitted line through the scatter of points, that is accompanied by equation.

3.1.2 Bathymetry map

A total of 167945 data points was used for the interpolation of the bathymetry, presenting values between 8.9 and 154 meters. The layer of the predicted depth values is presented in Figure 9. The pattern shown by the layer of the predicted values presents a high concordance with the measured bathymetry values. Both data sets show well the rock-outcrop of 'Pedra da Galega' (cf. Figure 9), revealed by the sudden change of bathymetry.

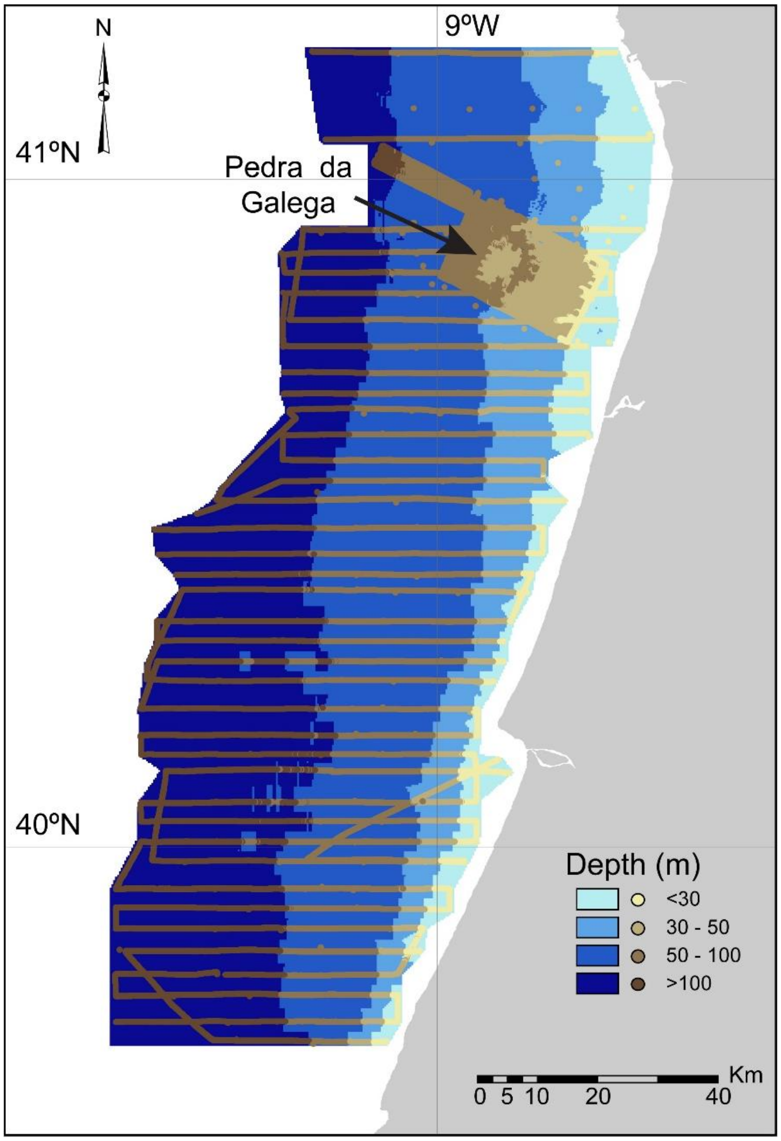


Figure 9. Bathymetry layer produced by EBK superimposed by the acoustic transects. The observed values are represented in yellow/brown and the predicted in blue.

3.1.3 Maps of the sedimentary parameters

The sampling point data and the interpolated layers with the values of the fines%, sand%, gravel% and kurtosis are presented in Figure 10 (A to D, respectively). The four sediment parameters showed a close agreement between the observed point sampling site values and the estimated values obtained for the interpolation layers. The measured sediment fractions ranged from 0 (in 10 sites) to 97.8% for mud, 2.2 to 100% for sand and 0 (in 92 sites) to 86.3% for gravel. Regarding with kurtosis, this parameter presented values between 1.1 and 54.3. The sediments with higher fines content are located deeper, manly in the northwest and southwestern parts of the sampling area, below 100 meters (cf. Figure 10A). The exception to this pattern is located off Douro River where sediments with higher fines content come much closer to shore, to the river mouth (cf. Figure 10A). The sand fraction was quite ubiquitous, with a content above 50% in a large extension of the study area (cf. Figure 10B). Gravel, was mainly present in two areas, the larger off Ria de Aveiro and around ‘Pedra da Galega’, between 20 and 100m deep, and the smaller off Mondego estuary around the 50m bathymetric line (cf. Figure 10C).

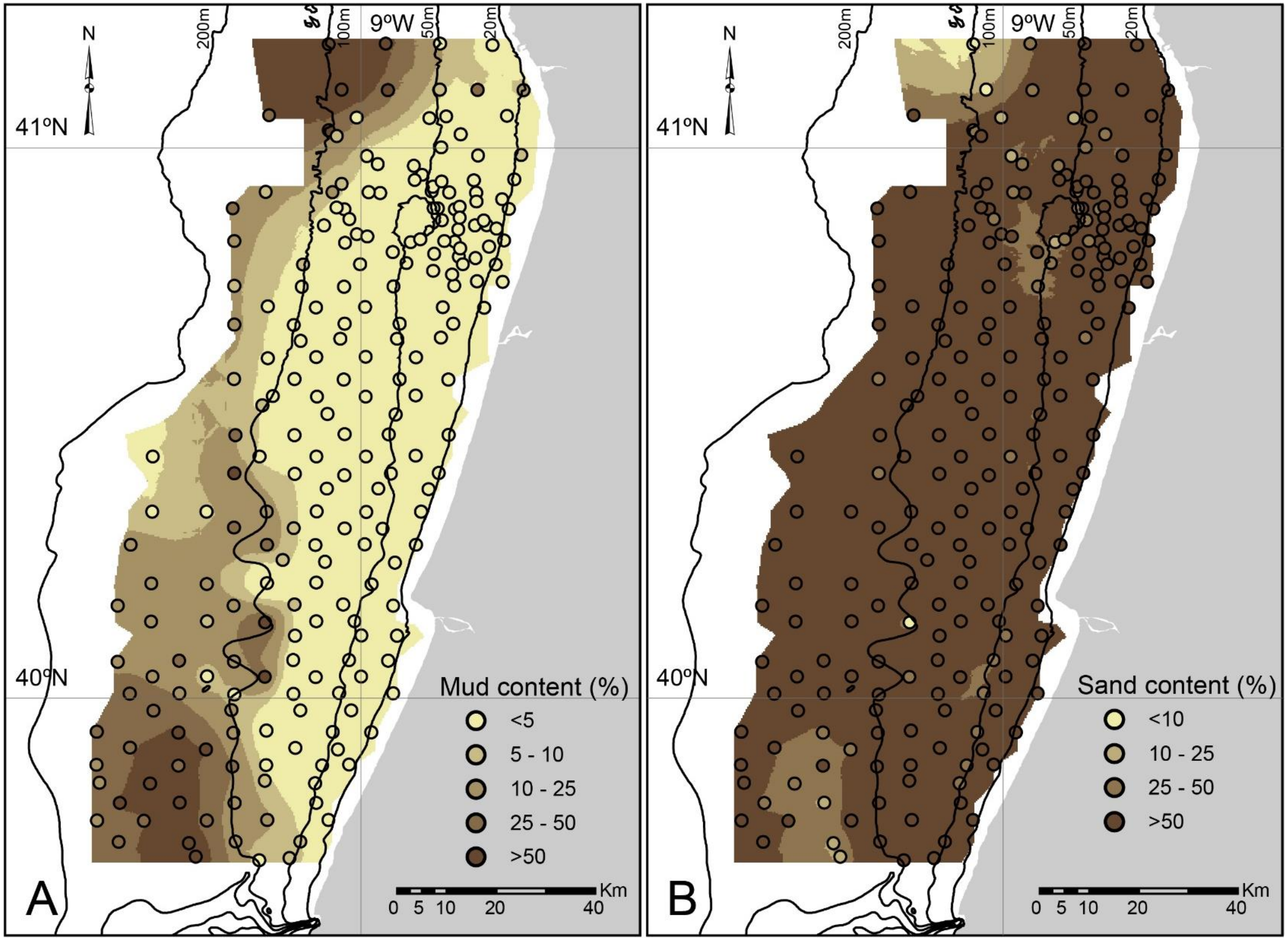


Figure 10. Spatial distribution of the superficial sediment parameters data and interpolation resulting layers using EBK: A – Mud; B – Sand; C – Gravel; D – Kurtosis.

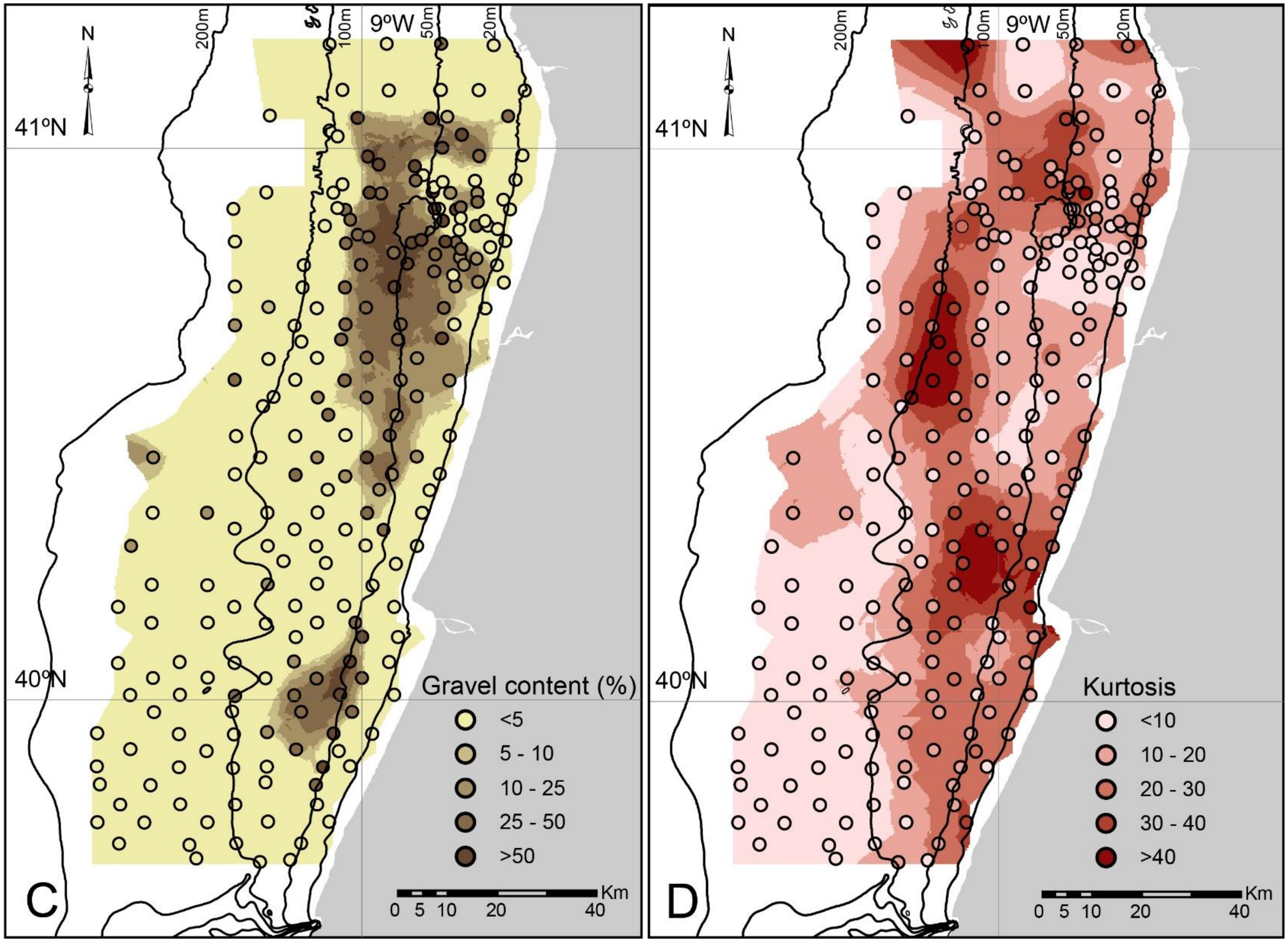


Figure 10 (Cont.). Spatial distribution of the superficial sediment parameters data and interpolation resulting layers using EBK: A – Mud; B – Sand; C – Gravel; D – Kurtosis.

3.2 Sedimentary map presenting the Folk-MeshAtlantic system

The spatial distribution of the superficial sediments classified using the modified Folk-MeshAtlantic system is presented in Figure 11. Table 6 shows the agreement between the observed point sediment data and the estimated interpolated layer. The overall concordance between the two was high (86.3%, cf. Table 6), as visually appreciated in Figure 11. The spatial distribution of the finer class sediments (i.e. mud, muddy sand and sandy mud) reflects, as expected, the spatial distribution of the fines fraction (cf. Figure 10A and 11). They predominate below 100m deep, off Douro and Mondego estuaries, except two muddy sand sites south of Douro estuary, above 50m deep. A vast area is occupied by sand, expanding from the shallower bottom, along the whole study area through depths below 100 meters. The three mixed sediment point samples are present in deeper areas, and do not coincide with the respective class in the sediment layer (cf. Figure 11, Table 6). A portion of this sediment class is estimated in the northern part of the study area, being clearly an artifact of the EBK calculations. The coarse sediments spatial distribution is very close to that presented by the gravel content (cf. Figure 10C and 11), being present at almost all latitudinal extension of the study area between the 20 and 100m, occasionally interrupted by sections of sand.

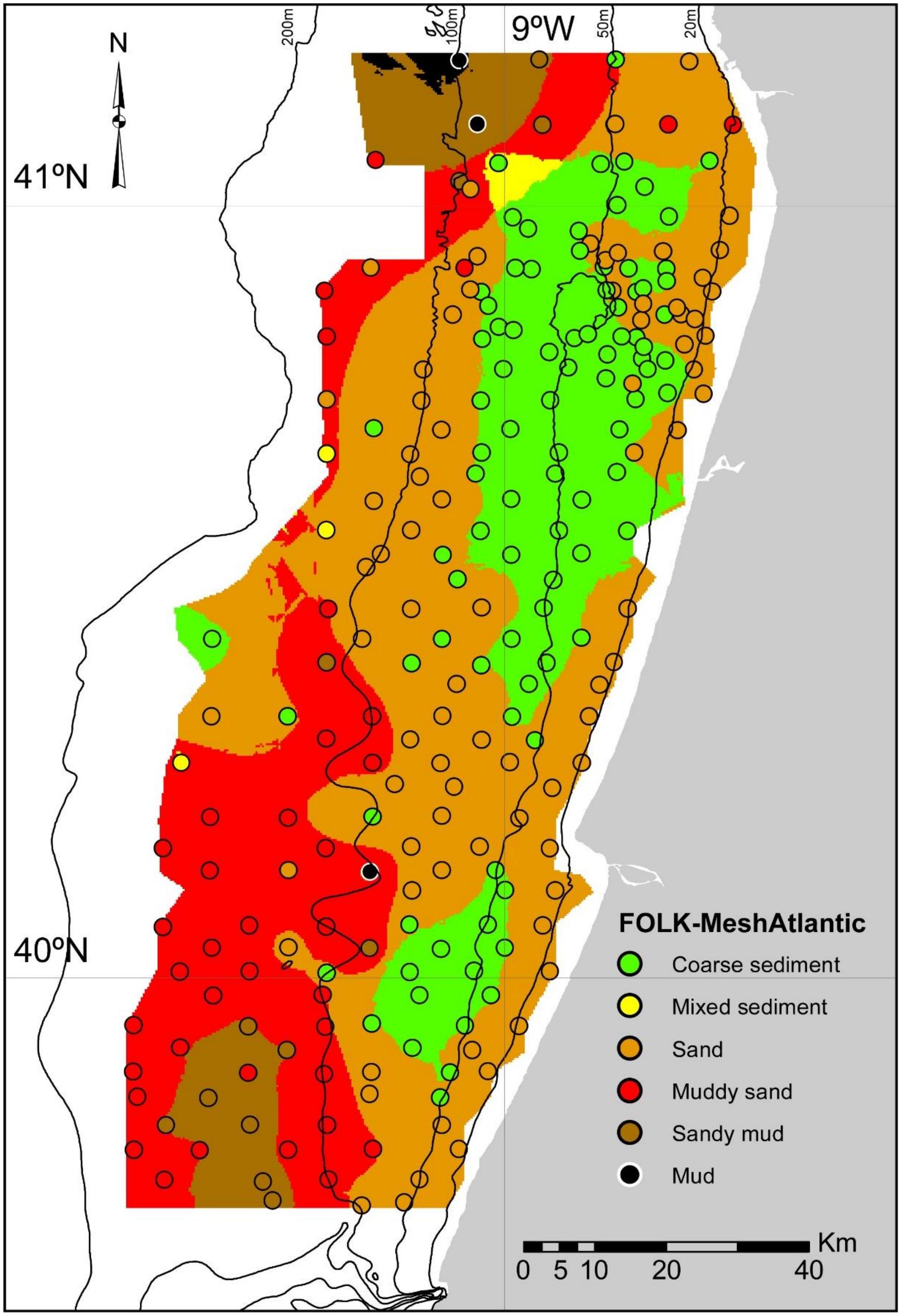


Figure 11. Spatial distribution of the superficial sediments classified accordingly to the Folk-MeshAtlantic system, represented through the sample point data and the interpolated layer.

Table 6. Agreement between the sediment point sample data and the interpolated layer, classified according to the Folk-MeshAtlantic system. Overall = ratio between the total number of correctly estimated samples and the number of total samples.

Original group	Mud	Sandy mud	Muddy sand	Sand	Mixed sediment	Coarse sediment	Total (samples)	%Correct
Mud	1	2	0	0	0	0	3	33.3
Sandy mud	0	8	4	0	0	0	12	66.7
Muddy sand	0	2	32	3	0	0	37	86.5
Sand	0	0	4	73	0	2	79	92.4
Mixed sediment	0	0	2	1	0	0	3	0.0
Coarse sediment	0	0	1	9	1	81	92	88.0
Overall							226	86.3

3.3 Sediments classified according to the Wentworth scale

Figure 12 presents the spatial distribution of the superficial sediments classified by the median value according to the Wentworth scale, showing sediments ranging from mud to fine gravel. Mud and very fine sand were predominant to the southwest and northwest sections of the study area, off Mondego and Douro estuaries, on deeper areas (generally > 100m), except a few shallower sites south of Douro estuary. Medium sand was relatively uncommon while fine sand was observed in a wide depth range, i.e. near shore, the mid-shelf and in deeper areas. In this section of the Portuguese continental shelf, the sediments were, in general, coarser towards the north and inshore up to 100m depth. The coarser sediments, namely fine gravel and very coarse sand, occurred across almost all the latitudinal extension of the study area, mainly off Ria de Aveiro, around ‘Pedra da Galega’ outcrop and off Mondego estuary, close to the 50m bathymetry line. Generally, the patterns presented by the two sediment classification systems were quite similar (Figures 11 and 12).

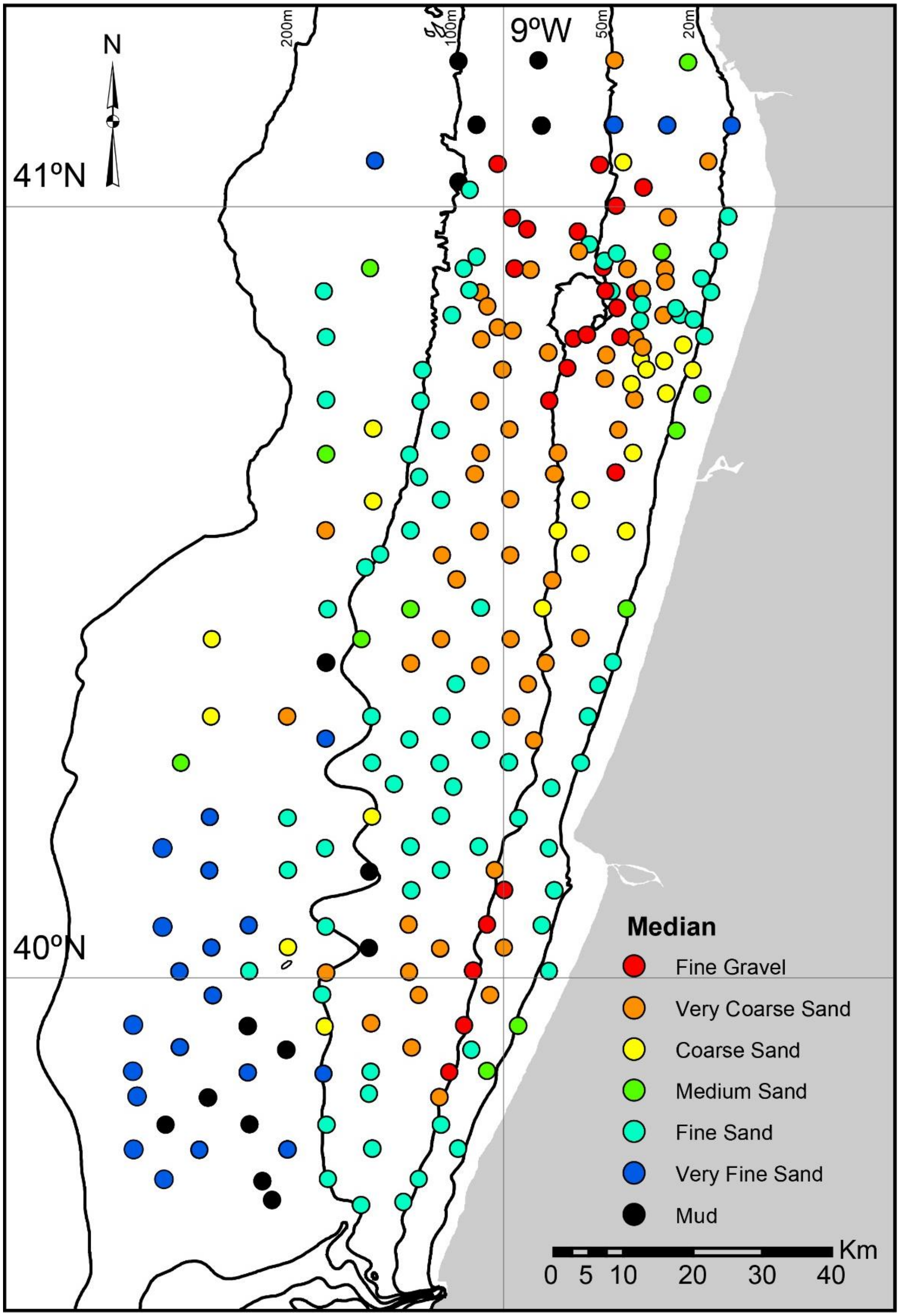


Figure 12. Spatial distribution of the superficial sediments classified according to the Wentworth scale, based on the grain-size median value.

3.4 Acoustic data variability study

$H_0$1: The Euclidean distance within site replicates is not significantly different when the acoustic data are integrated at various spatial steps (125, 250, 500, 750, and 1000 meter blocks).

Figure 13 shows the mean Euclidean distance within site replicates at the various acoustic integration spatial steps. The lowest value was obtained at 250m, indicating that this spatial step minimized the residual or error variance (within site replicates). Nevertheless, the null hypothesis was only borderline rejected for the pairwise comparisons between the spatial steps 125 - 250m (t = 2.0619; p = 0.041) and 250 - 1000m (t = 1.9683; p = 0.048).

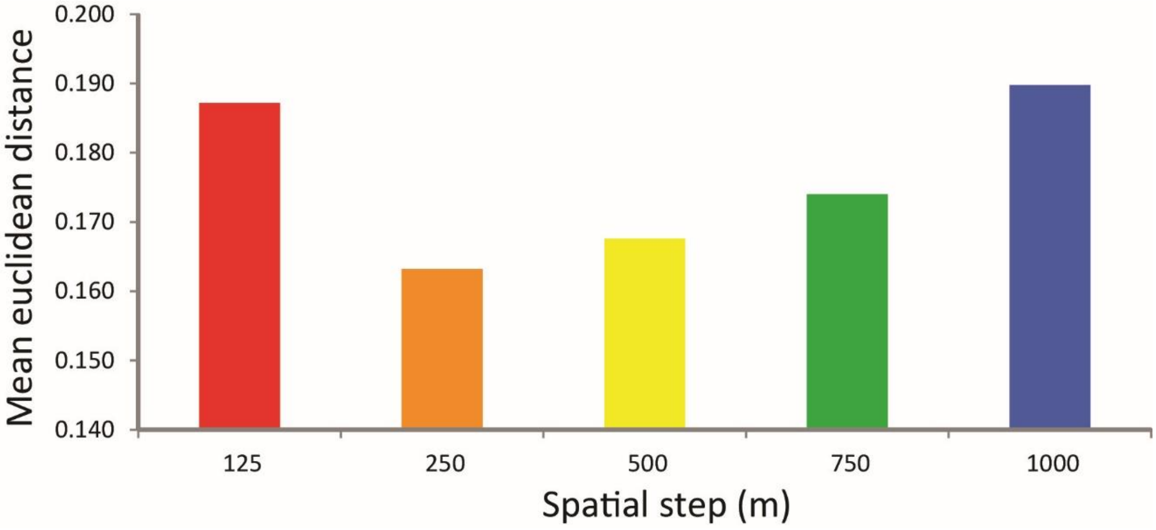


Figure 13. Mean Euclidean distance within site replicates per acoustic integration spatial step.

$H_0$2: No significant differences exist among sites when the acoustic data are integrated at various spatial steps (125, 250, 500, 750, and 1000 meter blocks).

This null hypothesis was rejected at all acoustic data integration steps. Figure 14A shows the pseudo-F values of the PERMANOVA main test using sites as the single factor, revealing that the acoustic data integrated at 250m maximized the variance among sites. In the pairwise comparisons, the highest ratio of pairs that rejected the null hypothesis (Figure 14B) was also obtained at the 250m spatial step. Despite the apparent differences in the pseudo-F values of the main tests conducted separately for each spatial step (cf. Figure 14A), the two-way crossed model, using sites and spatial step as factors, revealed no statistical differences between the spatial steps. The t-statistic were higher for the pairwise comparisons 250 - 125m (t = 1.6809; p = 0.067) and 250 - 1000m (t = 1.5729; p = 0.099), but neither rejected the null hypothesis. Given the expected large differences among the sites, this should not be surprising, making it almost impossible to reject the null hypothesis when overall comparing the spatial steps. In fact, even when comparing the spatial steps within each site, only 10 among the 121 sites presented some significant differences between the spatial integration steps. Generally, these differences were observed between the pairs 125 - 750m, 125 - 1000m, 250 - 750m or 250 - 1000m.

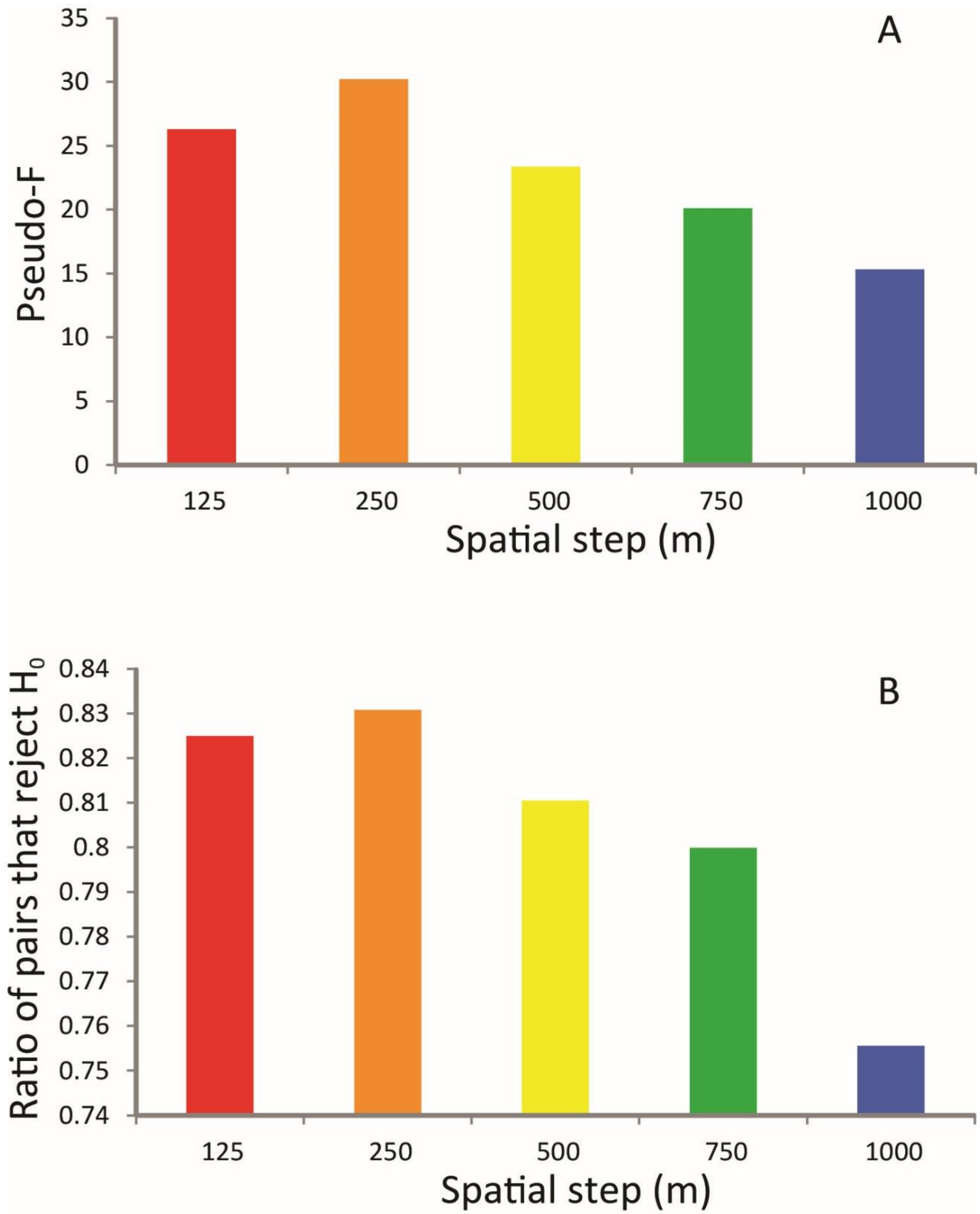


Figure 14. Results of the PERMANOVA test of the null hypothesis that no significant differences exist between sites when the acoustic data is integrated at differing spatial steps: A) main test pseudo-F values; B) ratio of pairs rejecting the null hypothesis in the pairwise comparisons.

$H_0$3: No significant differences exist between the acoustic groups representing the sediment types when the acoustic data are integrated at various spatial steps (125, 250, 500, 750, and 1000 meter blocks).

This null hypothesis was rejected in all cases and Figure 15A shows that the highest pseudo-F value in the main tests conducted separately for each acoustic integration step was obtained at 250m. This indicated that integrating the acoustic data at this spatial step maximized the distinction between the acoustic groups representing the sediment types. Figure 15B shows also that the number of pairwise comparisons rejecting the null hypothesis between the acoustic groups was slightly higher at the 125 and 250m integration spatial step, although no significant differences among the spatial steps were noted, as in the previous example.

Despite the results of this H_0 were considered satisfactory, some pair-wise comparisons presented results difficult to interpret. Even in the case of the 250m, that presented the best results, was not found a pattern between the pairs presenting significant differences. As example, the acoustic data of the fine gravel group was considered significantly different from the very coarse sands, but not from the medium sands. This incoherence of the acoustic data was explored in the further analysis.

The contents of this section were published in Mamede et al. (2015).

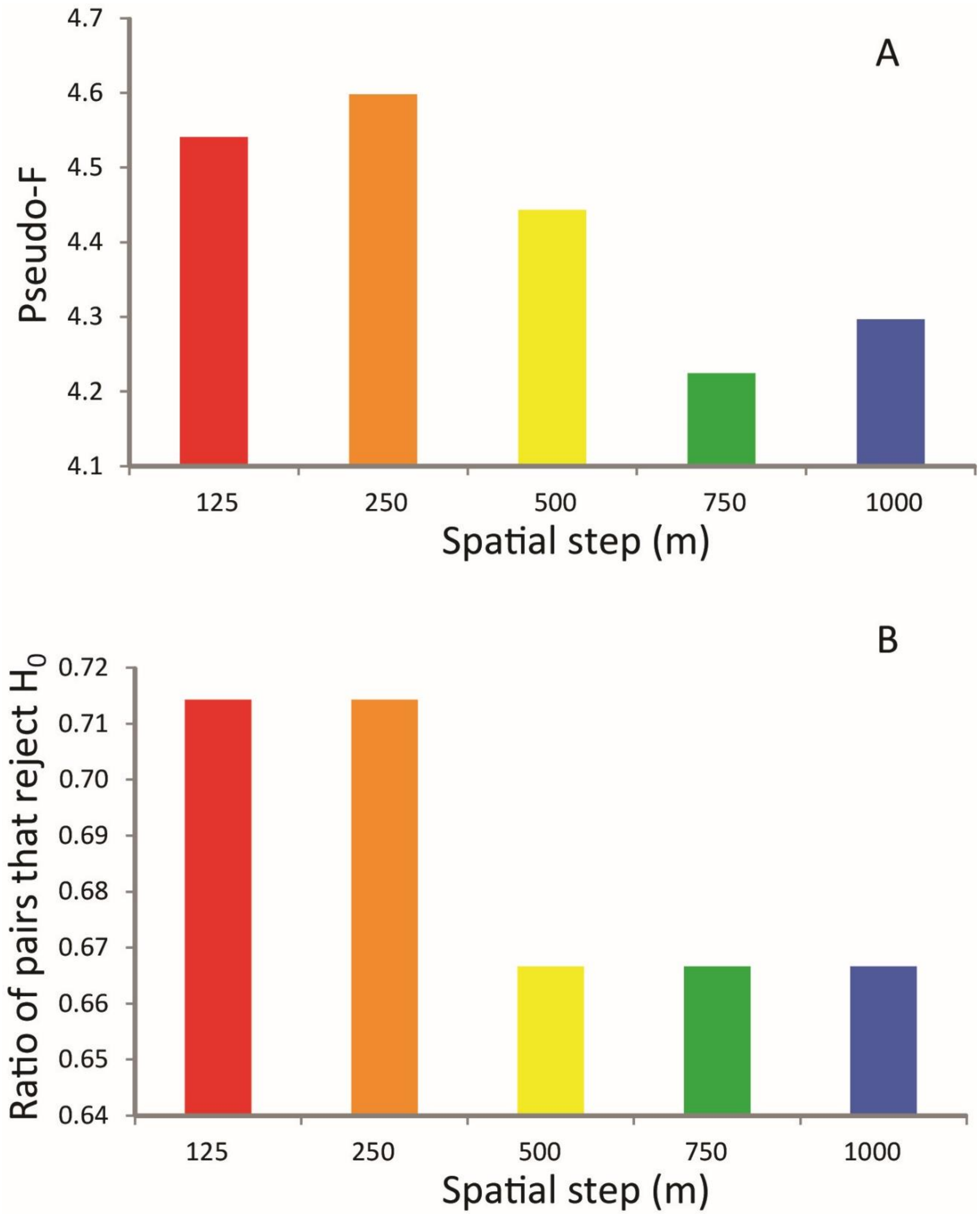


Figure 15. Results of the PERMANOVA test of the null hypothesis that no significant differences exist between the acoustic groups representing the sediment types when the acoustic data are integrated at differing spatial steps: A) main test pseudo-F values; B) ratio of pairs rejecting the null hypothesis in the pairwise comparisons.

3.5 Acoustic diversity pattern and depth

The acoustic data manual clustering methodology, splits the class with the lower total score and chooses how many classes should be represented using the highest CPI rate value (QTC IMPACT, 2004). However, the only consistent acoustic pattern achieved presented only two classes (Figure 16A and B). A total of 89526 and 55692 records were used in the acoustic classification in the analysis with all the records and with the records presenting p-values > 90%, respectively.

The spatial distribution of the acoustic classes is shown in Figure 16 (A and B) and the assignment of the sampling sites, classified according to the sediment types, to an acoustic class is given in Figure 17 (A and B). Figure 16 shows the presence of an inshore-offshore acoustic pattern. When using all the records in the classification, the two acoustic classes were not well separated, with portions of the acoustic transects of one class presenting what seems to be interference patterns of the other class (cf. Figure 16A). This condition creates ambiguous classification areas where was not possible to attribute an acoustic class to some sediment samples (‘Not Classified’ in Figure 17A). The attempt of solve this problem by using only the records with p-values > 90% was insufficient, leading only to a decrease from 26 to 21 samples not classified (Figure 17B). Further, even with this low resolution of two acoustic classes, it was not possible to discriminate well the sediments, both acoustic classes presenting a wide range of sediment types. The only relevant note is the absence of the two finer sediment types in the acoustic class one, in the case of the analysis with all the records (Figure 16A).

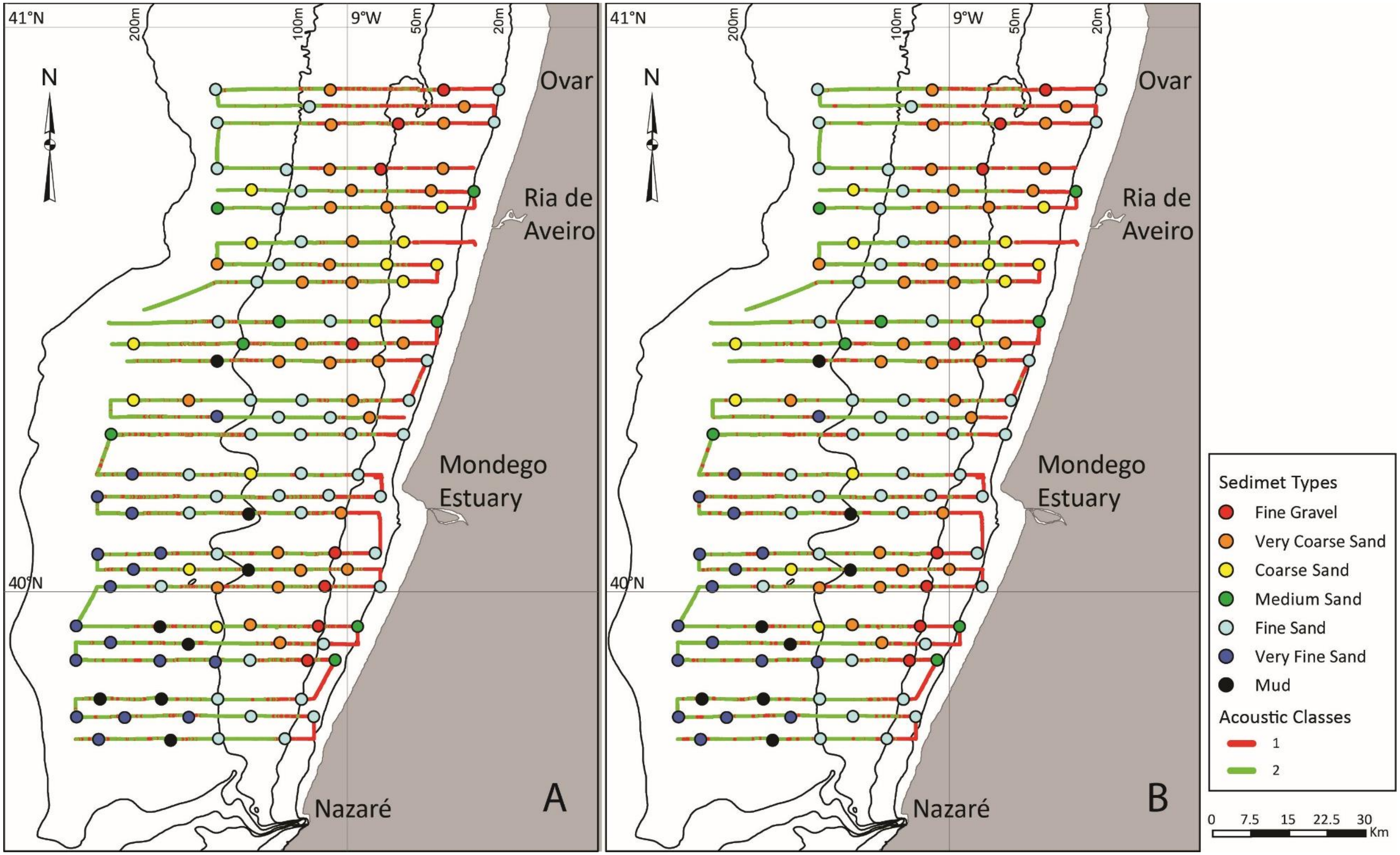


Figure 16. Spatial distribution of the acoustic classes with the superficial sediment types superimposed. A – Analysis with all records; B – Analysis using only the records with p-value > 90%.

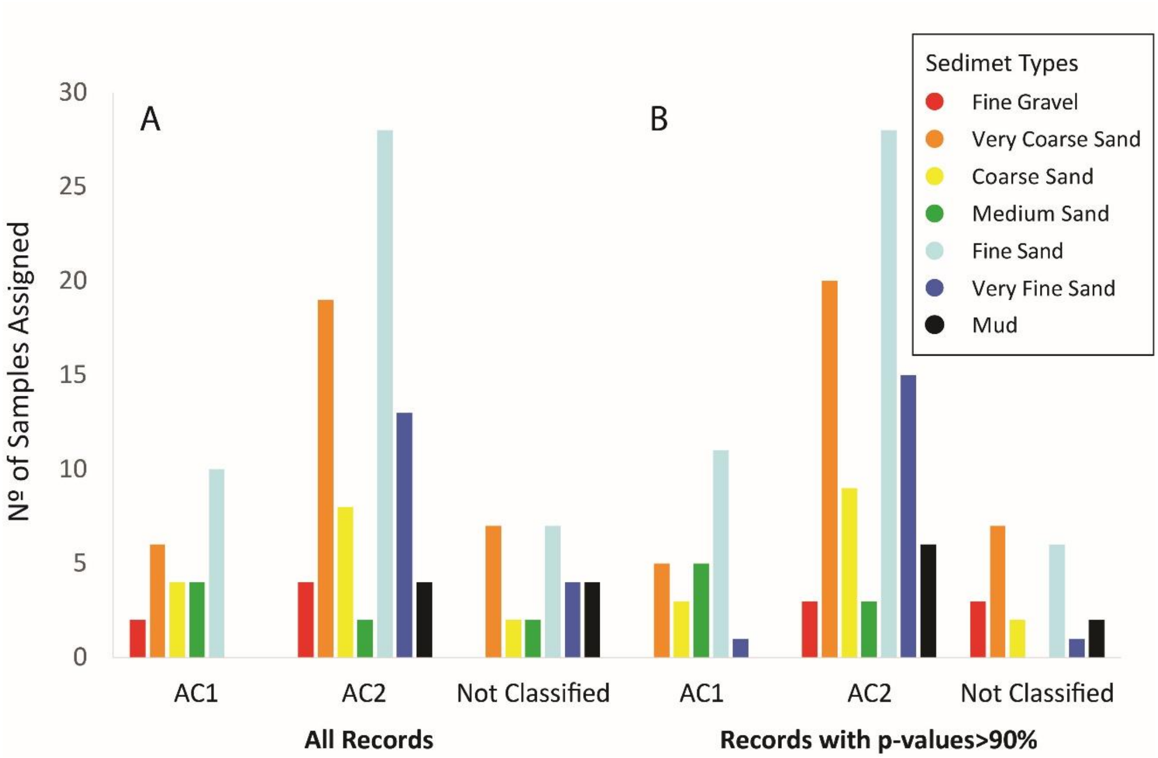


Figure 17. Number of samples assigned to each acoustic class (AC1 and AC2) discriminated by sediment type. A – Analysis with all records; B – Analysis using only the records with p-value > 90%.

H_0: No significant differences exist between the acoustic groups representing the depth classes.

To run this null hypothesis, the acoustic data was organized into classes representing the depth ranges < 30m; 30 - 50m; 50 - 70m; 90 - 110m; 110 - 130m and > 130m. This null hypothesis was rejected, with a pseudo-F of 13.96 and associated $p < 0.0001$. In the pair-wise comparisons, the ratio of pairs that reject the null hypothesis was 0.71. Figures 18A and B show the nMDS of the acoustic data, to which depth classes and the sediment types were superimposed as factors. The nMDS allow to visualize the close relationship between the acoustic data and depth, illustrating the rejection of H_0. On the contrary, when superimposing the sediment classes to the acoustic data ordination, no obvious relationship emerged. This analysis indicated a clear contamination of the acoustic data by depth, jeopardizing its use as an explanatory variable for the modelling of the benthic habitats.

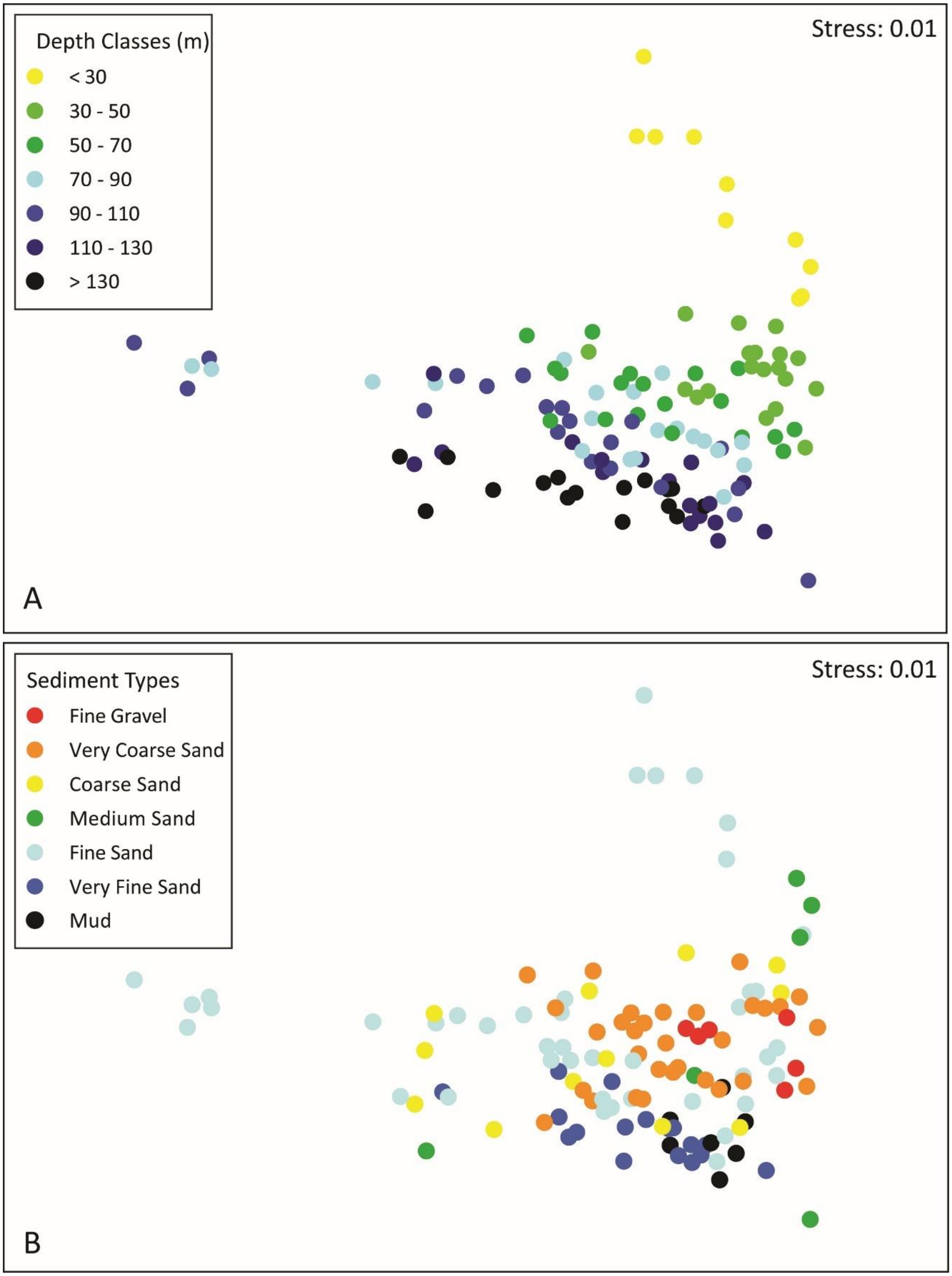


Figure 18. Ordination diagrams (NMDS) of the acoustic data represented by all levels of the depth and sedimentary factor.

3.6 Environmental data exploration

The relationships between environmental explanatory variables is presented in Figure 19, expressed both in terms of Spearman correlation coefficients (lower-left) and pairwise scatterplots (upper-right). Sediment sorting presented high correlation, 0.69 and 0.68, with well-known benthic macrofauna communities environmental drivers, namely depth and fines%, and was therefore excluded from the modelling studies. Depth and fines%$_{4throot}$ presented a relative high correlation value, however both were kept for the modelling studies given their commonly important relationship with the benthic macrofauna composition. In the modelling works, special attention was given to the p-values of these variables, specially to the fines%$_{4throot}$, the one presenting the highest variance inflation factor value.

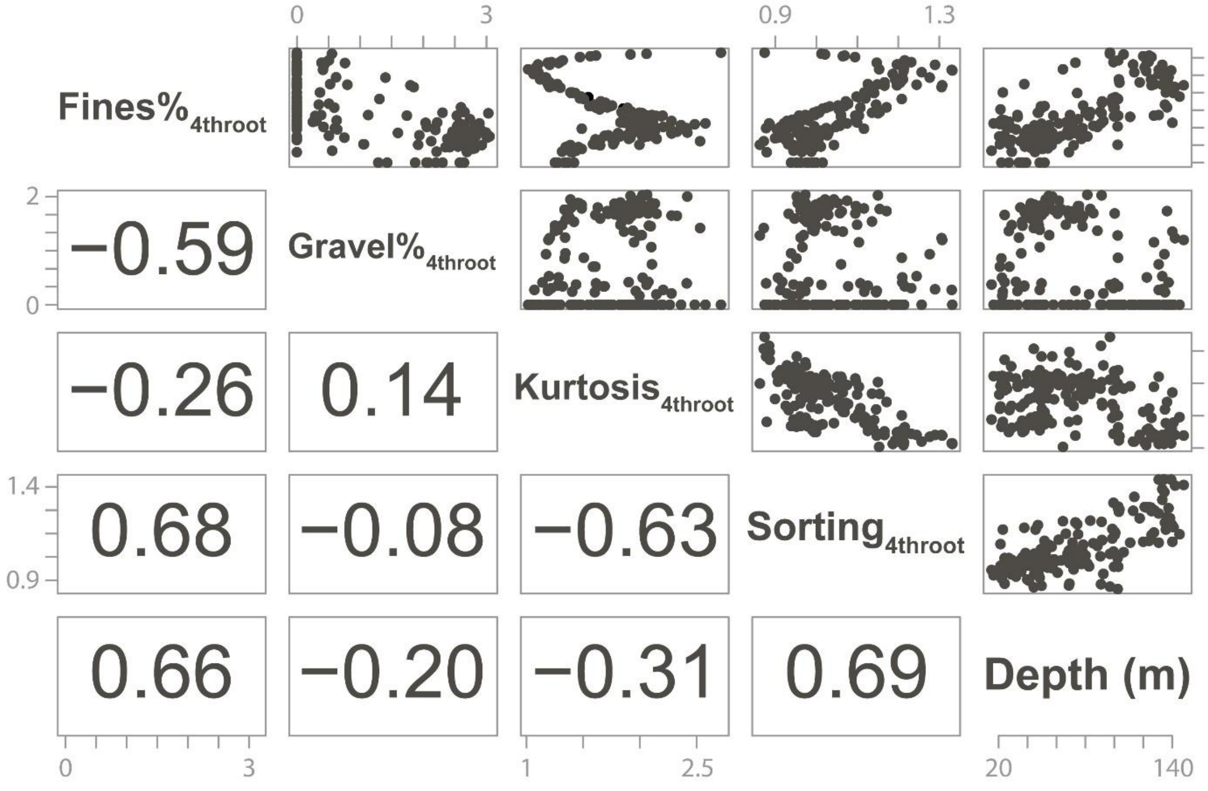


Figure 19. Multi-panel scatterplot of the continuous explanatory variables. The upper-right panels show the pairwise scatterplots and the lower-left the Spearman correlation coefficients.

3.7 Macrofauna abundance and diversity patterns

In the 169 sites for the macrofauna study, a total of 64485 individuals were sampled (mean = 381.6 ind./0.1m^2), belonging to 708 taxa (mean = 44.8 taxa/0.1m^2) and distributed by 11 phyla (echiuridians were included in the annelids). The relative (% of the total) abundance (A_R) and number of species (NS_R) per phylum are shown in Figure 20. Except for the Nemertea, the sequence of the most abundant phyla was also followed by the higher number of species (cf. Figure 20). The phylum presenting higher abundances were the Annelida (50270 individuals, A_R = 78.0%, of which 49872 ind. were Polychaeta), Arthropoda (6829 ind., A_R = 10.6%, of which 6826 ind. were from the subphylum Crustacea), Nemertea (2522 ind., A_R = 3.9%), Mollusca (2350 ind., A_R = 3.6%), Echinodermata (1364 ind., A_R = 2.1%) and Cnidaria (487 ind., A_R = 0.8%). In terms of number of species, the phyla that presented higher values were Annelida (329 species, NS_R = 46.5%, of which 327 polychaetes, NS_R = 46.2%), Arthropoda (202 spp., NS_R = 28.5%, of which 200 crustaceans, NS_R = 28.2%), Mollusca (108 spp., NS_R = 15.3%), Echinodermata (41 spp., NS_R = 5.8%), Cnidaria (10 spp., NS_R = 1.4%) and Sipuncula (9 spp., NS_R = 1.3%). The most abundant taxa (> 2000 ind.) were *Hesionura elongata* (7896 ind.; A_R = 12.2%), *Polygordius appendiculatus* (6447 ind., A_R = 10.0%), *Mediomastus fragilis* (5931 ind., A_R = 9.2%), *Spio filicornis* (3347 ind., A_R = 5.2%), *Magelona johnstoni* (2804 ind., A_R = 4.3%), *Pisione parapari* (2766, A_R = 4.3%), Nemertea n.i. (2522 ind., A_R = 3.9%) and *Protodorvillea kefersteini* (2071 ind., A_R = 3.2%). The taxa that presented higher frequencies (F, present in > 70 sites) were Nemertea n.i. (in 129 sites, F = 76.3%), *M. fragilis* (in 97 sites, F = 57.4%), *Glycera lapidum* (in 94 sites, F = 55.6%), *Goniadela gracilis* (in 74 sites, F = 43.8%), *P. appendiculatus* (in 73 sites, F = 43.2%), *P. kefersteini* (in 73 sites, F = 43.2%) and *Notomastus latericeus* (in 72 sites, F = 42.6%).

The spatial distribution of total abundance, α-diversity and Shannon-Wiener diversity index per sampling site are presented in Figure 21 (A, B and C, respectively). In Figure 22 are displayed the relationships between the continuous environmental variables (fines%, gravel% and depth) and these macrofauna indices, while Figure 23 shows box-and-whisker plots representing the samples distribution of these macrofaunal indices per sedimentary class according to the Wentworth scale. Abundance per site ranged from 9 to 2623 ind./0.1m^2, in a mud and a medium sand site, respectively. The macrofauna abundance decreased with increasing distance to the coast or depth (cf. Figures 21A and 22), presenting constantly higher values from the shallowest areas to slightly above the 50 m. However, it was also in this depth ranges that abundance values presented very high variance (cf. Figure 22). The sediment class with the highest mean abundance was medium sand but the highest median was the fine gravel. Both, lowest mean and median abundance values were found in mud (cf. Figure 23A).

With regards to alpha diversity, the lowest value (9 spp./0.1m^2) was registered in mud and the highest (93 spp./0.1m^2) in very coarse sand. Figure 21 shows that the higher alpha diversity values were concentrated around the 50 meters bathymetry, being this also demonstrated in Figure 22 where is evident the nonlinear relationship between this index and depth. Concerning to the sediment, alpha diversity presented a negative relationship with fines% and positive with gravel% (cf. figure 22). Moreover, the two parameters of central tendency (i.e. mean and median) used to represent the indices values per sediment class presented a similar pattern through the sedimentary gradient (cf. Figure 22), resulting in a nonlinear pattern. However, the coarser sediments (i.e. very coarse sand and fine gravel) presented the higher mean and median values of α-diversity and the finer sediment type (i.e. mud) the lower (cf. Figure 23B).

Concerning the Shannon-Wiener index, the lowest value (1.16) was reported in a medium sand and the highest in a very coarse sand (5.68) site. For this index, the higher values were found in depths below the 50m (cf. Figures 21 and 22). A nonlinear relationship was found between the Shannon-Wiener index and fines% with the higher values of this index appearing on sediments containing approximately 20% of fines while with gravel% no clear relationship was found (cf. Figure 22). The relationship between this variable and the Wentworth sediment classes was non-linear, as indicated in Figure 23.

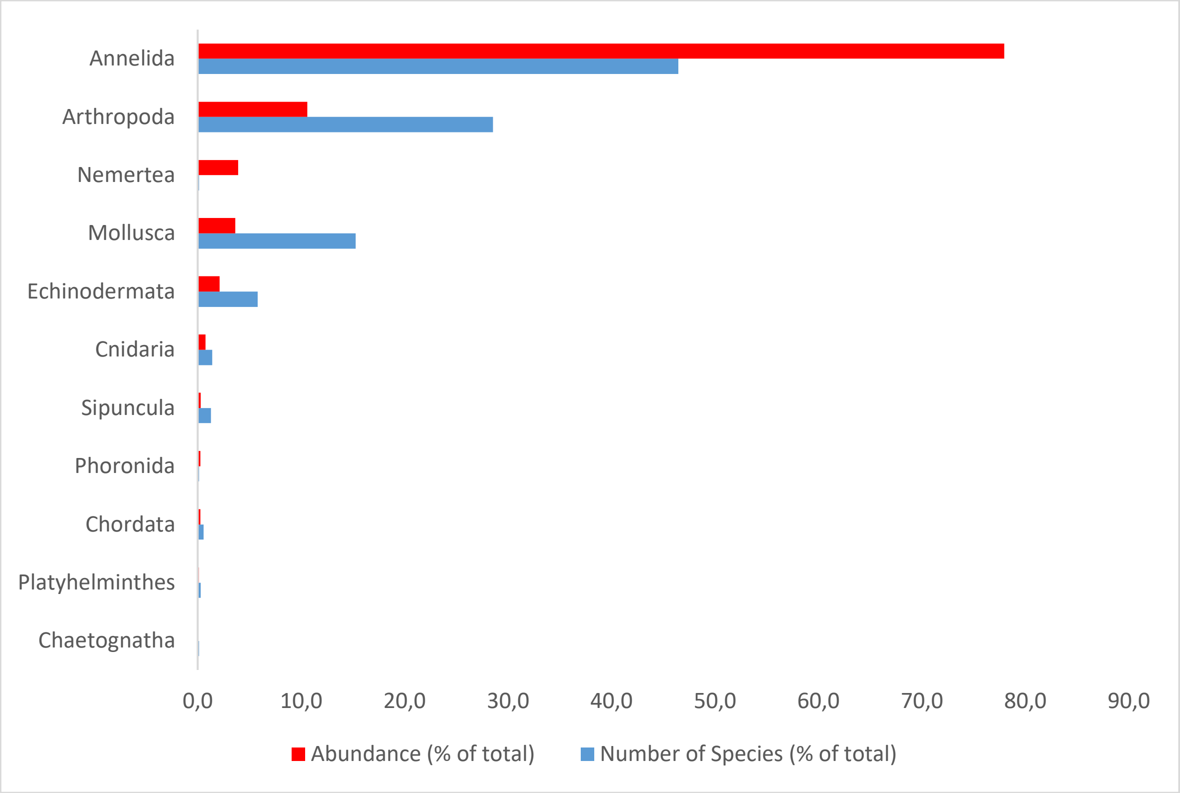


Figure 20. Relative abundance and number of species (% of the total) per phylum.

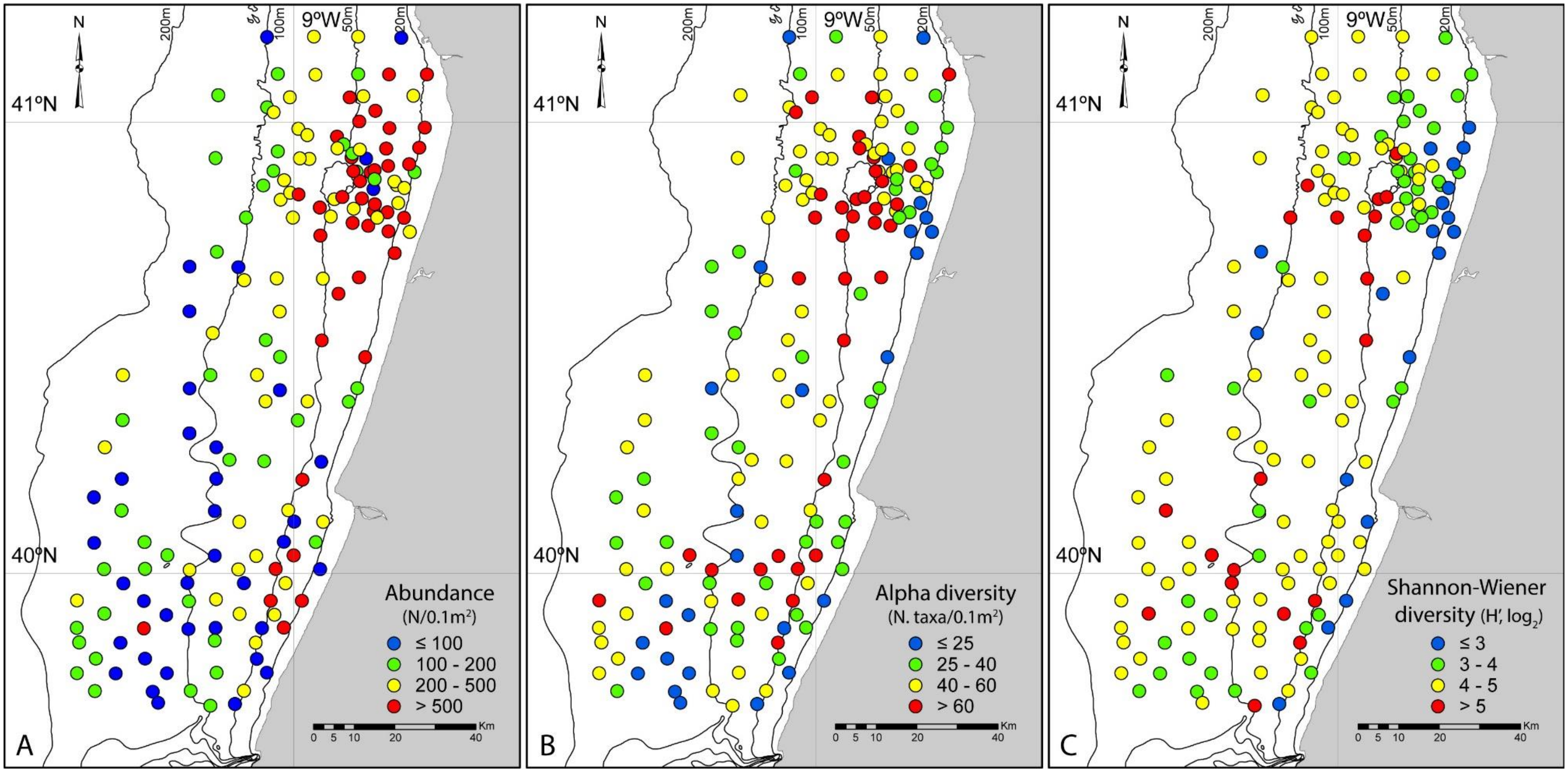


Figure 21. Spatial distribution of macrofauna total abundance (A), alpha diversity (B) and the Shannon-Wiener diversity (C) per site in the study area.

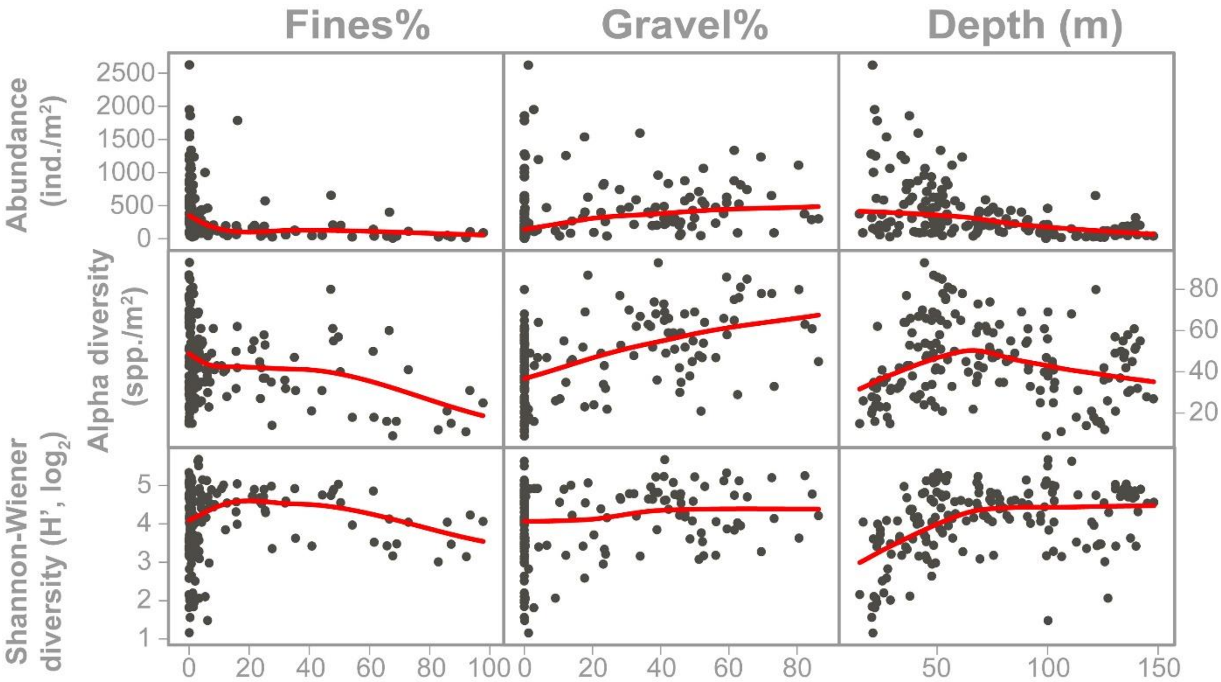


Figure 22. Scatterplots of the relationship between macrofauna indices (abundance, alpha diversity and Shannon-Wiener diversity) and environmental variables (fines%, gravel% and depth). A LOESS smother (red line) was added to support the visual interpretation.

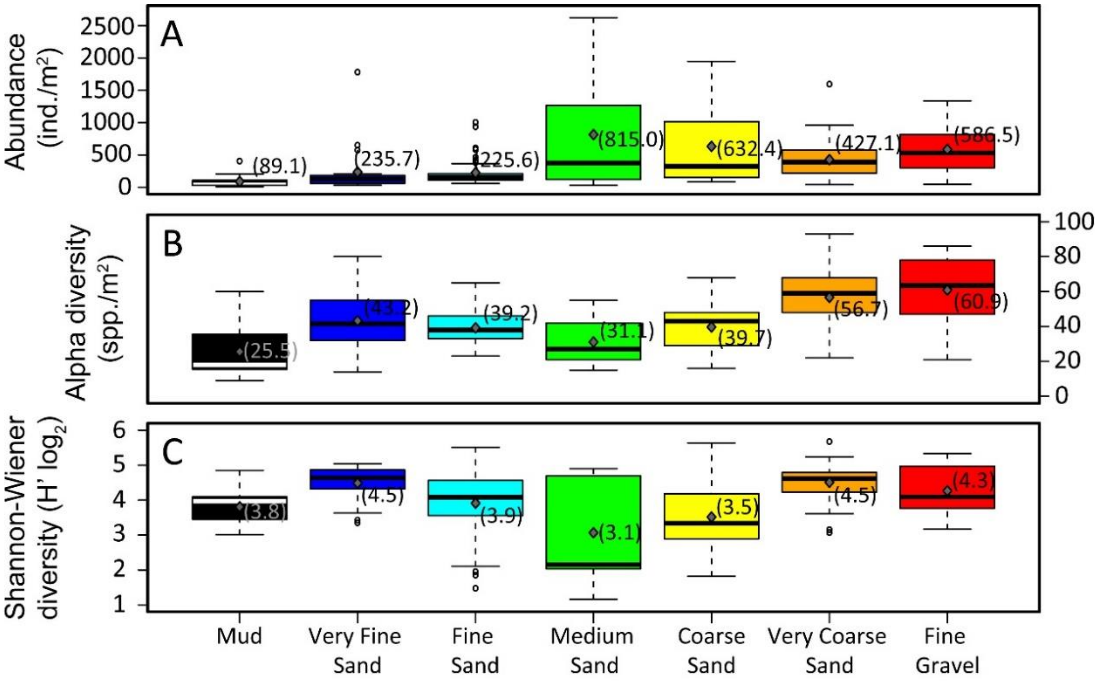


Figure 23. Box-and-whisker plots representing the abundance (A), alpha diversity (B) and Shannon-Wiener diversity (C) per sediment class obtained using the Wentworth grain-size sediment scale. Values in brackets correspond to the class mean value.

3.8 Macrofauna abundance and diversity distribution models (DM)

The relationships between the response and the transformed explanatory variables for the training dataset are shown in Figure 24, while the regression and EBK models are given in Table 7. Except for abundance, only the regression models that presented spatial independence of the residuals are shown. All models were statistically significant. The explanatory variable fines%$_{4throot}$ was not retained in any of the final models (cf. Table 7).

For abundance, all the regression models presented spatial dependency among the residuals, so an autocovariate was added (cf. Table 7). Even so, only one model was able to produce residuals non-significantly spatial correlated. The relationships between abundance and the environmental explanatory variables were mainly linear, being the exception the not so clear relationship with kurtosis$_{4throot}$ (cf. Figure 24). Thus, the significant model that could produce non-significantly autocorrelated residuals was a GLM, with the explanatory variables gravel%$_{4throot}$, kurtosis$_{4throot}$ and depth (cf. Table 7). Table 7 also presents a model with spatial dependence, given the need to compare the predictions with the kriging results, as it was not possible to create predicting values for the testing dataset with a model that includes an autocovariate.

Regarding alpha diversity, the relationship with the covariates presented both linear, in the case of fines%$_{4throot}$ and gravel%$_{4throot}$, and non-linear relationships, in the case of kurtosis$_{4throot}$ and depth (cf. Figure 24). Three models presented spatial independency, the best performance, both in terms of R^2 and NRMSE, being the GAM quasipoisson, which also presented the lowest NRMSE (cf. Table 7). In this model, gravel%$_{4throot}$ and depth were significantly related to alpha diversity, gravel%$_{4throot}$ with a linear positive correlation and depth a nonlinear (cf. Table 7).

In the case of the Shannon-Wiener diversity, the relationships with the explanatory variables was less clear, except with depth where a positive relationship was observed (cf. Figure 24). For this macrofauna index, two models presented spatial independency of the residuals. Each of these obtained the best performance for one of the parameters used, the R^2 in the case of the LR and the NRMSE for the GLM gamma. The explanatory variables that remained in the final models of the Shannon-Wiener diversity were $gravel\%_{4throot}$ and depth (cf. Table 7). Despite these models presented the lowest fitted explained variance, they obtained the highest accuracy in terms of R^2, compared to the models of the other macrofauna indices.

Amongst the EBK models, the highest performance both in terms of NRMSE and R^2 was achieved for the Shannon-Wiener diversity (cf. Table 7). This methodology revealed a low performance in both parameters, NRMSE and R^2, when compared to the best regression models for each macrofauna index.

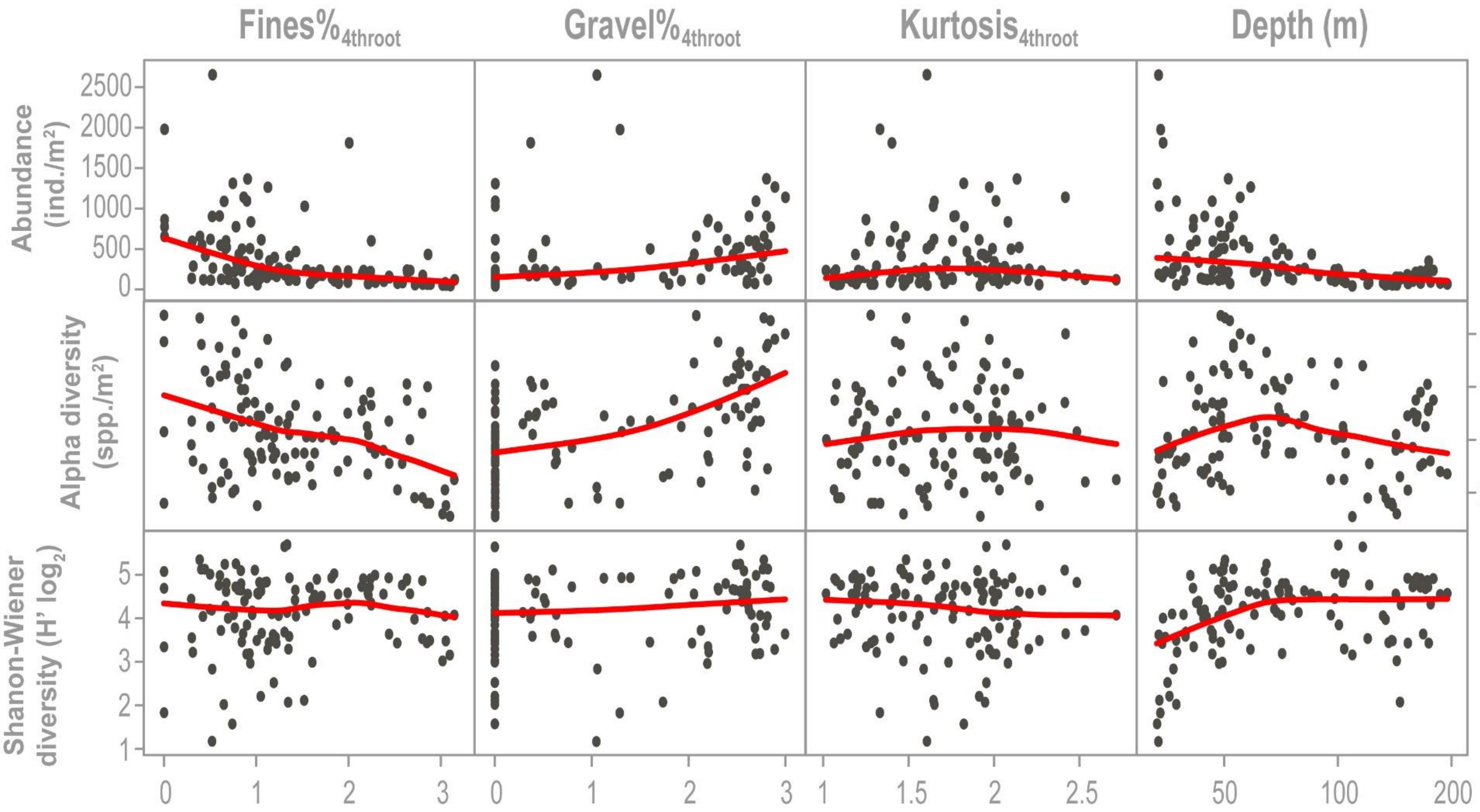


Figure 24. Scatterplots of the relationship between three macrofauna indices (abundance, alpha diversity and Shannon-Wiener diversity) and four environmental variables (fines%$_{4throot}$, gravel%$_{4throot}$, kurtosis$_{4throot}$ and depth), for the training dataset. A LOESS smother (red line) was added to support the visual interpretation.

Table 7. Distribution model results for the three macrofauna indices, showing for each explanatory variable the respective coefficient; $F\%_{4thrt}$ = $Fines\%_{4throot}$; $G\%_{4thrt}$ = $Gravel\%_{4throot}$; K_{4thrt} = $Kurtosis_{4throot}$; NRMSE = Root mean squared error (normalized to the different data scales); R^2 = Coefficient of determination; SF = Smoothing Function; P-value: < 0.001 = ***, < 0.01 = **, < 0.05 = *, non-significant = n.s.

Models	**Model Fitting**						**Model Evaluation**	
	$F\%_{4thrt}$	**$G\%_{4thrt}$**	**K_{4thrt}**	**Depth**	**Autocovariate (Abundance)**	**Deviance Explained (%)**	**NRMSE** (%, range)	**R^2** (obs. vs. fitted)
Abundance								
GLM negative binomial[1]		0.331***	- 0.592**	- 0.0168***		52.3	20.4	0.280
GLM negative binomial		0.339***	- 0.537**	- 0.0176***	- 0.000698(n.s.)	53.2		
EBK (Spatial interpolation)							23.2	0.183
Alpha diversity								
GLM quasipoisson		0.189***				29.4	20.7	0.167
GLM negative binomial		0.187***				26.7	20.7	0.167
GAM quasipoisson		0.142***		SF*		35.6	19.3	0.269
EBK (Spatial interpolation)							23.5	0.0493
Shannon-Winner								
Linear regression		0.192**		0.00897***		16.9[2]	21.8	0.356
GLM gamma		0.0498**		0.00237***		15.3	21.7	0.352
EBK (Spatial interpolation)							23.1	0.187

[1] This model that presented spatial autocorrelation among residuals

[2] For the multiple linear regression the deviance explained is given by the adjusted R^2.

3.9 Multivariate analysis

The ordination diagrams relative to the multivariate analysis of the benthic macrofauna abundance data are displayed in Figure 25 (A to E). From the classification analysis, seven benthic communities were identified (cf. Figure 25A and B) and their spatial distribution is shown in Figure 26. Table 8 resumes the environmental and biological parameters characterizing each macrofauna affinity group, whilst in Table 9 the species succession among the macrofauna assemblages is represented. Figure 27 (A to H) displays the spatial distribution in the study area of the most characteristic species of each of the seven groups and one of the most abundant and frequent species (*M. fragilis*). The NMDS representing the ordination of the macrofauna affinity groups (Figure 25A), assisted by the NMDS of the bubble plots expressing the environmental variables (Figure 25C, D and E), reveals a separation in terms of fines% and depth of the metagroups A and B from the metagroup C. Further, the separation between the metagroups A and B was justified by gravel% (cf. Figure 25D). Regarding the PCO (Figure 25B), the first axis (horizontal) captured 19.3% of the total variation, isolating the shallow coarser sediment groups (A1 and A2, cf. Table 8) on the positive pole, from the rest of the macrofauna assemblages on the negative. The second axis (vertical) accounts for 10.8% of the total variation, and generally demonstrates the depth gradation of the other macrofauna assemblages, ranging from the shallowest on the positive pole to the deepest assemblages, on the negative pole (cf. Table 8 and Figure 25B).

Group A1 is composed by 9 sites of clean (mean fines% = 0.10) medium and coarse sands, located near the shoreline (cf. Table 8 and Figure 26). It presents the highest mean abundance (1014 ind./0.1 m^2) and the second lowest mean α-diversity (23.0 spp./0.1m^2), resulting in a low β-diversity and the lowest mean evenness and Shannon-Wiener index (cf. Table 8). This group accounts with only three exclusive species, with the crustacean *Gastrosaccus spinifer* and the polychaeta *Nephtys cirrosa* being the most characteristic (cf. Table 8), while the most abundant were *H. elongata* and *P. parapari* (cf. Table 9).

The larger of all groups, i.e. A2, included 59 sites with coarser sediments (very coarse sand and fine gravel), with high mean gravel content (41.94%) and low mean fines content (1.30%)

(cf. Table 8). Spatially distributed along almost all the latitudinal extension of the study area, it is essentially located in depths between 20 and 100 m (cf. Figure 26). This group presented the highest mean α-diversity, total species richness and exclusive species (147 spp.), also presenting the second highest mean abundance, β-diversity and Shannon-Wiener index (*ex aequo* with B2, cf. Table 8). The characteristic species were the polychaetes *Gyptis propinqua* and *Malmgrenia ljungmani,* and the cephalochordate *Branchiostoma lanceolatum* (cf. Table 8), whereas the most abundant were *P. appendiculatus* and *M. fragilis* (cf. table 9).

Group A3 comprises 5 sites and represents the deeper coarse sands (mean depth = 120.5 m, cf. Table 8, Figure 26). This group displayed the lowest (with B2) β-diversity and only five exclusive species. Nevertheless, it presented average values for mean abundance, mean species richness and mean Shannon-Wiener index. Its characteristic species were *Scalibregma celticum* and *Urothoe marina* (cf. Table 8), while the most abundant were *Syllis garciai* and *Mesochaetopterus sagittarius* (cf. Table 9).

Group B1 comprised 53 sites mainly of fine sand with low fines content (5.90%, cf. Table 8). Their placement from the shallowest sites until approximately the 100m results is the highest depth range presented among all the communities (cf. Figure 26). Furthermore, this group is present in all north-south extension of the study area (cf. Figure 26). Embracing a high number of exclusive species (82 spp.), it presented the highest β-diversity value. The most characteristic species were the amphipod *Urothoe pulchella* and the polychaeta *Glycera tridactyla* (cf. Table 8), whilst the most abundant were the polychaetes *M. johnstoni* and *Spiophanes bombyx* (cf. Table 9).

Group B2 was the smallest in the study area and included 4 deep mud sites situated in the northwestern part of the study area off Douro estuary (cf. Table 8, Figure 26). This group presented the highest mean fines content (78.64%) and the lowest (with C2) gravel content (0.04%). Presenting the lowest β-diversity (2.7) and number of exclusive species (2 spp.), the most characteristic species were the bivalves *Tellina compressa* and *Thyasira* sp., being also important to notice the presence of other species of the *Thyasira* genera (*T. flexuosa*) among the most characteristic (cf. Table 8). The most abundant species were the annelids *Prionospio* sp. and *Prionospio ehlersi* (cf. Table 9).

Group C1 represents the deep very fine sands, with the highest mean depth (126.8 m) and is located mainly in the southwestern part of the study area, off the Mondego estuary (cf. Figure 26). This group presented the highest Shannon-Wiener index and the second highest mean alpha diversity, embracing 53 exclusive species. The most characteristic species were the polychaetes *Auchenoplax worsfoldi* and *Terebellides stroemii* (cf. Table 8) and the most abundant were *Ampharete finmarchica* and *Aphelochaeta* sp. (cf. Table 9).

Group C2 gathered mostly the muddy sediment sites in the south part of the study area (cf. Table 8, Figure 26). Located in deep bottoms (mean depth = 122.0 m) off Mondego estuary, the sediment of this assemblage presented the lowest gravel% (0.04 %, *ex aequo* with B2) and second highest fines content (55.56%, cf. Table 8). The lowest mean abundance and α-diversity were registered here, 122 ind./0.1m^2 and 21.3 spp./0.1m^2, respectively (cf. Table 8). Both most characteristic and abundant species were the polychaetes *Sarsonuphis bihanica* and *Nephtys incisa* (cf. Tables 8 and 9).

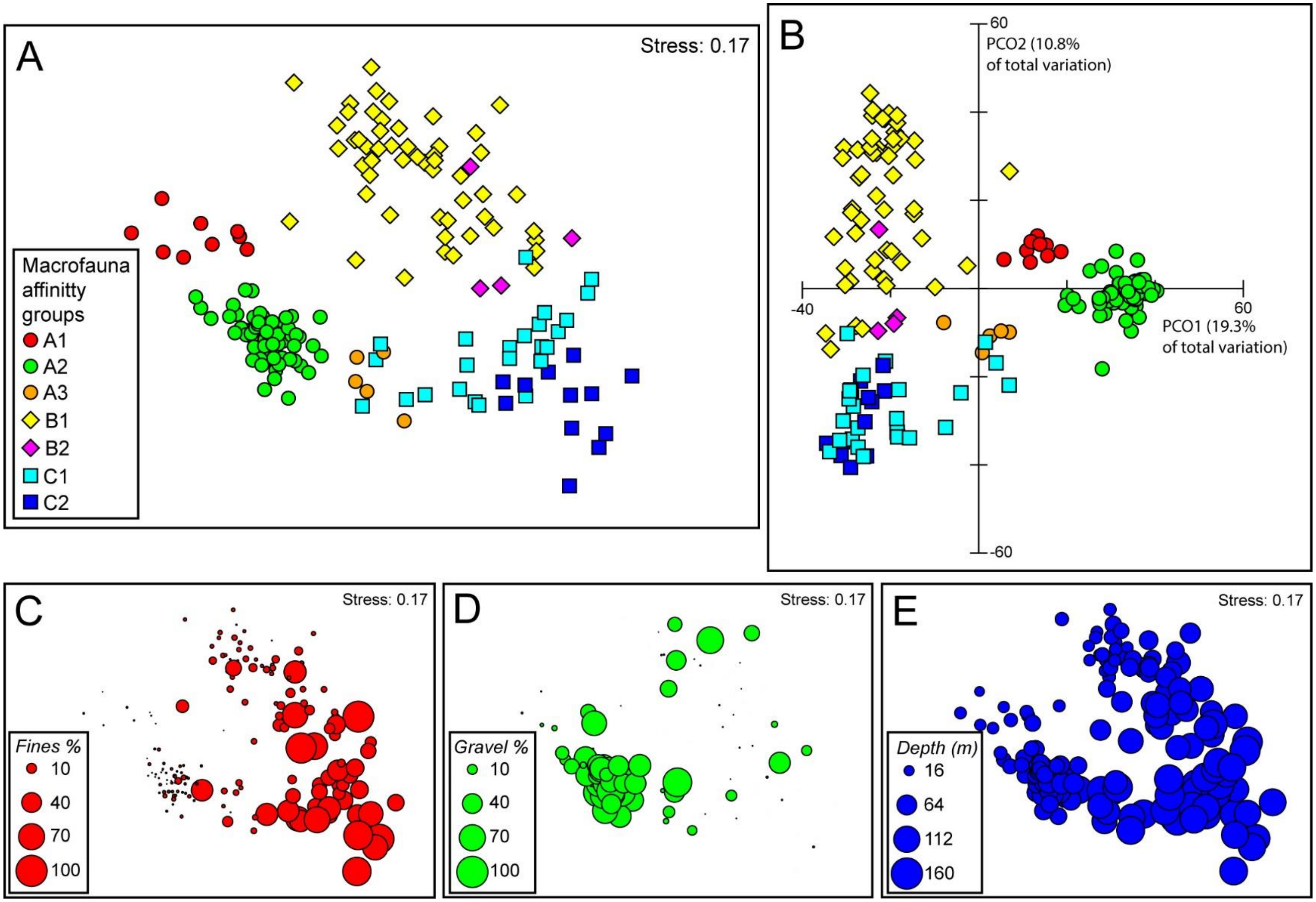


Figure 25. Ordination diagrams based on the macrofauna abundance data. The macrofauna affinity groups resulted from a classification analysis. A – NMDS displaying the macrofauna affinity groups; B – PCO displaying the macrofauna affinity groups; C, D and E – NMDS displayed as bubble plots of the environment variables.

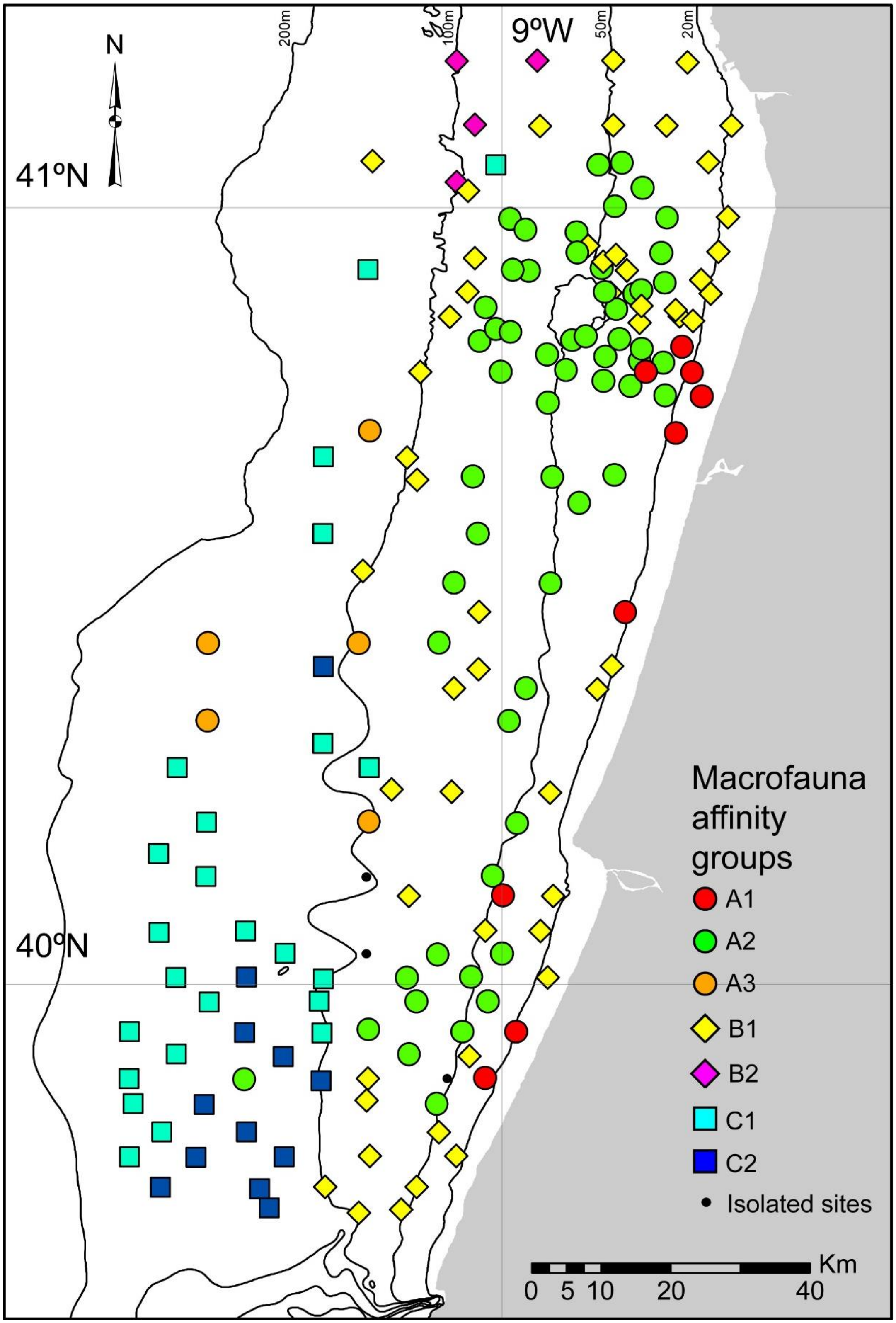


Figure 26. Spatial distribution of the benthic macrofauna affinity groups in the study area.

Table 8. Macrofauna affinity groups characterization. Mean values are reported to the unit sampling area ($0.1m^2$). G = gravel, VCS = very coarse sand, CS = coarse sand, MS = medium sand, FS = fine sand, VFS = very fine sand, M = mud (number of sediment samples within brackets); Constancy: Cn = constant, C = common, O = occasional; R = rare; Fidelity: E = elective, P = preferential, I = Indifferent, A = accessory; * = Exclusive species in each group.

Affinity groups	A1	A2	A3	B1	B2	C1	C2
Number of sampling sites	9	59	5	53	4	24	12
Main sediment type	Medium sand	Very coarse sand	Coarse sand	Fine sand	Mud	Very fine sand	Mud
Sediments types	MS(5), CS(3), FG(1)	VFS(1), FS(1), MS(1), CS(6), VCS(31), FG(19)	MS(1), CS(4)	Mud(1), VFS(4), FS(42), MS(1), VCS(4), FG(1)	Mud(4)	Mud(1), VFS(13), FS(2), MS(3), CS(2), VCS(2), FG(1)	Mud(7), VFS(4), FS(1)
Folk-MeshAtlantic sediment	Sand	Coarse sediment	Coarse sediment	Sand	Mud/Sandy mud	Muddy sand	Sandy mud
Fines content (mean, %)	0.10	1.30	1.92	5.90	78.64	23.59	55.56
Gravel content (mean, %)	10.23	41.94	8.30	3.58	0.04	8.19	0.04
Depth (mean, m)	25.4	57.1	120.5	56.5	90.2	126.8	122.0
Abundance (mean, ind./$0.1m^2$)	1014	629	156	248	129	129	52
Total species richness	92	470	115	386	92	327	112
α-diversity (mean, spp./$0.1m^2$)	23.0	60.15	42.6	39.0	34.3	45.7	21.3
Beta diversity (within the group)	4.0	7.8	2.7	9.9	2.7	7.2	5.3
Exclusive species	3	147	5	82	2	53	7
Margalef (mean)	3.6	9.47	8.4	7.3	6.9	9.3	5.2
Pielou’s evenness (mean)	0.51	0.72	0.75	0.75	0.83	0.89	0.86
Shannon-Wiener ($\log_2$, mean)	2.3	4.2	4.1	3.9	4.2	4.8	3.7
Simpson (1-λ, mean)	0.63	0.88	0.81	0.85	0.92	0.95	0.90

Table 8 (Cont.). Macrofauna affinity groups characterization. Mean values are reported to the unit sampling area ($0.1m^2$). G = gravel, VCS = very coarse sand, CS = coarse sand, MS = medium sand, FS = fine sand, VFS = very fine sand, M = mud (number of sediment samples within brackets); Constancy: Cn = constant, C = common, O = occasional; R = rare; Fidelity: E = elective, P = preferential, I = Indifferent, A = accessory; * = Exclusive species in each group.

Affinity groups	A1	A2	A3	B1	B2	C1	C2
Characteristic Species (With Constancy and Fidelity indications)	*Gastrosaccus spinifer* (Cn/P)	*Gyptis propinqua* (Cn/E)	*Scalibregma celticum* (Cn/P)	*Urothoe pulchella* (C/E)*	*Tellina compressa* (Cn/P)	*Auchenoplax worsfoldi* (Cn/E)	*Sarsonuphis bihanica* (Cn/I)
	Nephtys cirrosa (Cn/I)	*Malmgrenia ljungmani* (Cn/P)	*Urothoe marina* (Cn/E)	*Glycera tridactyla* (C/E)*	*Thyasira* sp. (Cn/E)	*Terebellides stroemii* (Cn/I)	*Nephtys incisa* (Cn/I)
	Pisione parapari (Cn/I)	*Branchiostoma lanceolatum* (Cn/P)	*Chaetozone carpenteri* (Cn/I)	*Ampelisca brevicornis* (Cn/I)	*Ampelisca spinimana* (Cn/P)	*Onchnesoma steenstrupii steenstrupii* (Cn/I)	*Ampharete finmarchica* (Cn/A)
	Nototropis falcatus (Cn/P)	*Guernea (Guernea) coalita* (Cn/E)	*Aricidea (Acmira) lopezi* (Cn/P)	*Phoronida n.i.* (Cn/I)	*Thyasira flexuosa* (Cn/P)	*Callianassa subterranea* (Cn/I)	*Labioleanira yhleni* (Cn/I)
	Hesionura elongata (Cn/I)	*Megamphopus cornutus* (Cn/E)	*Mesochaetopterus sagittarius* (Cn/I)	*Spiophanes bombyx* (Cn/I)	*Westwoodilla caecula* (C/E)	*Aricidea (Acmira) laubieri* (C/P)	*Paralacydonia paradoxa* (Cn/I)
	Pisione remota (Cn/I)	*Eurysyllis tuberculata* (Cn/E)	*Eulalia mustela* (Cn/I)	*Edwardsia claparedii* (Cn/I)	*Diastylis bradyi* (Cn/I)	*Euclymene* sp. *A* (C/P)	*Aphelochaeta* sp. (Cn/I)
	Saccocirrus papillocercus (C/E)	*Thracia villosiuscula* (Cn/I)	*Aricidea (Acmira) cerrutii* (Cn/P)	*Magelona filiformis* (Cn/I)	*Prionospio fallax* (Cn/I)	*Saccella commutata* (C/E)*	*Maldane glebifex* (A/P)
	Platyhelminthes n.i. (C/P)	*Sarsinebalia cristoboi* (C/P)	*Euclymene droebachiensis* (Cn/P)	*Magelona johnstoni* (Cn/I)	*Prionospio ehlersi* (Cn/I)	*Monticellina heterochaeta* (Cn/I)	*Chirimia biceps* (C/I)
	Spisula solida (C/P)	*Pulliella* sp. (Cn/I)	*Protodorvillea kefersteini* (Cn/I)	*Tellina fabula* (Cn/I)	*Ampelisca ruffoi* (C/P)	*Scoloplos (Scoloplos) armiger* (C/P)	*Gallardoneris iberica* (C/I)
	Polygordius appendiculatus (Cn/A)	*Aonides oxycephala* (Cn/I)	*Oestergrenia digitata* (Cn/I)	*Bathyporeia tenuipes* (C/E)*	*Abyssoninoe hibernica* (Cn/I)	*Lysippe labiata* (C/E)	*Magelona wilsoni* (A/I)

Table 9. Distribution of the species per affinity groups according to the mean abundance (ind./0.1m^2). Orange = the 3 exclusive species with the highest abundance, whenever possible. Yellow = species with the highest mean abundance in the group. *= Mean abundance below 0.05 individuals/0.1m^2.

	A1	A2	A3	B1	B2	C1	C2
Hesionura elongata	615.0	39.7	1.8	0.1		0.2	
Pisione parapari	124.1	27.8		0.1		0.1	
Gastrosaccus spinifer	54.4	2.4		0.1		*	
Pisione remota	49.2	12.7	2.2	*		0.3	
Saccocirrus papillocercus	25.9	*					
Gastrosaccus sanctus	11.8			*			
Nephtys cirrosa	5.9	0.1	0.2	1.2			
Tellina pygmaea	3.9	1.3		*			
Glycinde nordmanni	2.3	0.4		0.5	0.3		
Diogenes pugilator	0.8			0.5		*	
Spirobranchus triqueter		2.1					
Leptocheirus pectinatus		0.8					
Conilera cylindracea		0.2					
Polygordius appendiculatus	30.7	102.6	0.6	2.1		0.1	
Mediomastus fragilis	0.2	84.9	3.0	15.4	1.5	3.4	0.1
Spio filicornis	33.2	49.4		2.4	0.8	0.2	
Protodorvillea kefersteini	1.1	33.8	5.4	0.3		0.8	
Nemertea n.i.	18.1	20.3	6.6	19.8	3.5	2.0	1.1
Glycera lapidum	0.6	12.1	0.4	1.1		1.8	0.2
Aonides oxycephala	2.0	9.7	0.8	2.1	0.3		
Sphaerosyllis bulbosa	0.1	9.4	5.2	0.2		0.4	
Goniadella gracilis	1.3	8.0	2.8	0.2		0.4	
Socarnes erythrophthalmus		7.9		0.3	1.3	*	
Eulalia mustela	0.2	6.6	2.8			0.2	0.1
Malmgrenia ljungmani	0.4	6.5		*		0.5	
Cheirocratus sundevalli		6.2	0.2	0.1		0.2	
Oligochaeta n.i.	0.8	5.6		0.1		2.0	0.7
Caecum sp.		5.3				0.1	
Sarsinebalia cristoboi		5.3		0.1			
Othomaera othonis		5.2	0.2	0.6		0.6	
Psamathe fusca		5.0	1.4	0.1		0.1	
Apherusa bispinosa		4.9		0.2		*	
Echinocyamus pusillus	0.1	4.9		2.3	3.3	0.2	
Eumida sanguinea	1.8	4.8		2.2		0.2	
Gyptis propinqua		4.6				*	
Aponuphis bilineata		3.9	1.8	0.6		0.3	
Galathea intermedia		3.7		0.1		0.5	
Polycirrus medusa		3.4	0.8	0.1	0.3	0.8	0.1
Pulliella sp.	0.1	3.3	0.2	0.3			
Pista cristata		3.1	0.2	0.1		0.8	
Amphiura filiformis	0.1	3.0	0.6	0.2		0.1	0.1
Guernea (Guernea) coalita		2.9		*			
Amphiura chiajei		2.9		2.7	1.3	0.4	0.3
Sphaerosyllis sp.		2.7				0.7	
Eurysyllis tuberculata		2.5				*	

Table 9 (Cont.). Distribution of the species per affinity groups according to the mean abundance (ind./0.1m^2). Orange = the 3 exclusive species with the highest abundance, whenever possible. Yellow = species with the highest mean abundance in the group. *= Mean abundance below 0.05 individuals/0.1m^2.

	A1	**A2**	**A3**	**B1**	**B2**	**C1**	**C2**
Notomastus latericeus		2.4	0.4	0.4	0.5	1.5	0.2
Syllis licheri	0.2	1.8		0.1			
Hydroides norvegica		1.5		0.1		0.4	
Haplostylus normani		1.0	0.2	0.1		*	0.5
Spisula elliptica		0.9		0.1			
Ampelisca spinipes		0.6		0.5		0.3	
Chamelea striatula		0.3		0.2		*	
Syllis garciai		3.7	34.4	0.1		0.5	
Mesochaetopterus sagittarius		0.6	18.6	2.8		2.6	
Prionospio multibranchiata		0.6	5.6	0.5	0.3	1.0	0.2
Chaetozone carpenteri		0.3	4.6	*		0.1	0.8
Paradoneis lyra		2.3	3.2	0.6	1.0	1.4	0.5
Aricidea (Aricidea) pseudoarticulata			2.4	2.0		2.0	0.1
Aspidosiphon (Aspidosiphon) muelleri		0.3	2.4			0.1	
Sphaerosyllis taylori		1.0	1.6	*		0.1	
Autonoe spiniventris		0.2	1.4	0.3		0.6	0.3
Oestergrenia digitata		*	1.0	0.2			0.4
Spiochaetopterus solitarius			1.0	0.6	0.5	0.6	0.3
Chaetozone sp.2		*	0.8	0.3		0.3	0.3
Aricidea (Aricidea) wassi		*	0.6	0.2		0.6	
Glycera tridactyla				3.0			
Urothoe pulchella				2.3			
Myriochele danielsseni				0.7			
Bathyporeia gracilis				0.5			
Bathyporeia elegans				0.4			
Mactra stultorum				0.4			
Urothoe brevicornis				0.3			
Bathyporeia pelagica				0.2			
Magelona johnstoni	0.3	0.4		52.4	0.3		0.1
Spiophanes bombyx	0.3	0.1	0.6	10.2	1.3	0.3	0.3
Edwardsia claparedii		0.2		8.4		0.1	0.4
Magelona filiformis	0.1	0.2		7.8		0.8	
Prionospio fallax		0.8		6.7	4.3	0.3	
Owenia fusiformis			0.6	6.2		*	
Ampelisca brevicornis				4.2	2.0	0.2	
Phoronida n.i.		*		3.1	0.3	*	0.5
Lagis koreni		*		3.0	2.8		
Tellina fabula		*		3.0	1.0		
Pariambus typicus		1.1		2.1			
Leucothoe incisa		1.3		1.9		0.1	
Necallianassa truncata			0.2	1.9	0.5	*	
Magelona alleni		0.1		1.9	0.8	0.4	0.5
Bodotria scorpioides		*		1.7			
Abra alba		0.5		1.5	0.5	0.5	0.1
Aricidea (Strelzovia) roberti		0.3	0.4	1.5	0.5	0.9	0.1

Table 9 (Cont.). Distribution of the species per affinity groups according to the mean abundance (ind./0.1m^2). Orange = the 3 exclusive species with the highest abundance, whenever possible. Yellow = species with the highest mean abundance in the group. *= Mean abundance below 0.05 individuals/0.1m^2.

	A1	A2	A3	B1	B2	C1	C2
Chaetozone gibber			1.4	1.5	0.3	0.4	
Prionospio steenstrupi				1.0		0.7	0.2
Lanice conchilega		0.2	0.2	1.0		0.3	
Phaxas pellucidus				0.9	0.5	0.5	
Aponuphis grubii		*	0.2	0.8		0.4	0.2
Pseudopolydora antennata				0.7	0.3	0.1	0.1
Scolelepis sp.		*		0.6			
Chaetozone zetlandica			0.2	0.6		0.1	
Urothoe grimaldii		*		0.4			
Apseudopsis latreillii		*		0.3		0.1	
Echinocardium cordatum		0.1		0.3	0.3		0.2
Ampelisca typica		*		0.3	0.3	0.3	
Abra prismatica		*	0.2	0.2			
Prionospio sp.	0.2	4.0		4.2	12.8	1.2	0.2
Prionospio ehlersi		0.1		0.2	12.0	1.7	0.1
Kurtiella bidentata		1.4		0.4	7.8	0.1	
Thyasira sp.		*		0.1	5.5		
Tellina compressa				0.2	4.8	0.1	
Nucula nitidosa		*		*	4.3	0.1	0.3
Cylichna cylindracea		0.1	0.2	0.5	4.0	*	
Labioleanira yhleni		*		*	3.3	0.3	1.3
Sthenelais limicola		*	0.4	1.0	2.8	0.1	
Euspira nitida	0.7	0.2		0.9	2.3		
Nephtys kersivalensis	0.8	0.2		1.2	2.3	1.0	
Poecilochaetus serpens		0.1		0.7	2.0	0.5	0.4
Nephtys hombergii				0.5	1.8	0.3	
Ampelisca spinimana				1.6	1.8		0.1
Corbula gibba			0.2	0.3	1.8	*	0.3
Abyssoninoe hibernica		*			1.5	0.4	0.8
Levinsenia gracilis		*		*	0.8	0.6	0.4
Ampelisca ruffoi					0.5	0.3	
Cirriformia tentaculata		*		0.1	0.3	0.1	
Onchnesoma magnibathum						0.2	
Scalpellum scalpellum						0.2	
Ampharete finmarchica		0.1	0.6	0.5	0.8	6.3	3.2
Aphelochaeta sp.		0.1	0.6	0.2		6.1	1.9
Monticellina *heterochaeta*		0.1	3.6	0.2	1.5	5.1	2.5
Onchnesoma steenstrupii steenstrupii		0.1	0.2	0.1		3.0	1.9
Lumbrineris lusitanica		1.6		2.0		2.8	0.3
Galathowenia oculata		*	0.6	0.7	0.3	2.6	0.8
Terebellides stroemii		*		*		2.3	0.3
Spiophanes kroyeri		0.1	0.6	1.0	1.0	2.0	0.5
Auchenoplax worsfoldi				0.1		1.8	
Harpinia antennaria		*		0.3	0.8	1.7	
Gallardoneris iberica						1.6	0.8

Table 9 (Cont.). Distribution of the species per affinity groups according to the mean abundance (ind./0.1m^2). Orange = the 3 exclusive species with the highest abundance, whenever possible. Yellow = species with the highest mean abundance in the group. *= Mean abundance below 0.05 individuals/0.1m^2.

	A1	**A2**	**A3**	**B1**	**B2**	**C1**	**C2**
Callianassa subterranea				0.2		1.5	0.8
Magelona minuta		0.1		1.2	1.3	1.5	0.3
Euclymene sp. A		*		0.1		1.4	0.1
Aponuphis brementi				*	0.5	1.3	0.3
Aricidea (Acmira) assimilis		*	0.2	*		1.2	0.7
Euclymene oerstedi				0.1	0.3	1.0	0.1
Lysippe labiata				*		1.0	
Isolda pulchella				*		0.9	
Aricidea (Acmira) laubieri		*		0.1		0.7	
Paraprionospio pinnata		*		0.2		0.7	0.1
Malmgrenia mcintoshi		0.2				0.5	
Sipuncula n.i.		0.1	0.2	*		0.5	
Ampelisca tenuicornis				0.1		0.4	0.1
Hydrobia acuta neglecta							0.3
Sarsonuphis bihanica		0.5		*		9.3	14.1
Nephtys incisa		0.1			1.0	0.1	1.6
Chirimia biceps		*				0.9	1.3
Ninoe armoricana					0.3	0.2	0.5
Ophiura albida		0.2	0.2	0.3	0.3	0.1	0.5

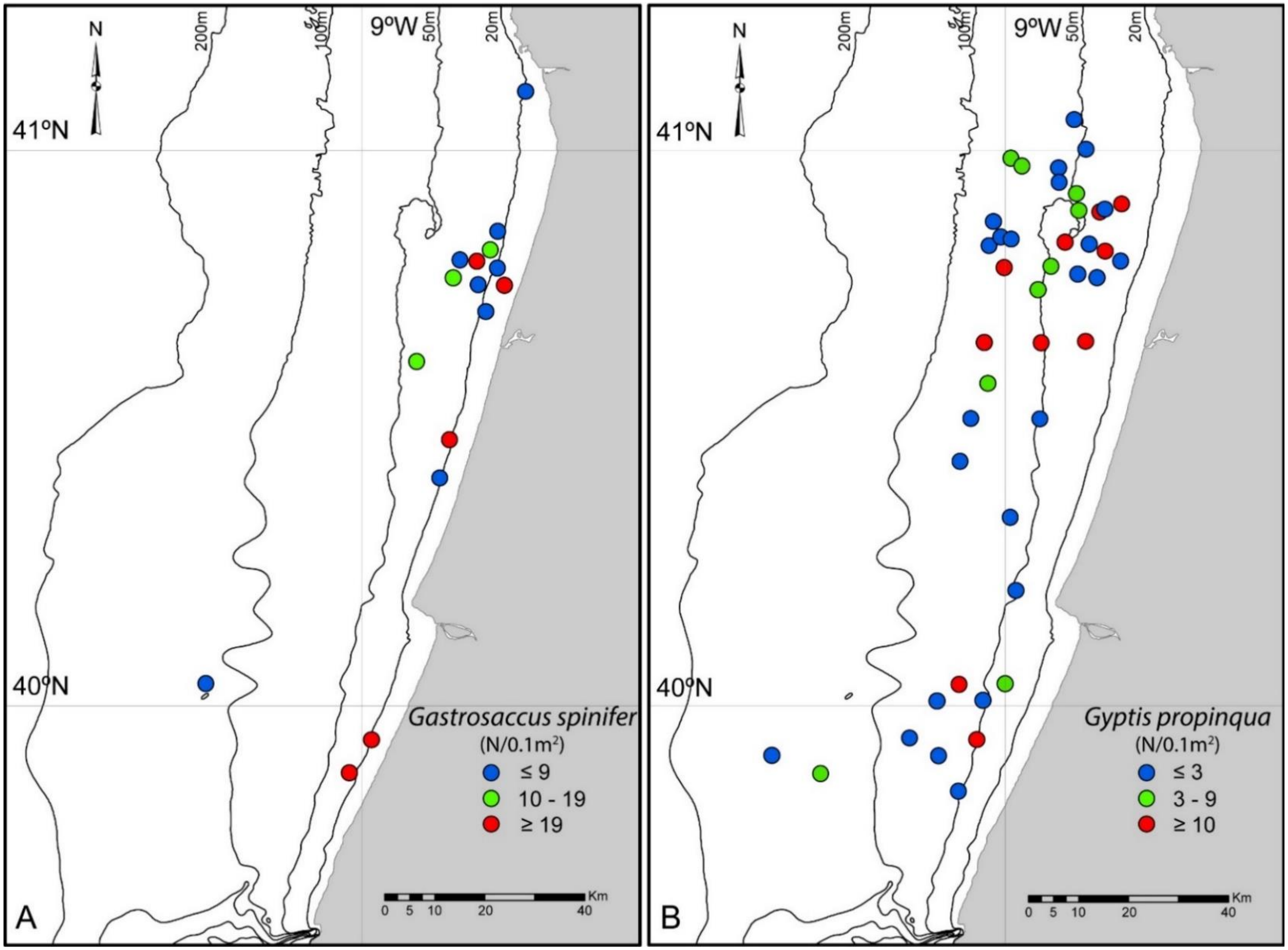


Figure 27. Spatial abundance patterns of characteristic species of the macrofauna communities A1 (A), A2 (B), A3 (C), B1 (D), B2 (E), C1 (F) and C2 (G), and one of the most abundant and frequent species (H).

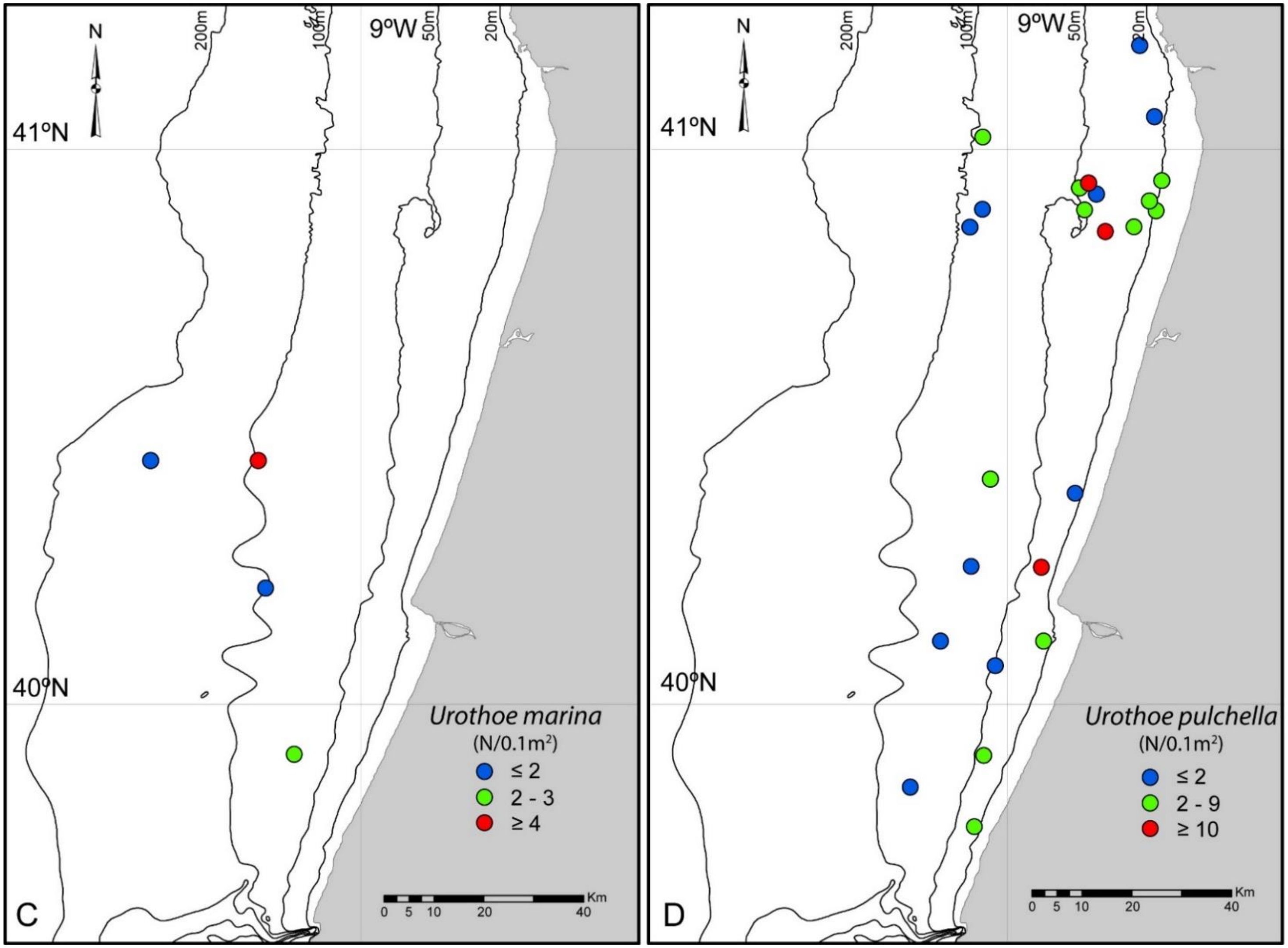


Figure 27 (Cont.). Spatial abundance patterns of characteristic species of the macrofauna communities A1 (A), A2 (B), A3 (C), B1 (D), B2 (E), C1 (F) and C2 (G), and one of the most abundant and frequent species (H).

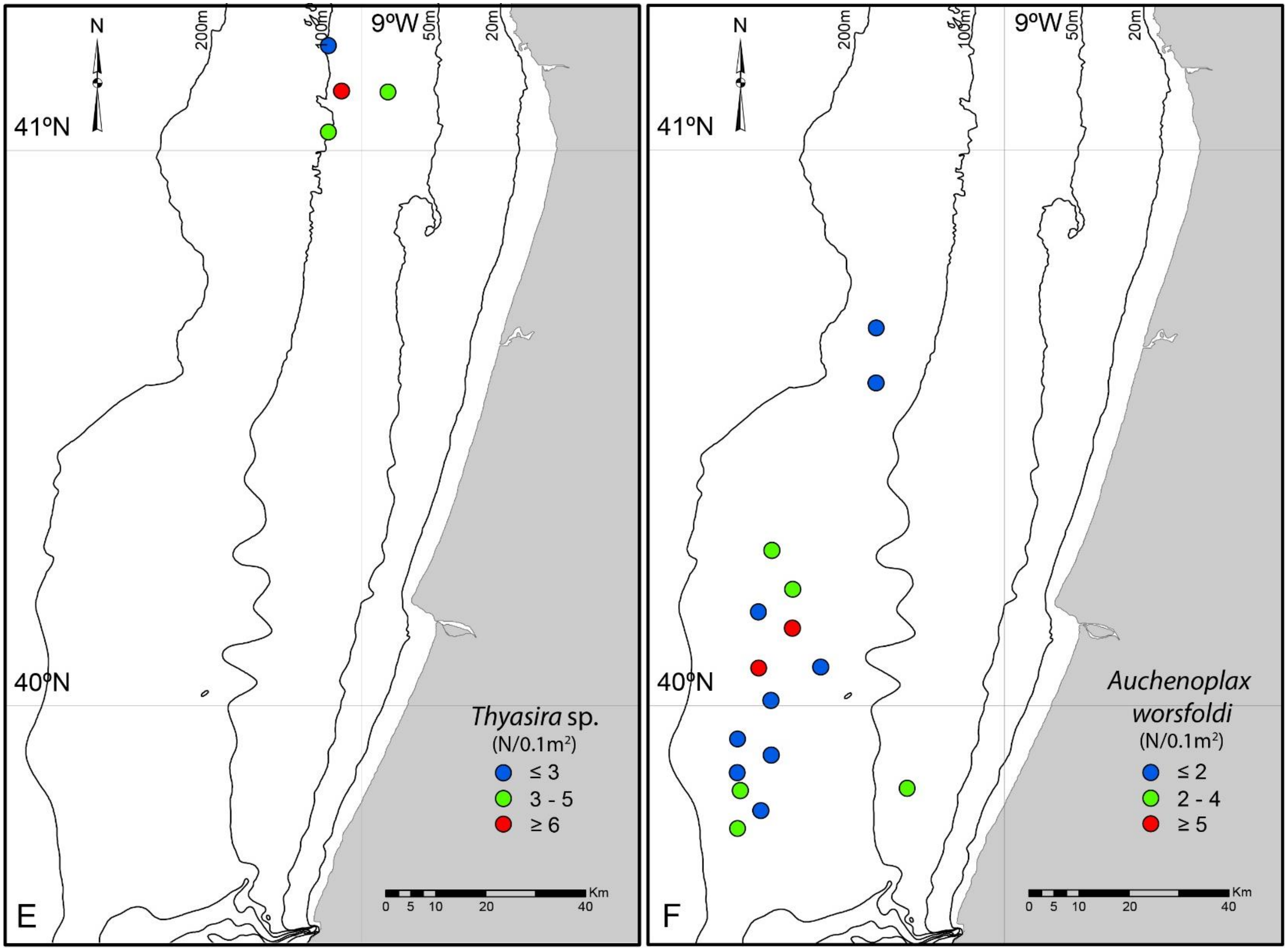


Figure 27 (Cont.). Spatial abundance patterns of characteristic species of the macrofauna communities A1 (A), A2 (B), A3 (C), B1 (D), B2 (E), C1 (F) and C2 (G), and one of the most abundant and frequent species (H).

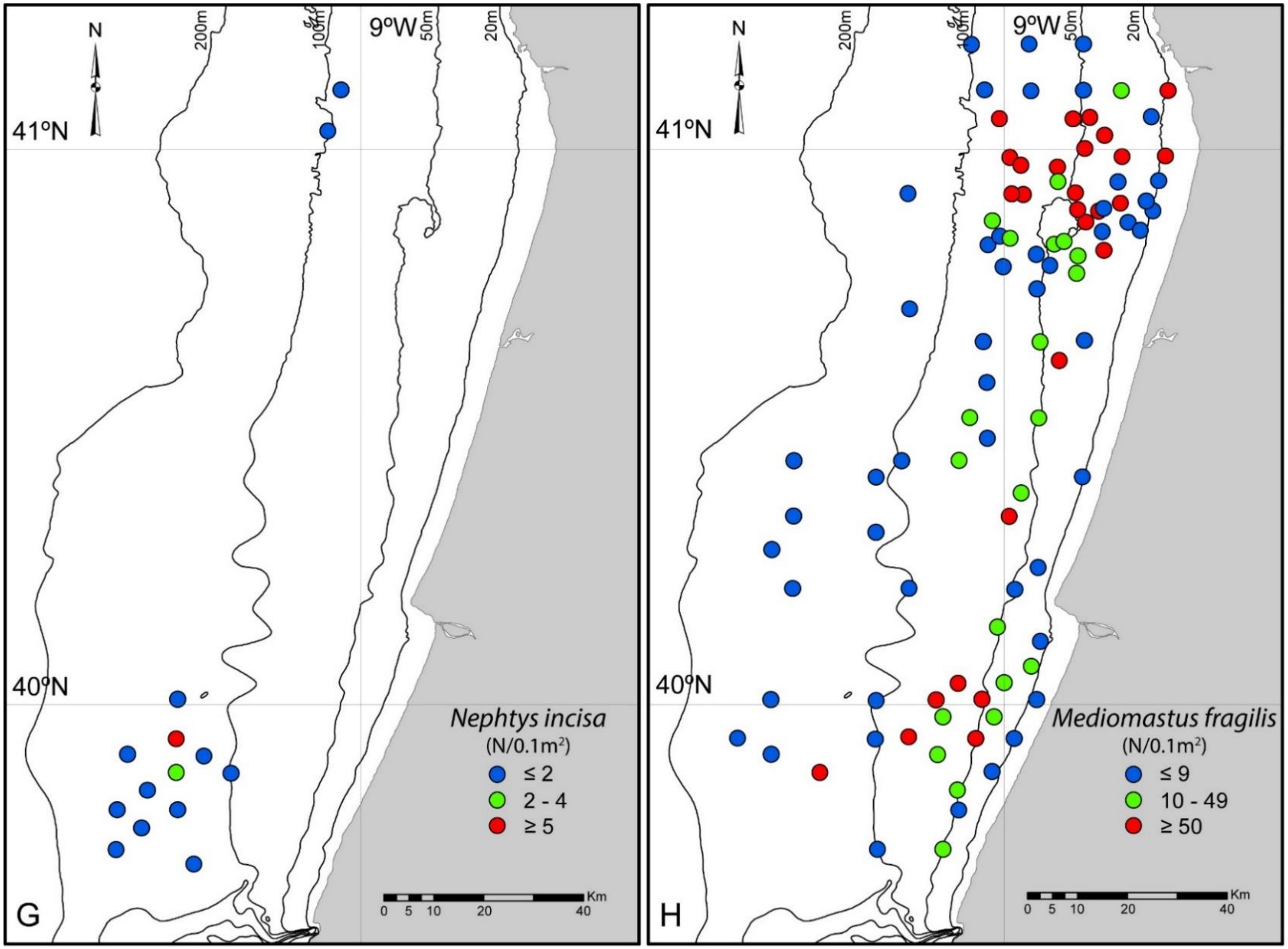


Figure 27 (Cont.). Spatial abundance patterns of characteristic species of the macrofauna community A1 (A), A2 (B), A3 (C), B1 (D), B2 (E), C1 (F) and C2 (G), and one of the most abundant and frequent species (H).

3.10 Relationship between environmental and multivariate macrofauna data

Table 10 and Figure 28 display, respectively, the results of the DISTLM and dbRDA analyses overlaying the vectors of the significant explanatory variables. The model presenting the best result in terms of AIC value included all the explanatory variables. The total explained variance was 26.94% of which 22.7% (84.2% of the total) was captured by the two first axes. All explanatory variables presented significant p-values in both marginal and sequential tests (cf. Table 10). In both tests, $\text{gravel\%}_{4\text{throot}}$ was the variable that presented the highest explained variance (R^2 and R^2 added), whereas for the sequential tests, $\text{fines\%}_{4\text{throot}}$ and $\text{kurtosis}_{4\text{throot}}$ presented the lowest (cf. Table 10). The explanatory variables more correlated with dbRDA axis 1 were $\text{gravel\%}_{4\text{throot}}$ (positive correlation) and depth (negative correlation). This explains the separation between the coarser groups (i.e. A1 and A2) in the positive pole and the deeper groups, usually with finer sediment, to the negative pole of axis 1. The same variables were the most correlated with the dbRDA axis2, however in this case $\text{gravel\%}_{4\text{throot}}$ and depth presented positive correlations. The dbRDA diagram shows the same general patterns as the macrofauna PCO analysis (Figure 25B), indicating the appropriateness of the explanatory variables to the overall main pattern of the benthic communities.

Table 10. Results of the DISTLM analysis, presenting also the correlations between each explanatory variable and the two first axis of the dbRDA.

	Marginal tests		Sequential tests		dbRDA Correlations	
Variable	**p-value**	**R^2**	**p-value**	**R^2 added**	**Axis 1**	**Axis 2**
$\text{Fines\%}_{4\text{throot}}$	< 0.001	0.117	< 0.001	0.0247	-0.335	-0.194
$\text{Gravel\%}_{4\text{throot}}$	< 0.001	0.123	< 0.001	0.0639	0.700	0.587
$\text{Kurtosis}_{4\text{throot}}$	< 0.001	0.0419	< 0.001	0.0258	-0.009	-0.211
Depth (m)	< 0.001	0.106	< 0.001	0.0475	-0.631	0.757

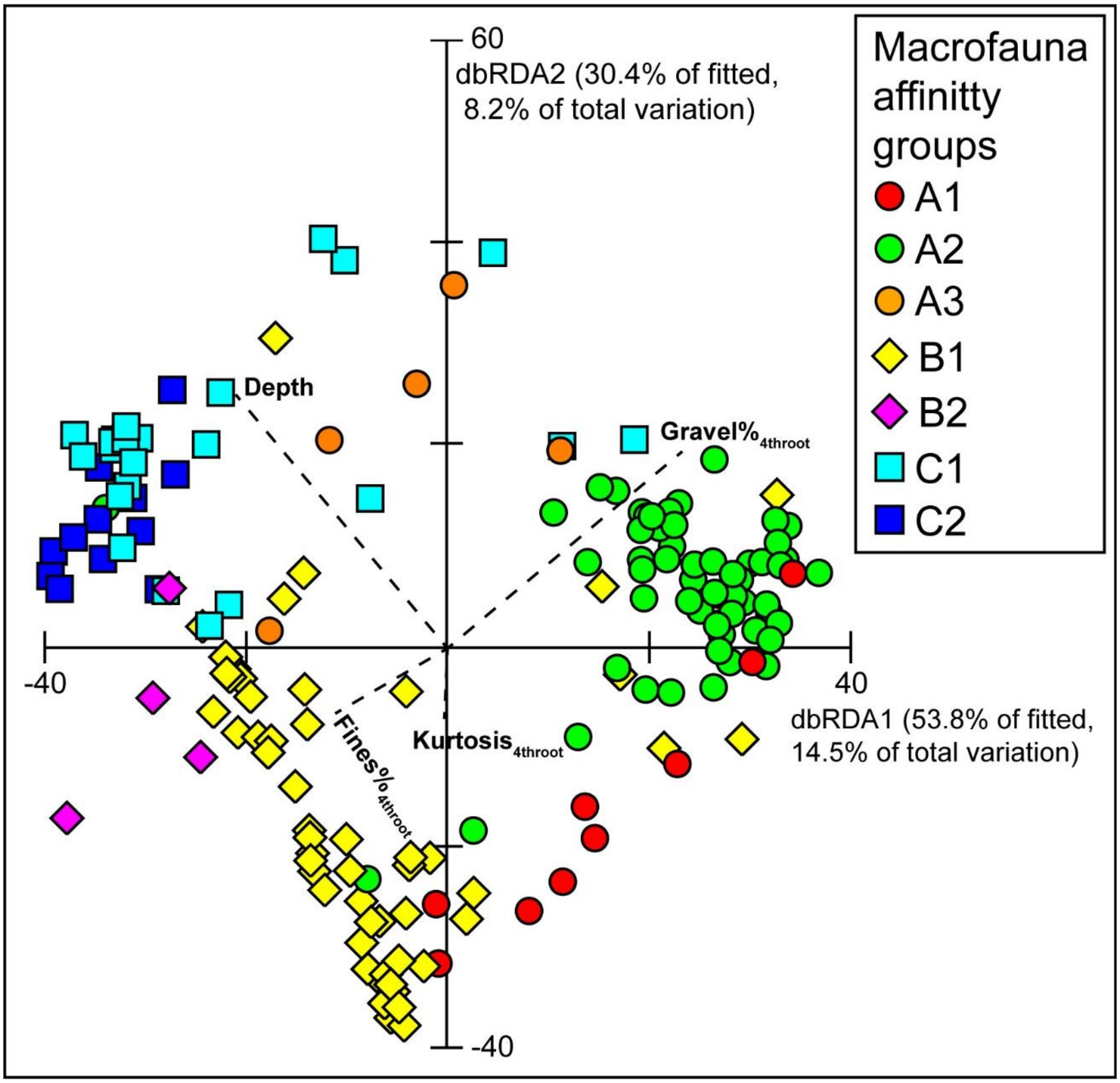


Figure 28. Diagram of the dbRDA analysis representing the macrofauna groups. Dashed lines represent the vectors of the explanatory variables used in the model.

3.11 Community distribution models (CDM)

The results obtained with the binomial GLMs performed under the presence/absence of the macrofauna communities are presented in Table 11. The maps of the spatial distribution with the probability of presence of each macrofauna assemblage are shown in Figure 29 (A to G). The map combining the previous analyses and showing the spatial distribution of the most probable community is presented in Figure 30, while the evaluation of this layer is given in

Table 12. The map in Figure 30 indicates that the spatial distribution of the expected benthic communities accompanied closely the spatial distribution of the observed macrofauna affinity groups, strengthening the community distribution output here developed. The results given in Table 11 show that the presence of each macrofauna assemblage is explained by different environmental variables, however autocovariates were added to the models that previously presented spatial autocorrelation of the residuals (i.e. A3, B1, C1 and C2). The accuracy performance of all models was high, with AUC values above 0.9. Also, in the habitat suitability maps representing the probability of the presence of each macrofauna community (Figure 29), is noticeable the general agreement to the spatial distribution of each observed community and the higher percentages in the respective suitability maps. The map showing the most probable community (Figure 30) and the results presented in Table 12 also confirmed the high agreement between the observed communities for each sample and those predicted as the most probable (overall = 80.7%).

The spatial distribution of the assemblage A1 was significantly explained by fines$\%_{4throot}$ and depth (cf. Table 11). The layer with the spatial distribution of the model probability is quite coincident with the real spatial distribution of this group (cf. Figure 29A). However, only 33% of the sampling sites where this community was described matched with the areas where this community was predicted as the most probable (cf. Figure 30, Table 12).

The spatial distribution of the affinity group A2 was significantly correlated with fines$\%_{4throot}$ and gravel$\%_{4throot}$ (cf. Table 11). Figure 29B shows that the observed spatial distribution of this group is accompanied by the higher probability values of the expected distribution. This was also supported by the patterns shown on the map of the expected communities (Figure 30) and the coincidence value of 88.1% (cf. Table 12).

Regarding group A3, the use of the environmental variables was not sufficient to eliminate the natural spatial correlation, leading to the use of an autocovariate (cf. Table 11). This CDM presented the lowest deviance explained (35.4%, cf. Table 11). Depth was the only environmental variable that presented a significant correlation with the spatial distribution of group A3 (cf. Table 11). This was also the community for which the observed distribution and the higher probabilities of its expected presence were visually less coincident (cf. Figure 29C, Figure 30), supported also by the low coincidence value of 20% (1 of 5, cf. Table 12) between the real and the predictive distribution of the most probable community.

Another CDM that needed the inclusion of an autocovariate concerned the assemblage B1. The significant environmental variables contributing for the distribution of this community were gravel$\%_{4throot}$, kurtosis$_{4throot}$ and depth. The image representing the probability of presence of this community indicated a distribution very similar to the observed point sample data (cf. Figure 29D). This is confirmed by the map of Figure 30, presenting the higher concordance between the layer of the most probable assemblage and the real point distribution of the respective assemblage (90.6%, cf. Table 12).

The spatial distribution of group B2 was significantly related with fines$\%_{4throot}$ and depth. This CDM presented the highest deviance explained (74.8%, cf. Table 11). Its point sample spatial distribution was well captured by the binomial model, i.e. the high predictive percentages were present in the northwestern part of the study area (cf. Figure 29E and 30), with a relative high coincidence of 75%.

The CDM regarding the spatial distribution of the assemblage C1 needed the addition of an autocovariate, presenting, besides this, also depth as a significantly environmental variable. The layer of the probability of presence of this community (Figure 29F) presented a high concordance with the real point sample distribution, being this confirmed by the map of Figure 30 and by 83% concordance between the layer of the most probable community and the observed spatial distribution (cf. Table 12).

Concerning group C2, the respective CDM retained the explanatory variable fines$_{4throot}$. Despite of the maps of the probability of presence and of the most probable community have visually presented a similar distribution to the observed point sample distribution (cf. Figure 29G, Figure 30), the resulting coincidence was not very high (58.3%, cf. Table 12).

Table 11. Community distribution model results, showing the coefficients obtained for each significant explanatory variable in each benthic community, A1 to C2; AUC = Area under the ROC curve; P-value: < 0.001 = ***; < 0.01 = **; < 0.05 = *.

Explanatory variables	**Community Distribution Model**						
	A1	**A2**	**A3**	**B1**	**B2**	**C1**	**C2**
Fines%$_{4throot}$	-2.52**	-1.03**			8.96*		2.46**
Gravel%$_{4throot}$		1.30***		-1.10***			
Kurtosis$_{4throot}$				1.45**			
Depth	-0.183**		0.0327*	-0.0121*	-0.0737*	0.0574***	
Autocovariate$_{A3}$			40.4 *				
Autocovariate$_{B1}$				1.69**			
Autocovariate$_{C1}$						12.6**	
Autocovariate$_{C2}$							4.83**
AUC	0.971	0.945	0.929	0.913	0.997	0.960	0.973
Deviance Explained (%)	56.6	58.1	35.4	46.6	74.8	56.8	61.4

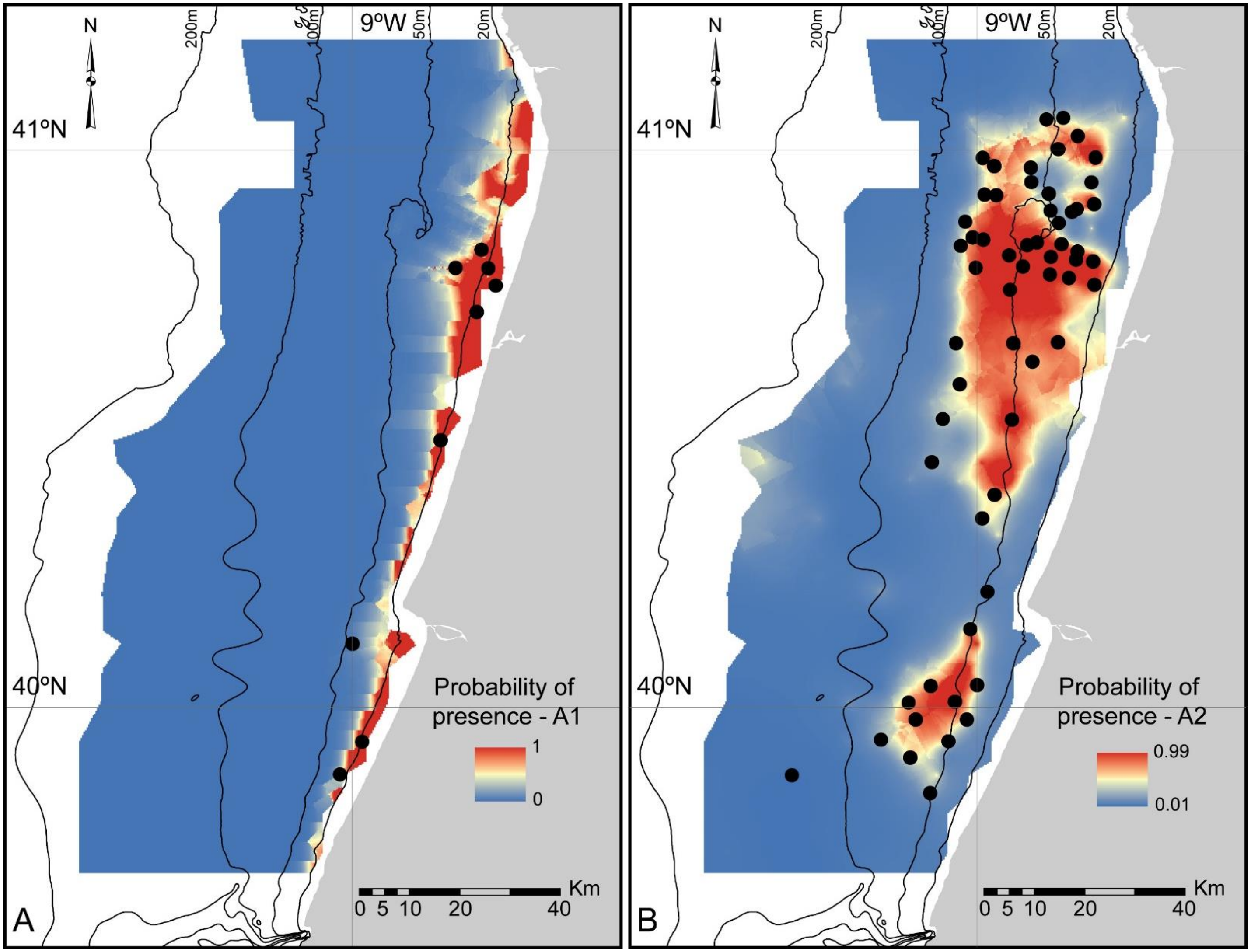


Figure 29. Maps representing the probability of presence of the macrofauna communities. Black dots represent the point sample distribution of the respective macrofauna community. Figure 29 A to G represent the communities A1, A2, A3, B1, B2, C1 and C2, respectively.

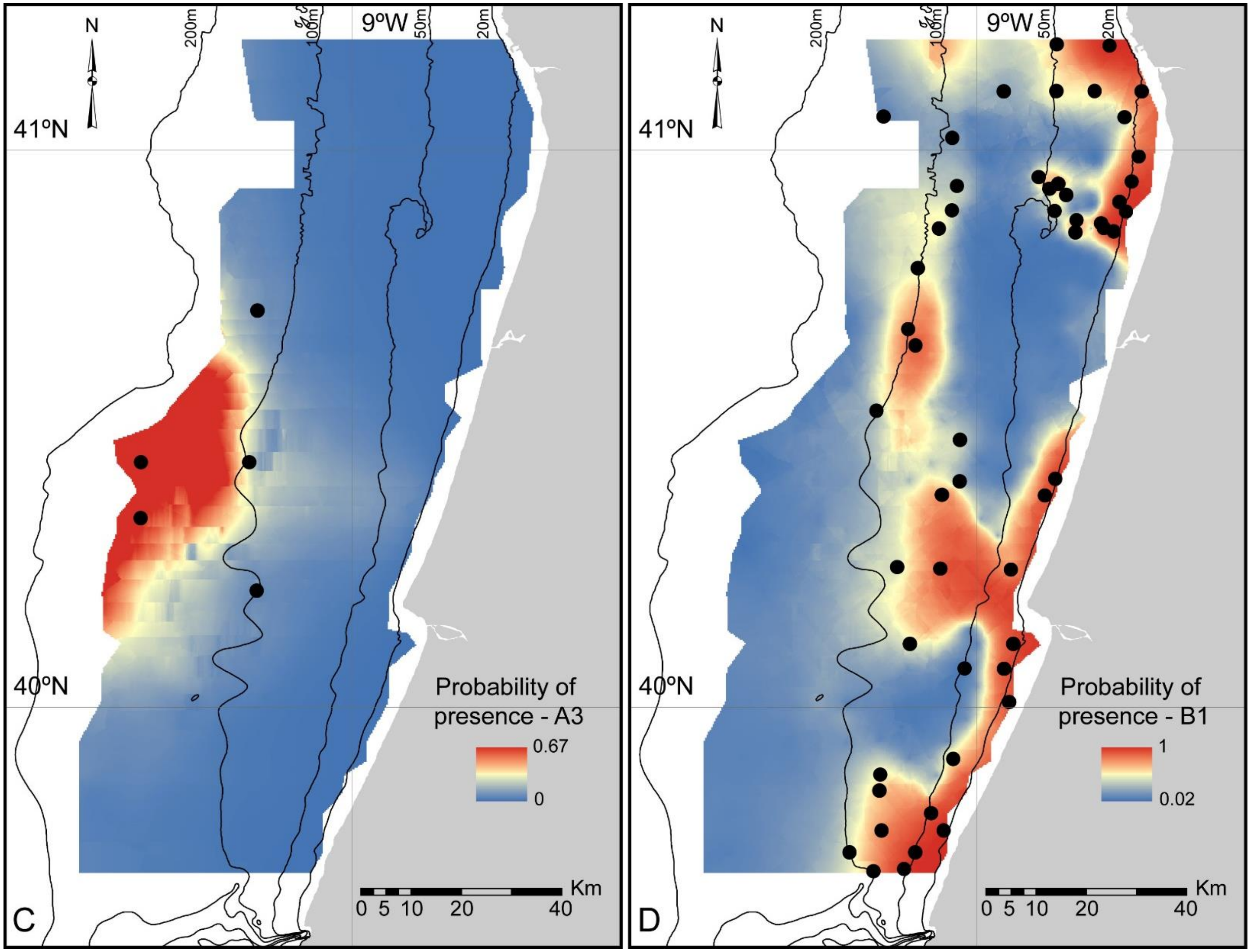


Figure 29 (Cont.). Maps representing the probability of presence of the macrofauna communities. Black dots represent the point sample distribution of the respective macrofauna community. Figure 29 A to G represent the communities A1, A2, A3, B1, B2, C1 and C2, respectively.

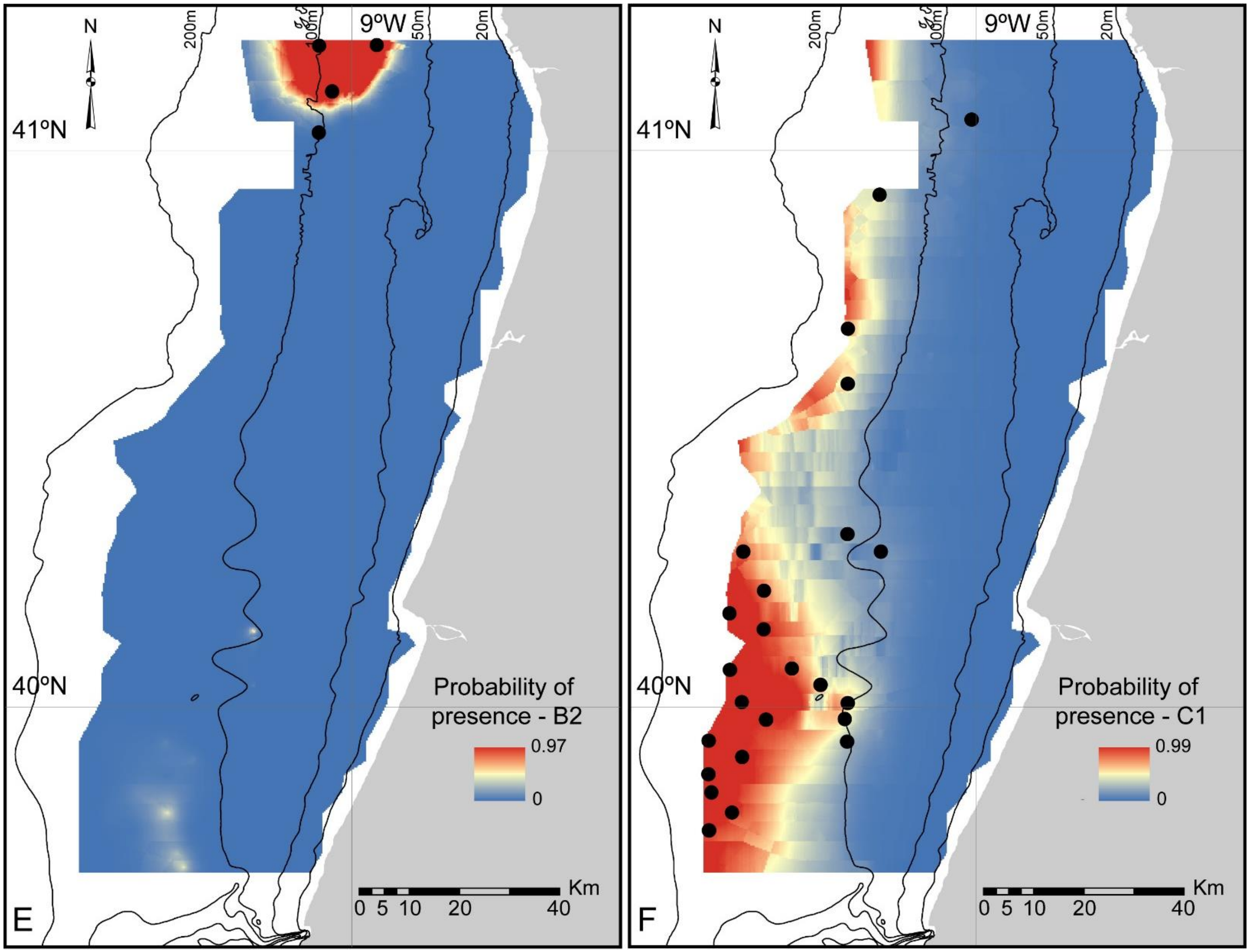


Figure 29 (Cont.). Maps representing the probability of presence of the macrofauna communities. Black dots represent the point sample distribution of the respective macrofauna community. Figure 29 A to G represent the communities A1, A2, A3, B1, B2, C1 and C2, respectively.

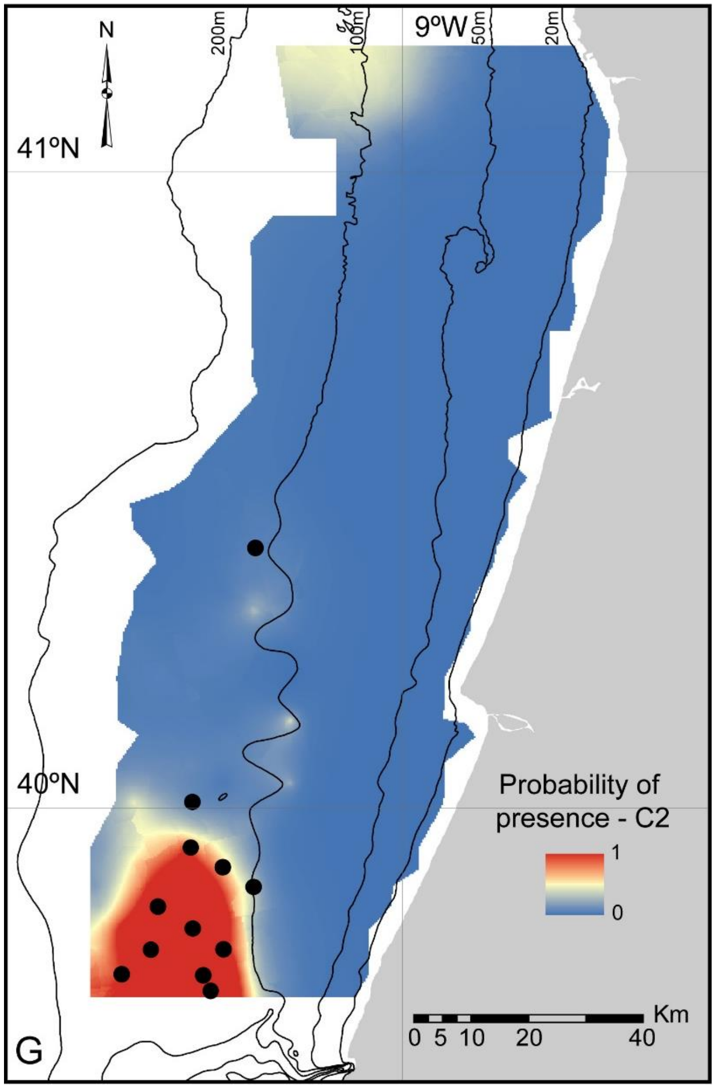


Figure 29 (Cont.). Maps representing the probability of presence of the macrofauna communities. Black dots represent the point sample distribution of the respective macrofauna community. Figure 29 A to G represent the communities A1, A2, A3, B1, B2, C1 and C2, respectively.

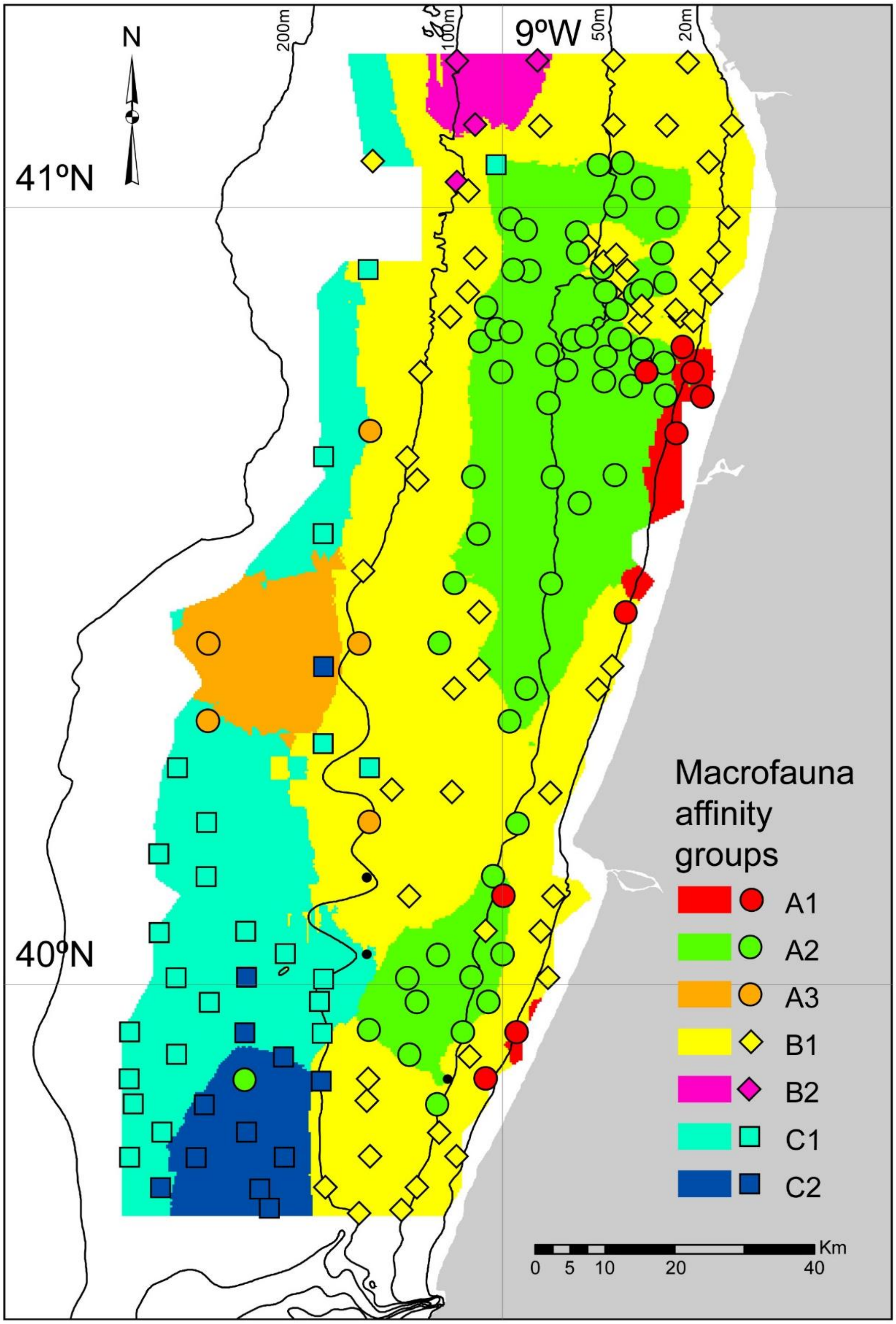


Figure 30. Map presenting the distribution of the most probable macrofauna community in the study area. The symbols represent the observed macrofauna communities.

Table 12. Coincidence between the observed presence of the macrofauna communities and the layer presenting the spatial distribution of the most probable community; Overall = (total correctly classified samples / total samples) * 100.

Original group	Expected distribution							Total (samples)	% Correct
	A1	A2	A3	B1	B2	C1	C2		
A1	3	2	0	4	0	0	0	9	33.3
A2	0	52	0	6	0	0	1	59	88.1
A3	0	0	1	2	0	2	0	5	20.0
B1	0	4	0	48	0	1	0	53	90.6
B2	0	0	0	1	3	0	0	4	75.0
C1	0	1	0	3	0	20	0	24	83.3
C2	0	0	1	1	0	3	7	12	58.3
Overall									80.7

3.12 EUNIS habitat classification assessment

The EUNIS habitat levels 3, 4 and 5 identified for this study area are presented in Table 13, with the respective coverage area. Three EUNIS level 3, eleven level 4 and seven level 5 habitats were identified. Six out of the seven level 5 habitat were not previously included in the EUNIS classification and therefore a new designation is proposed in this study (Table 13). This new designation is composed by the level 4 code, to which were added the EU abbreviation for Portugal and a number, attributed within a sequential list of habitats identified in the scope of the MeshAtlantic Project (Monteiro et al., 2013). Due to the hierarchical nature of EUNIS, some level 3 and 4 habitats were omitted in Table 13, since they are represented by the respective habitats level 4 and 5. The Figure 31 displays a comprehensive map of the spatial distribution of the habitats classified accordingly to EUNIS up to level 5, revealing the changes in the habitats driven by depth, hydrodynamics and the sediment type. This map reveals that the study area embraces a highly diverse range of bottom habitats. As result of both, the bottom-up approach and the modelling strategy, the level 5 habitats distribution follows in general the distribution of the macrofauna communities (see spatial distribution description on section 3.9; and compare Figures 30 and 31). Another important feature of this map is the inclusion of the spatial distribution of the rocky substrate in the study area (cf. Figure 31).

Table 13. EUNIS habitats identified in the study area, including new units (*) and new designations suggested in Henriques et al. (2015) (**). The macrofauna benthic communities corresponding to the EUNIS habitats level 5 and the area covered by each habitat shown in Figure 31 are presented.

EUNIS level	EUNIS code	Unit name	Benthic community	Area (Km^2)
3	A4.1	Atlantic and Mediterranean high energy circalittoral rock		47.7
3	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock		168.3
3	A4.3	Atlantic and Mediterranean low energy circalittoral rock		767.5
5	A5.14_PT29*	*Gyptis propinqua* and other interstitial annelids accompanied by *Branchiostoma lanceolatum* and *Malmgrenia ljungmani* in circalittoral coarse sediment	A2	1469.7
4	A5.15	Deep circalittoral coarse sediment		95.8
5	A5.15_PT30*	*Urothoe marina, Scalibregma celticum, Mesochaetopterus sagittarius* and other polychaetes in deep circalittoral coarse sediment	A3	59.7
4	A.5.23	Infralittoral sand**		0.5
5	A5.23_PT31*	*Gastrosaccus spinifer, Nephtys cirrosa, Hesionura elongata* and other polychaetes in infralittoral sand	A1	103.4
5	A5.25_PT32*	Sand with crustaceans *Urothoe pulchella* and annelids *Glycera tridactyla* in a wide depth range	B1	2534.9
4	A5.26	Circalittoral muddy sand		21.3
4	A5.27	Deep circalittoral sand		114.4
5	A5.27_PT33*	*Auchenoplax Worsfoldi*, *Terebellides stroemii*, *Onchnesoma steenstrupii steenstrupii*, *Callianassa subterranea* in deep circalittoral muddy sand	C1	1155.6
4	A5.35	Circalittoral sandy mud		0.2
4	A5.37	Deep circalittoral mud		67.1
5	A5.372	Foraminiferans and *Thyasira* spp. in deep circalittoral soft mud	B2	86.3
5	A.5.37_PT34*	*Sarsonuphis bihanica* and *Nephtys incisa* in deep circalittoral muddy sand and sandy mud	C2	300.3
			Total	6993.0

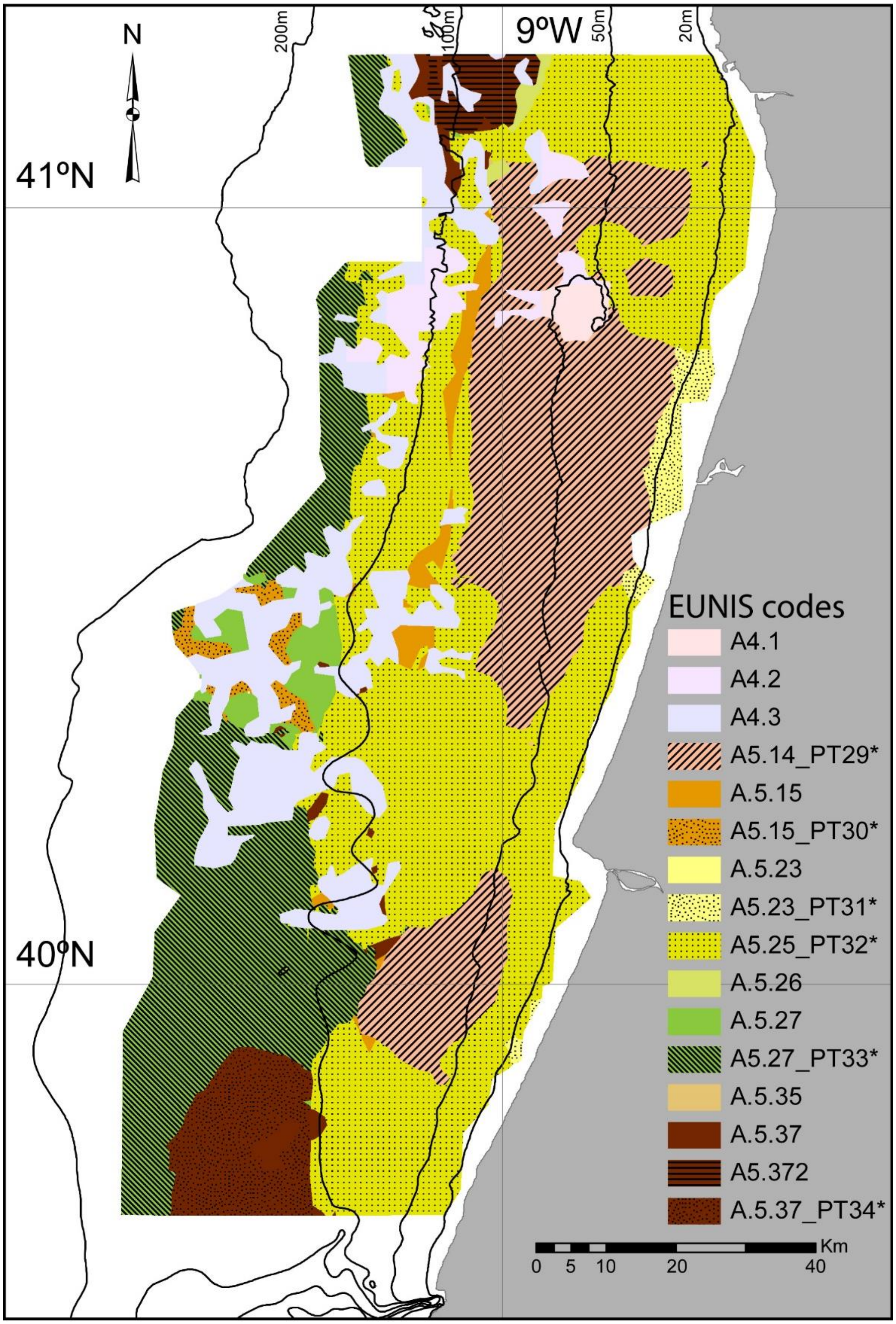


Figure 31. Predictive habitat map based on EUNIS classification, showing the habitat types up to level 5, in the study area. * Indicate new designations from this study (see Table 13 for the code correspondence).

3.13 Contributions to the environmental status (ES) assessment in the scope of the Marine Strategy Framework Directive (MSFD)

For the assessment of the descriptor 1 (biological diversity), the Marine Biological Valuation (MBV) was calculated for an area of 5729 km^2, the results being shown in Tables 14 and 15, and in the map of Figure 32. In the calculation of the MBV, the values were integrated into subzones corresponding to the level 5 EUNIS habitats identified in this thesis. Given that in parts of the study area the EUNIS classification did not reach level 5 (cf. Figure 31), some blank areas appear in the MBV map (cf. Figure 32). The values for the subzones that were used in the definition of class boundaries, ranging for each question from, Q1: 48.3 – 962.9 ind./$0.1m^2$; Q2: 3.1 – 11.9 spp./$0.1m^2$; Q3: 3.4 – 12.9 ind./$0.1m^2$; Q4: 0.2 – 4.2 spp./$0.1m^2$; Q5: 0.8 – 22.0 ind./m^2; Q6: 0.5 – 5.0 spp./$0.1m^2$; Q7: 0.7 – 18.7 ind./m^2; Q8: 21.3 – 60.2 spp./$0.1m^2$. The highest MBV was obtained for the subzone corresponding to the mid-shelf coarse sediment habitat EUNIS A5.14_PT29 (see Table 14 and Figure 31) being classified as very high, whilst the subzone presenting the lowest MBV corresponded to the deep muddy sand/sandy mud habitat (i.e. EUNIS A5.37_PT33), considered as very low (cf. Table 14). It is important to highlight the absence of subzones classified with low, resulting of the very low MBV of the subzone A5.37_PT33 when compared with the others. A final EQR of 0.77 was calculated for the study area (cf. Table 15) representing an overall good quality status for the study area.

For the indicator a) of the descriptor 6 (seafloor integrity), the AMBI values ranged from 0.38 to 2.8 classifying all the samples as undisturbed or slightly disturbed. Due to the absence of sites classified as moderately disturbed or worse, the EQR for this indicator was assigned as 1 (high). For the indicator b) used here, the M-AMBI results for this area showed a quality status ranging from moderate to high with a mean EQR of 0.70 (std = 0.078, n = 169), representing an overall good quality status for the study area.

Table 14. Scoring of the assessment questions (Q) of the marine biological valuation based on macrofauna data per subzone. The final classification per subzone is displayed. The assessment questions (Q) are given in Table 4.

Assessment questions	A5.14_PT29	A5.15_PT30	A5.233	A5.25_PT31	A5.27_PT32	A5.372	A.5.37_PT33
Q1	4	1	5	2	1	1	1
Q2	4	4	1	3	5	2	1
Q3	2	2	5	2	2	1	1
Q4	2	5	1	4	5	2	3
Q5	1	5	1	4	3	1	1
Q6	5	2	2	3	2	4	1
Q7	5	1	2	3	1	5	1
Q8	5	3	1	3	4	2	1
Sum	28	23	18	24	23	18	10
Final classification	Very High	High	Medium	High	High	Medium	Very low

Table 15. Integrating the marine biological valuation of the subzones into a unique value (EQR).

	Very Low	Low	Medium	High	Very High	Total
Equivalence (E)	1	2	3	4	5	
Percentage of the area	5.2	0	3.3	65.8	25.7	100
Rate per one (R)	0.052	0	0.033	0.658	0.257	1
Total (E x R)	0.052	0	0.099	2.632	1.283	4.066
EQR ((Total - 1)/4)						0.77

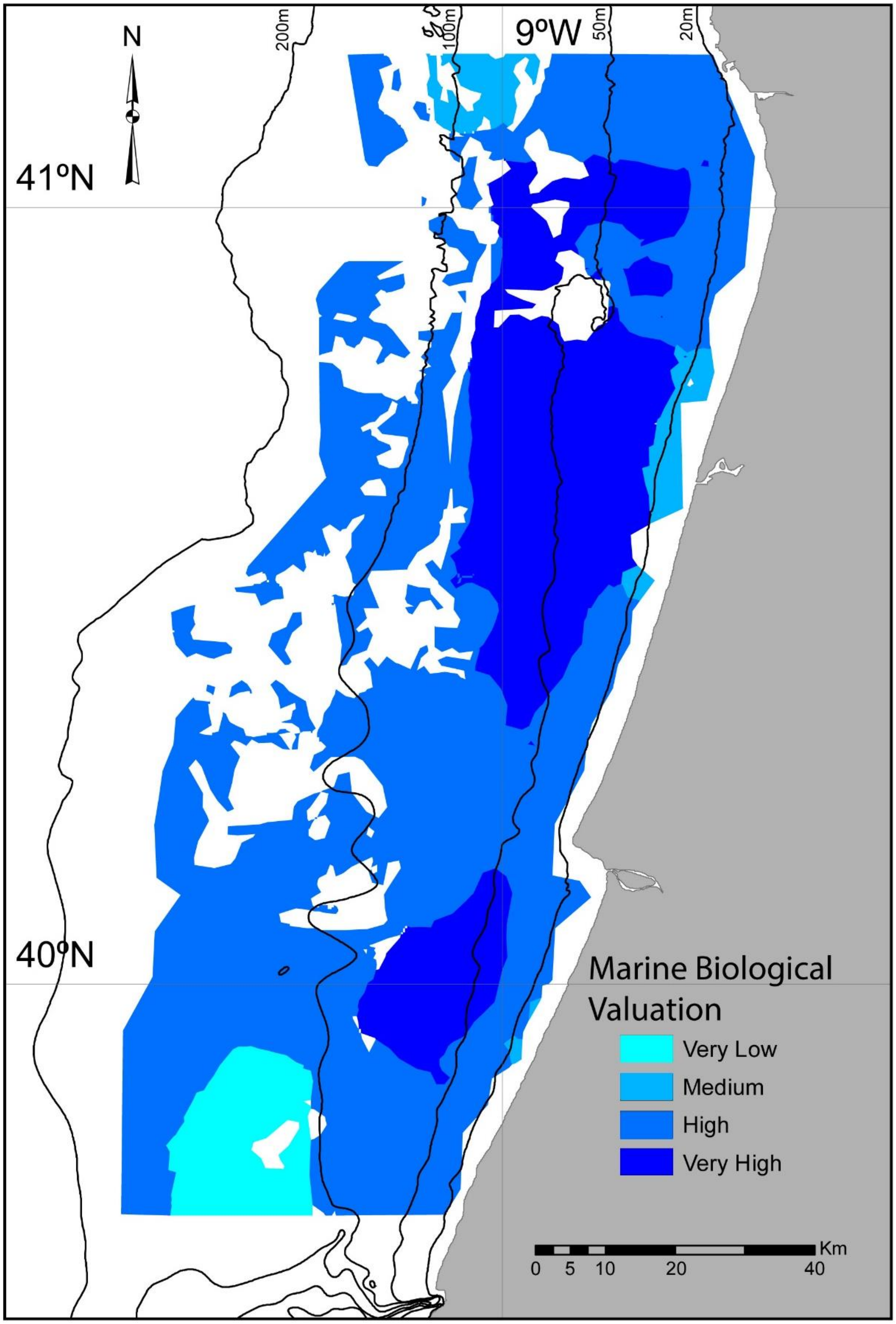


Figure 32. Marine biological valuation (MBV) map based on macrofauna data. The MBV was obtained for the different EUNIS habitat types of level 5 present in the study area.

Chapter 4. Discussion

4.1 Environmental data spatial interpolation

This work presents a methodology to map some important environmental variables, using spatial interpolation. For the data interpolation of sediment parameters and depth, several transformations were considered due to the different characteristics of the data. The compositional sedimentary parameters (i.e. fines, sand and gravel contents) were submitted to an additive log transformation (alr), recommended for this type of data (Aitchison, 1986). Although the standard deviation is a useful tool in the analysis of the interpolated data, Filzmoser et al. (2009), considered that this statistical parameter should not be used with compositional data, as also suggested by Van den Boogaart and Tolosana-Delgado (2013) when they affirmed "…that there is no straightforward definition of a compositional standard deviation". Therefore, the variance or standard deviation of log transformed data should not be back transformed because this transformation changes the distances to the mean asymmetrically (Filzmoser, 2009).

The slope of the cross-validation line was found to be lower than one, as in other works (e.g. Tripathi et al., 2015) since the kriging methods tend to underpredict large values and overpredict small ones[14]. The results of the EBK cross-validation revealed that the most reliable layer was obtained for depth, mainly because of their constant and predictable variation and higher density of data points (Li and Heap, 2011; Li et al., 2011), when compared to the sediment data.

Besides their direct use in this work, the maps of the environmental data could also be used in the context of marine spatial planning. In the context of this thesis, they were essential to estimate and produce maps of biological variables, as in other marine modelling studies (among others, Degraer et al., 2008; Gogina et al., 2010b; Moritz et al., 2013).

4.2 Sediments spatial distribution using the Folk-MeshAtlantic system and the Wentworth grain-size scale

Two different sediment classification systems were exploited in this work, namely the Folk-MeshAtlantic system and the Wentworth scale. In general, the patterns presented by the two sediment classification systems were very close, leading to similar interpretations during the characterization of the benthic communities. The Folk-MeshAtlantic system was used namely to permit the habitats classification according to the European Nature Information System (EUNIS).

Generally, the sediment grain size results obtained in this study were in agreement with the shelf sediment charts of the SEPLAT project from the Portuguese Hydrographic Institute[15] for this area (MAMAOT, 2012). Part of the grain size data used in this work were previously published (Martins, et al., 2012a) and combined with those charts, to be included on the broad scale map of the European shelves substrates (Mata Chacón et al., 2013). Given the higher resolution sampling grid that was used in this study, the results here obtained confirmed and detailed previous work regarding the distribution of superficial sediments in the Portuguese continental shelf north of the Nazaré Canyon (Martins et al., 2012a). The mid-shelf gravels are one of the main sediment features in this section of the Portuguese continental shelf. According to Martins et al. (2012b), they result from the deposition of this sediment type during low sea level stands (probably during the Last Glacial Maximum), combined with the present hydrodynamic conditions, not allowing the settlement of fine sediment particles in this area but also not eroding the coarser ones.

4.3 Acoustic data variability study

Despite the recognized value of acoustic remote sensing techniques for the survey of the seafloor and as benthic habitat mapping tools (Anderson et al., 2008b; Pandian et al., 2009; Brown et al., 2011), little attention has been given to the inherent acoustic variability and the optimal spatial step to integrate single-beam acoustic data. This part of the study focused on these aspects, using as test data the MeshAtlantic 2010 acoustic survey conducted on the continental shelf, covering an area of approximately 5400 km^2, between 15 and 150m water depth and with sediments varying from mud to fine gravel. Using the single-beam AGDS QTC VIEW series V, acoustic data were collected in 27 transects perpendicular to the coast line, totaling more than 1000Km of survey line. Given the large area surveyed and ship time involved, it was not possible to complement the survey with lines running along the coast, forming a grid pattern, commonly used when the survey area is smaller (see namely Freitas et al., 2003a; 2003b). A grid survey pattern, or alternatively navigating repeatedly over the same survey area (see namely Quintino et al., 2010) has the advantage of inspecting the coherence of the acoustic response, especially where the lines intercept. Sediment ground-truth grab samples were also collected in sites positioned along the acoustic transects. The variability of the acoustic data was characterized by averaging the data in sections of 125, 250, 500, 750 and 1000 meters long, using five replicate acoustic sections per sediment ground-truth data point and studying the within replicates variability. These sizes of the spatial steps were determined after the survey was conducted and considering the density of the acoustic echoes. The smallest step size was set at 125 meters long, because under that value very few acoustic echoes would be included in some samples, being very unlikely that a single or very few echoes could reasonably represent a sediment grain-size sample. So, we were assuming from the start that there is more variability between echoes than there will be between sediment grain-size replicates. Certainly, there was considerable small-scale variability in echoes as variability within acoustic replicates decreased when averaging the acoustic data from 125 to 250m sections. Following on the decision of the smallest step size, the next ones were obtained by doubling the figure and including an extra step size between 500 and 1000m long. This allowed reaching the final step sizes mentioned. The longest acoustic section, 1000m was also determined by positioning the ground-truth sediment sampling sites at a distance of no less than 5 to 6Km from each other. This did not allow integrating the acoustic data in spatial steps larger than 1000m, in order to ensure the acoustic sections comprised exclusive echoes. A disadvantage of setting the size of the acoustic sections a posteriori, as in this study, relates to the impossibility of matching the interspacing among replicates of the ground-truth sites to the replication of the acoustic sections. This could allow a detailed study and comparison of the variability in the two data sets. In practical terms however, this would only be reasonable to do in a reduced number of sites and at a single step size, otherwise the number of ground-truth samples would amount to a very large number (in the case of this study, a total of 15 sediment replicates would be required per ground-truth site, in order to match the sediment samples and all the acoustic sections spacing).

Durand et al. (2006) studied the ability of a single-pencil-beam sonar to discriminate between habitat types of a hydrothermal vent field at three different footprint sizes, by controlling the distance at which the acoustic device was operating from the seafloor. The resulting percentage differences of correct classifications between each spatial step took them to conclude that the footprint could affect the ability to discriminate habitat types. In their study, the footprint sizes varied from 3 to 30cm in diameter and so were much smaller than the acoustic sections used in the present study. Furthermore, Sutherland et al. (2007), studying multi-beam backscatters, investigated the representativeness of acoustic data selected by radius ranging from 2 to 20m, also a much smaller spatial step than used in this work. This difference is a consequence of the acoustic technique, multi or single-beam and the data itself, pixels or acoustic echoes respectively, as well as the survey distance from the seafloor, much smaller in the work of Durand et al. (2006), controlled by positioning the acoustic device on a ROV platform. In the case of our survey, the area to be selected could be smaller if vessel speed was lower and/or by running multiple acoustic lines over the same area, and so increasing the number of acoustic points per spatial step; both these procedures were used by Quintino et al. (2010), allowing them to select the acoustic data using much smaller spatial steps.

The 250m acoustic section size minimized the acoustic variability within sites, i.e. the variability associated with the five replicate acoustic sections representing each ground-truth data point. This step size was the one that better represented the acoustic data at the level of the sampling site. At a lower step size, 125m, the mean Euclidean distance within sampling point replicates was significantly higher than that observed at 250m. This could have happened because the reduction in the number of the acoustic echoes at the smallest spatial step diminished the capability of the data to comprehend the variability of the seafloor. Although due to different reasons, unpublished work by Quintino has also shown that the mean Bray–Curtis similarity of 10 benthic macrofauna replicate 0.01m^2 corer samples was smaller (61.44%) than that obtained with 10 replicates 0.05m^2 Ponar grab samples at the same site (80.63%), the smaller sampler being less able to capture the microdistribution of the benthic populations. At the largest spatial step, 1000m, the mean Euclidean distance within sampling point replicates was also significantly higher than that observed at 250m. The increase of variability in this case could be due to changes in the seascape, namely sediment type, which then become inappropriately depicted by the acoustic data. This result, namely at the larger step size, could however have not been the same, in case the survey lines were running parallel, instead of perpendicular, to the main environmental variables, in the sense that even the largest acoustic sections would have less chance of sampling different habitats/sediment types, the distribution pattern of which, as shown in this study, broadly follows parallel to the coastline. Even so, knowing that this coastal shelf presents very wide habitat units (this is not an area of small seascape heterogeneity) we believe that the main conclusion of the current work would still hold, that the residual variance diminished from the smaller step size (125m) to the next (250m) and increased thereafter.

The 250m spatial step also maximized the variability between groups. This integration step was the best to distinguish the acoustic sites and the acoustic groups representing the sediment types. In very different contexts, and also using very distinct equipment and survey techniques, Sutherland et al. (2007) and Durand et al. (2006) also concluded that it was not the smallest step size they used that provided the best discrimination of the habitats under survey. In their work, they concluded that the acoustic integration area that optimized the correlation between the backscatter values and the habitat parameters was between 8 and 20m and 20–30cm, respectively.

Representing the acoustic data as numerical matrices proved to be a very interesting tool in the exploitation of acoustic seabed data. This feature had been used before by Quintino et al. (2010) and is surely one of the advantages of this AGDS comparing to the others acoustic systems used in benthic habitat mapping. Overall, the results from this work indicate that the discriminant capability of the acoustic data will not be indifferent to the step size considered to integrate the data and conclude that 250m should be used in the modeling work of the benthic habitats of this continental shelf.

4.4 Acoustic diversity pattern and depth

The acoustic ground discrimination system (AGDS) used in this work was successfully employed in other studies, by obtaining acoustic classes through manual clustering with QTC IMPACT, and relating them to sediment types (among others, Ellingsen et al., 2002; Freitas et al., 2003a, 2006). In this work, however, the AGDS was not able to produce acoustic classes that could be related to the sediment types. Collins and Rhynas (1998) described several factors that could influence the quality of the acoustic data collected, namely depth and vessel speed, that could be adjusted to the needs, or the state of the sea that is totally outside of the researcher control. The QTC VIEW settings and speed vessel were adjusted for the collection of data, and as such it is not probable that the problem detected would be related to that.

To understand the relationship between acoustic and sediment data, acoustic data representing the sediment types according to the Wentworth scale was integrated at 250m sections and the obtained data matrix was represented in an ordination diagram. The lack of a clear overall pattern and the rejection of the null hypothesis comparing acoustic data according to a depth factor, indicated the contamination of the acoustic data by depth, which was visually confirmed by representing depth classes on the acoustic ordination. Such contamination prevented using the acoustic survey data further, as initially intended, to model the benthic habitats.

4.5 Macrofauna abundance and diversity: spatial patterns and distribution models (DM)

In this study, 64485 individuals were identified belonging to 708 taxa, with annelids representing most of the species and specimens, respectively 46.5% and 78.0% of the total. From the species lists accepted for European waters, in this work were identified 16.7% of the annelids (329 of 1971 spp.), 4.1% of crustaceans (200 of 4904 spp.), 4.2% of mollusks (108 of 2566 spp.) and 6.9% of echinoderms (41 of 592 spp.)[16]. The dominance of annelids in the total species richness has been constantly observed in other benthic macrofauna studies conducted in Europe, namely Portugal (respectively 46% and 43%, Freitas et al., 2011; Martins et al., 2013a), Norway (43%, Ellingsen and Gray, 2002), Belgian (43%, Van Hoey et al., 2004) or Greece (44%, Karakassis and Eleftheriou, 1997). Regarding to abundance, this was not always observed, even other studies have also highlighted abundance dominance of other groups for the Portuguese shelf, namely the bivalve *Ervilia castanea* (Freitas et al., 2011; Henriques et al., 2015).

The comparison of the macrofauna indices here obtained to other studies, only considered marine soft sediment studies where the same sampler area ($0.1m^2$) and sieve mesh size (1mm) were used. Even so, no other studies with similar characteristics to this one were found, namely the number of samples, geographic extension and the depth range. The total species richness reported in this work is similar to that mentioned in the work of Martins et al. (2013a) (747 spp. in 145 sites), for the whole Portuguese shelf. It is higher than total species richness mentioned in other studies conducted in the Portuguese shelf, these studies covering smaller areas and with fewer samples, like Freitas et al. (2011), with 451 taxa in 88 samples and Henriques et al. (2015), with 236 taxa in 137 samples. For other regions of the globe, in a study embracing a larger extent of the respective continental shelf, Ellingsen and Gray (2002) in the Norwegian shelf, identified 809 species in 505 samples (101 sites x 5 replicates). However, comparing with other studies comprising smaller areas, like Martínez and Adarraga (2011) conducted in the continental shelf of the Basque Country (Spain) with 404 taxa in 72 samples, or the Van Hoey et al. (2004) of the Belgium continental shelf with 254 taxa in 758 samples, the total number of species here identified was higher. In terms of total abundance, and comparing to the same previous works, this study identified fewer individuals than in two studies only, Van Hoey et al. (2004) and Henriques et al. (2015), confirming the findings of Martins et al. (2013a) that this section of the shelf presents higher abundances than other areas of the Portuguese continental shelf.

Several studies confirmed the influence of the environmental factors in the distribution and composition of the benthic macrofauna, namely the sedimentary characteristics, depth, oxygen, hydrodynamic conditions, total organic matter, temperature, salinity, among others (Beukema, 1990; Ellingsen, 2002; Dolbeth et al., 2007; Gogina et al., 2010a; Martins et al., 2014). However, in regional oceanic waters, the variables that have a more pronounced influence in the distribution of the macrofauna communities are the sediments and depth, given the relative constancy of the others (Basford et al., 1990). Also, due to their covariance demonstrated in several studies (Bobertz and Harff, 2004; Martins et al., 2012a), these two factors could work as proxies for the other environmental variables. Aiming to permit a simple, comparable and straightforward interpretation, it is important to evaluate the relation between the response and explanatory variables in the original measurement scales. In this study, the environmental variables were also transformed trying to find the best relation to the biological parameters in the regression models. The relation pattern between the biological and the explanatory environmental variables was similar using either environmental variables transformed or untransformed. These patterns were also maintained with the train dataset used in the modelling work, which included 70% of the total samples.

The abundance per sampling site decreased from coarser to finer sediments and with increasing depth, in agreement with previous studies in the Portuguese continental shelf (Martins et al., 2013a). This pattern however was not linear, due to some samples of intermediate sediment grain-size with extremely high abundances. Three of the environmental variables (gravel%$_{4throot,}$ kurtosis$_{4throot}$ and depth), were significantly related to the macrofauna abundance patterns. Sediment sample kurtosis, although not so frequently used in benthic studies comparing to other sediment parameters, has also been significantly related to the distribution of benthic macrofauna by Cisneros et al. (2011) and by Dowd et al. (2014).

Contrary to abundance, alpha diversity demonstrated a general non-linear relationship with depth, increasing until the 50 - 60m and then decreasing for deeper bottoms. Low alpha-diversity records in shallow waters were also reported elsewhere (Van Hoey et al., 2004; Dolbeth et al., 2007; Freitas et al., 2011; Sampaio et al., 2016), as consequence of a stressful environment caused by strong bottom currents. The inversion of this tendency near the 50 - 60m is coincident with the presence of the coarser sediments. Using regression methods, it was shown that both gravel and depth were significantly related to benthic macrofauna alpha diversity, but non-linearly in the case of depth. The mid-shelf high alpha diversity in coarse sediments was also reported for the Portuguese shelf by Martins et al. (2013a). This sediment type provides the optimal conditions for highly abundant, small interstitial species that live and move in the space between the grains (Martins et al., 2013b), mainly the annelids *Hesionura elongata*, *Pisione parapari*, *Pisione remota*, *Polygordius appendiculatus* and *Mediomastus fragilis*, and the mysid crustacean *Gastrosaccus spinifer*.

The Shannon-Wiener diversity index showed a visually nonlinear relationship with fines%, a positive linear with depth and no clear relationship with gravel. Concerning this biological index, two models shared the best accuracy results, in terms of NRMSE and R^2, respectively a GLM and a linear regression. In both regression models, significant positive relationships were found between $gravel\%_{4throot}$ and depth. For marine benthic studies, the approach used in this study was not common (Reiss et al., 2015), being the approach of trying to find linear relationships between pairs of variables using the Spearman coefficient more often used. Ellingsen et al. (2002) found low Spearman rank correlations between the Shannon-Wiener index and fines% and depth for the Norwegian shelf, respectively 0.18 and -0.01. Comparing with the present work, these results suggest different relationships between the Shannon-Wiener index and fines or depth.

Comparing model results from different works is not straightforward, mainly because the models outcomes are influenced by the data traits inherent to each study, the variance in the response data and the number of samples being particularly important in the case of abundance and diversity models (Bučas et al., 2013). Further, the method used in the model evaluation will influence the results of the model accuracy. Hence, the results here obtained will be compared only to works using identical methodologies.

In terms of the explained deviance of the training models, Rosa-Filho et al. (2004) developed linear regressions (LR) for the same three macrofauna indices used in this work, but for estuarine benthic macrofauna, with a set of only 22 species. The best models presented here showed a higher value for abundance, 0.53 against 0.26, whilst for the other two indices the explained variance was lower, 0.356 against 0.47 for species richness and 0.169 against 0.26 for the Shannon-Wiener index.

The accuracy of the distribution models for the macrofauna indices, both in terms of R^2 and RMSE (of the LR of the observed vs. fitted of the testing dataset) were within the range of quantitative models of diverse benthic groups developed by Bučas et al. (2013) ($0.02 \leq$ NRMSE ≤ 1.07; $0 \leq R^2 \leq 0.73$), where a wide variety of model techniques were used (i.e. GAM, RF and MARS). In Bučas et al. (2013) the model results of the indices used here were merged. The best models for each biological parameter developed in this thesis, revealed higher values than the mean obtained in that study (mean RMSE = 0.17 and mean $R^2 = 0.24$), revealing lower accuracy in terms of RMSE but higher in terms of R^2.

Although direct spatial interpolations have been successfully used for some marine biological parameters (Monestiez et al., 2006; Chen et al., 2016), the EBK performed poorly in this work. These models, as most of geostatistical methods, are less performant for describing ecological patterns, than for continuous linear environmental data, as the elevation, soil properties or atmospheric pressure (Miller et al., 2007). To what is known, the comparison here presented, between the accuracy of regression models and direct spatial interpolation models of benthic macrofauna parameters, was performed for the first time. Further, this comparison has been scarce in all distribution modelling works (Franklin, 2010).

In this work a methodological approach was presented to potentially predict values of three benthic macrofauna indices, abundance, species richness and Shannon-Wiener diversity, in areas where biological data has not been collected. The relevance of this work is accentuated by the low number of marine species distribution modelling works conducted when compared to the terrestrial realm (Robinson et al., 2011) and because the majority of the marine species distribution modelling (SDM) works found in the literature focused on the distribution of single species (Reiss et al., 2015). Gravel%$_{4throot}$ and depth were the most important environmental variables, selected in the models that showed the best performances, for the three biological response variables. In turn, the absence of the fines%$_{4throot}$ in all final models was a consequence of the collinearity between this variable and those selected.

Although the SDM here developed performed well, future improvements can be made, namely by including more environmental explanatory variables that could potentially be important to relate to the marine soft sediments species compositions, such as the hydrodynamic variables, total organic matter, temperature and primary production, among others (Reiss et al., 2015). Some of these variables nevertheless should present high collinearity to the ones used while others could present limited variability in the study area, meaning that their inclusion in the models would introduce a small improvement. Also, if the aim of the model would only be the spatial prediction, which was not the present case, where significant relationships between the response and explanatory variables were also pursued, other model selection tools, such as AIC or BIC, could be more appropriate for the model selection (Shmueli, 2010). Finally, the inclusion of more samples in the model could improve accuracy (Bučas et al., 2013).

4.6 Multivariate analysis and community distribution models (CDM)

The macrobenthic communities from the Atlantic and Mediterranean shelves have been widely studied (among others, Stephen, 1934; Spärck, 1935; Jones, 1950; Thorson, 1957; Pérès and Picard, 1964; Glémarec, 1973). A comprehensive study of those communities in the Portuguese continental shelf was performed very recently (Martins et al., 2012a, 2013a, 2013b, 2014; Sampaio et al., 2016), although many other studies were also conducted but in restricted parts of the shelf (among others, Marques, 1987; Marques and Bellan-Santini, 1993; Freitas et al., 2003a; Henriques et al., 2015). The present work aimed to describe in detail and model the benthic macrofauna communities of the Portuguese continental shelf north of the Nazaré Canyon, where the shelf is the widest and soft sediment predominate. For this, multivariate statistical methods were used and community distribution models (CDM) were built, in order to map the spatial distribution of the most probable macrofauna assemblages across the study area.

The unconstrained multivariate analysis allowed to describe seven macrobenthic assemblages in the study area, while Martins et al. (2013a) described four. The difference could be explained by the higher sampling resolution used in the present study. The macrofauna assemblages here presented were distributed according to two main gradients, sedimentary and depth.

The benthic assemblage A1, representing the shallow medium and coarse sands, was quite poor in terms of diversity, while showing the highest mean abundance. It is equivalent to the coarse sands of *Echinocyamus pusillus – Tellina pygmaea* described by Glémarec (1973), confirmed by the presence of the species *G. spinifer, Nephtys cirrosa and T. pygmaea*. Also, for the European North Atlantic, this community has the analogue in the *Tellina tenuis* community of Spärck (1935), being also the equivalent of the boreal Lusitanian *Tellina* community (*Tellina tenuis – Tellina fabula*) community of Thorson (1957) and the boreal shallow sand association of Jones (1950). However, contrarily to these studies, the Tellinidae species present in this affinity group was *T. pygmaea*. In the Mediterranean, this community could be considered the analogue to the offshore sands and gravels under swell influence described by Pérès and Picard (1964), sharing with this the archiannelid *Saccocirrus papillocercus*. A very similar community was described in shallow waters off Aveiro (Freitas et al., 2003a), in the Algarve shelf, south of Portugal (Marques, 1987) and off Galician Rias (Moreira et al., 2006; Lourido et al., 2010). Further, Marques (1987) identified a facies of this community that he called the *Spisula solida* facies that presented a seasonal population, collected in July, with high abundances of the mysid *Gastrosaccus normani* (now *Haplostylus normani*). A mysid, in this case *G. spinifer*, was also a characteristic species of the assemblage. Quintino et al. (1987, 1989) and Rodrigues et al. (1993) also described similar assemblages at the entrance of Albufeira and Óbidos lagoons and the Sado estuary, respectively.

The assemblage of the coarser sediments (group A2), very coarse sands and fine gravels presented the highest mean α-diversity. This assemblage corresponds to the coastal gravels of *Branchiostoma lanceolatum – Venus fasciata* community described by Thorson (1957) and Glémarec (1973), and to the boreal offshore gravel association, by Jones (1950) for the North European shelves. As the previous assemblage, this community also has some correspondence with the offshore sands and gravels under swell influence, described by Pérès and Picard (1964) for the Mediterranean. A similar community was also described in the Basque shelf by Galparsoro et al. (2015), sharing some species such as *Sphaerosyllis bulbosa* and *P. appendiculatus.* For the Portuguese shelf, this same community was identified in coarse sediments by Martins et al. (2013a), for this part of the coastal shelf, sharing some important species, namely the bivalve *Thracia villosiuscula* and the polychaetes *Pulliella* sp. and *Malmgrenia ljungmani*.

The deep coarse sands, assemblage A3, has no equivalent in previous benthic studies conducted on the Portuguese continental shelf. A biocenosis of gravelly sand below 100m depth was described for the Algarve shelf by Marques (1987), the detritic offshore biocenosis, with which however no important species are shared. In the Northern European coasts, this community is also not well represented, possibly due to the rareness of similar coarse sediments in deep bottoms (mean depth = 120.5m). Coarse offshore sediments in the Portuguese shelf had already been signaled by Henriques et al. (2015). These authors produced a habitats map according to the EUNIS classification system, where the deep circalittoral coarse sediments was one of the habitats with less attributed area. Eleftheriou and Basford (1989) described a deep (between 100 – 120m) coarse sand community for the North Sea, having in common with the one here presented the annelid *Protodorvillea kefersteini*. Also, the biocenosis of the offshore detritic bottoms (> 80m, often named offshore sands and gravels) of Pérès and Picard (1964) could be considered an analogue assemblage, for the Mediterranean.

The fine sands assemblage here described, group B1, was distributed along a wide depth range. It corresponds well to the similar group identified by Martins et al. (2013a) for this coastal shelf area, although in the present study this community was mostly described for clean fine sand sediments (mean mud% = 5.90). A spatially coincident affinity group of crustaceans was described by Sampaio et al. (2016). For the Atlantic European shelves, this community is the equivalent to the *Venus Gallina* community (Thorson, 1957), the coastal fine sands of *Venus gallina – Dosinia lupina* (Glémarec, 1973) or the boreal offshore sand association (Jones, 1950). Further, this community corresponds to the well sorted fine sands biocenosis for the Mediterranean (Pérès and Picard, 1964). An equivalent circalittoral sand community was described for the Basque shelf (Spain) by Galparsoro et al. (2015), sharing with it the characteristic species *Magelona johnstoni* and *Spiophanes bombyx*. Henriques et al. (2015) also described an equivalent assemblage for the Luiz Saldanha Marine Park (Portugal), in this case however, with no shared characteristic species.

The macrofauna group B2 corresponds to the muds from the northwestern part of the study area, off Douro estuary. This assemblage corresponds well to the *Thyasira* community accompanied by foraminifera in the northern European shelves. High abundances of foraminifera were confirmed through visual examination of this group sediments. This community was firstly described for the Scottish bottoms of the North Sea by Stephen (1923) and for the eastern Greenland shelf by Thorson (1934). Jones (1950) included it in the broader boreal deep mud association, but later, Thorson (1957) confirmed this boreal foraminifera community as a separated assemblage. Also, in the North Sea, Künitzer et al. (1992) described this community in deep (> 100m) muddy bottoms where it had been previously found by McIntyre (1961). This community had not been described before for the Portuguese shelf (see among others, Martins et al., 2013a; Henriques et al., 2015), or for the Mediterranean (Pérès and Picard, 1964). Further, Glémarec (1973) affirmed that this community did not have an equivalent in the southern shelves of the European continent, which is contradicted by our results. Despite its distribution along the entire Portuguese continental shelf, *Thyasira flexuosa* higher abundances were found north, off Douro estuary (see Martins et al., 2014). Combining this knowledge with the map by Dias et al. (2002), presenting the extension of the Douro mud patch, it is possible that the sampling sites of the present work belong to the southernmost section of this biotope, being expected the prolongation of this community to northern sections of the Portuguese continental shelf.

Jones (1950) suggested that the boreal offshore muddy sands and muds should be separated in two different communities, which is in agreement to our findings in this work. Sampaio et al. (2016) could not separate these two communities on basis of crustacean alone for this same study area. The deep very fine sands assemblage (C1) described in this work was not found by Martins et al. (2013a) for this coastal area, certainly due to the lack of representation of this sediment type in Martins et al. (2013a) samples. The community here described is analogue to the muddy sands of *Onuphis lepta – Auchenoplax crinita* described for the southwest of Bay of Biscay by Glémarec (1973), by Cornet et al. (1983) and by Martínez and Adarraga (2011), being considered as a characteristic assemblage of the shelves of that region (Cornet et al., 1983). Several important species are shared between the assemblage presented here and the one described by Martínez and Adarraga (2011), like *Terebellides stroemii*, *Onchnesoma steenstrupii* and *Galathowenia oculata*. For the North Sea, the equivalent associations are the boreal offshore muddy sand association of Jones (1950), or as a modification of the shallower *Syndosmya* (now *Abra*) *alba* community described by Thorson (1957). This muddy sand community was considered by Glémarec (1973) as the first stage of sands contamination by fine particles (< 63 µm).

The affinity group C2 corresponds to the group of muds in the southeastern section of the study area. Martins et al. (2013a), had very few sampling sites in this particular area, only two, and they were part of the mud assemblage described for them, which shared with the mud community here presented, the annelids *Sarsonuphis bihanica*, *Nephtys incisa*, *Ampharete finmarchica* and *Labioleanira yhleni*. Marques (1987) described two mud biocenosis for the Algarve shelf, the coastal detritic muds and the offshore detritic muds. The assemblage described in the present study has more resemblance to the coastal detritic muds, sharing with it two important species, the annelids *N. incisa* and *L. yhleni*. Henriques et al. (2015) described a similar assemblage in the Portuguese shelf, that was classified as a habitat EUNIS level 5, having in common as characteristic species the annelids *Maldane glebifex* and *Chirimia biceps*. The mud assemblage here described has the North Sea analogous boreal offshore mud association (Jones, 1950) and the offshore muds of *Ninoe armoricana* – *Sternaspis scutata* from North Gascony (Glémarec, 1973), corresponding also to the terrigenous mud association described in Pérès and Picard (1964) for the Mediterranean. According to Jones (1950), this community usually occurs outside the muddy sand assemblage, in agreement to our findings. Considering the results obtained in this study and previous studies relative to the sediments and/or their benthic communities across the Portuguese shelf (Marques, 1987; Dias et al., 2002; Martins et al., 2012a, 2013a, 2014; Henriques et al., 2015), it is suggested that two mud assemblages are found along the Portuguese continental shelf, one off the Douro estuary and extending north and the other, off the Mondego estuary and extending South. These two communities correspond to assemblages B2 and C2 here described and they should illustrate a biogeographical cleavage on the offshore benthic communities.

Using a range of statistical methods, univariate and multivariate, this work showed the relationship between the spatial distribution of the macrofauna assemblages and baseline environmental variables. The DISTLM method indicated that all the environmental variables should be kept in the model as significant explanatory variables. Other studies have highlighted the significant relationship between benthic communities and sediment fines content (among others, Ellingsen, 2002; Henkel and Politano, 2017), gravel content (among others, Seiderer and Newell, 1999; Carvalho et al., 2017), sediment kurtosis (among others, Cisneros et al., 2011; Yu et al., 2012) and depth (among others, Ellingsen, 2002; Dolbeth et al., 2007; Gogina et al., 2010a). In agreement with Cisneros et al. (2011), the role of sediment kurtosis in the macrobenthic community structure is difficult to explain, which could justify why this variable is so seldom used in benthic macrofauna studies. The value of 26.94% of explained variance of the biological data by the environmental explanatory variables in the dbRDA approach is within the range of values for biological communities (Cottenie, 2005). Furthermore, the overall resemblance between unconstrained and constrained ordination patterns revealed that the dbRDA model, captured the main features of the biological multivariate data cloud (Anderson et al., 2008a).

Through building several community distribution models (CDM), it was possible to model the habitat suitability for the benthic macrofauna communities identified in the study area, by linking their spatial distribution to spatial environmental data. It was also possible to produce several broad-scale maps presenting the presence probability of each macrofauna assemblage and, through their combination, to obtain a map showing the most probable macrofauna assemblages across the study area. The environmental factors were significantly related to the spatial distribution of the seven macrofauna assemblages identified, despite that in some cases it was necessary to include a spatial autocovariate to eliminate the spatial autocorrelation (SAC) of the model residuals. A similar modelling of the spatial distribution of the macrobenthic communities using a binomial GLM was conducted by Moritz et al. (2013) on the Canadian Atlantic shelf.

The spatial distribution of each assemblage was affected by different environmental variables, depth being more often included in the final model than any other variable (5 of the 7 models), in agreement with Gogina et al. (2010a) probably due to its correlation with other environmental drivers not included in the models. In turn, sediment kurtosis was included in a single model. The mathematical signal of the coefficients of the variables in the final models were in line with the expected. As an example, if depth was kept in the final model for the shallower assemblages, its coefficient presented a negative signal, implying a negative correlation. The same was shown by the sediment variables. As examples, the CDM of the gravel (A2) and muddy sediments (B2 and C2) communities showed significant positive association to $\text{gravel\%}_{4\text{throot}}$ and $\text{fines\%}_{4\text{throot}}$ variables, respectively. For some models, an autocovariate had to be included, fixing the problem of the spatial autocorrelation of the model residuals. According to Austin (2002), if an autocovariate needs to be introduced in a model, it may indicate either a model misspecification, the missing of important environmental explanatory variables or unaccounted biological processes responsible for the species dispersion. In this work, apart the model misspecification, it is difficult to know which of the other reasons might have caused the spatial dependence of the model residuals, eventually both.

As mentioned before, comparing models from different benthic studies is delicate, due to the influence of the data traits in the model outcome, with emphasis for the sampling density and response prevalence for the case of presence/absence models (Bučas et al., 2013). In terms of variance explained, the CDM here developed ranged between 35% and 75%, close to that presented by Moritz et al. (2013) between 42% and 80%.

The final map with the distribution of most probable assemblage across the study area was consistent with the patterns of the observed distribution of the macrofauna communities. This was confirmed by the high overall percentage coincidence (80.7%) between the expected data layer and the observed sampling sites data. The lowest coincidence was shown by assemblages A1 and A3, with 20% and 33.3% respectively. Because the CDM were developed separately for each assemblage, areas where a community presented high occurrence probabilities could, nevertheless, be exceeded by others in the map combining the seven communities.

Even so, the statistical approach used in this work, developing CDMs, proved to be a valid methodology to obtain accurate expected maps of the benthic macrofauna communities. These maps are valuable ecological tools given their range of applications, such as ecosystem management, monitoring, non-indigenous species control or spatial planning (Reiss et al., 2015). Studies such as these gain special importance in areas with recognized fishery importance and related pressures for the benthic habitats, namely fishing trawls (MAMAOT, 2012).

Although the CDM performed well, it is possible to improve them. Some measures that could be taken to enhance such performance were already discussed in the macrofauna indices modelling section. Other measures could be taken in this case, for the maps production, namely including hard substrata data in the models, knowing that this type of seafloor is present in the study area. The inclusion of interspecific relationships has also been advised

(Austin, 2002; Franklin, 2010; Reiss et al., 2015), and species dispersal ranges could be added to enhance the performance of the distribution models (Reiss et al., 2015). However, in situations such as the present work, where the data is relative to hundreds of species, this is very difficult to ensure. Additionally, in this work, some communities were assessed from a low number of sites. The collection of future data relative to such communities should allow to develop more robust models, permitting namely to have training and testing datasets.

4.7 EUNIS habitat classification assessment

The EUNIS classification was implemented, to produce a habitat map of the Portuguese continental shelf north of Nazaré canyon, classifying the habitats up to level 5 of this system. To achieve this, the benthic macrofauna data was combined with relevant environmental factors. After scrutinizing the EUNIS habitat type classification[17] and related publications, it was concluded that this work proposed six new level 5 habitats to EUNIS. To these new habitats, the designation PT followed by a number were added identifying the origin and count of the new EUNIS habitats proposed for the Portuguese shelf (cf. Monteiro et al., 2013). Further, one of the habitats found in this work has a clear correspondence to a habitat already integrated in EUNIS, the "A5.372_Foraminiferans and *Thyasira* spp. in deep circalittoral soft mud". The new habitats here proposed have resemblances with some habitats already in EUNIS or considered as new EUNIS units in papers conducted in the same Atlantic Ocean sub region (Monteiro et al., 2013; Galparsoro et al., 2015; Henriques et al., 2015), exhibiting similar associations. Nevertheless, substantial differences were found with these habitats, in terms of the composition of the most important species, namely the "A5.23_ PT31: *Gastrosaccus spinifer*, *Nephtys cirrosa*, *Hesionura elongata* and other polychaetes in infralittoral sand" proposed in this work vs. the EUNIS "A5.233: *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand", or adding sediment properties, namely "A5.14_PT29: *Gyptis propinqua* and other interstitial annelids accompanied by *Branchiostoma lanceolatum* and *Malmgrenia ljungmani* in circalittoral coarse sediment" from this work vs. the EUNIS "A5.145: *Branchiostoma lanceolatum* in circalittoral coarse sand with shell gravel" vs. "A5.14_PT26:

Circalittoral coarse sand with *Branchiostoma lanceolatum*, *Eurydice grimaldii* and *Malmgreniella castanea*” for the Portuguese southwest coast in Monteiro et al. (2013), despite being included in the same level 4 unit. These habitats should also exist in other sections of the Portuguese coast and Iberian Atlantic shelfs, not having until now been classified accordingly to the EUNIS system.

To produce the EUNIS habitat map, three environmental layers were used: i) sedimentary, from the harmonization between historical data and data used in this work (Mata Chacón et al., 2013); ii) biological zonation, developed by Vasquez et al. (2015) in a broad scale habitat mapping work for the Northeast Atlantic, being recognized that these biological zones (e.g. infralittoral or circalittoral) accompanied increasing depth; iii) wave induced energy on the seabed, developed by MARETEC and using the WW3 model. The energy class boundaries were set following Monteiro et al. (2015). This kinetic energy layer presents a very coarse resolution (0.05˚), not permitting a good estimation of the hydrodynamic conditions of the seabed in the study area. The final EUNIS habitat map, was obtained by combining these three environmental layers with the biological layer presenting the most probable macrofauna community across the study area, as presented in the previous section. Given the good relationship between the biological and the sedimentary variables and depth, the EUNIS system was successfully implemented in the study area. Even so, in agreement with other studies (Coggan et al., 2011, 2012; Henriques et al., 2015), some harmonization problems were found in the translation of the described habitats to the EUNIS levels 4 and 5 units. To facilitate such harmonization, two suggestions by Henriques et al. (2015) were here adopted, relative to the denomination of the level 4 units, “A5.23: Infralittoral fine sand” and “A5.25: Circalittoral fine sand”. These authors argue that the sand classes in the EUNIS system should be renamed and replace by “A5.23: Infralittoral sand” and “A5.25: Circalittoral sand”, allowing to include a wider range of sand habitats. Further, relative to the level 5 units, the system already permits to denominate them with other sand types, not just fine sand. Also, in the present study, a similar community of level 4 unit, “A5.14: Circalittoral coarse sediment”, was found that could be confounded with others with different sediment, due to the inclusion of coarse sands in this coarse sediment level 4 unit. This problem in the EUNIS hierarchy has been approached by several authors (Pearce, 2011; Coggan et al., 2012; Galparsoro et al., 2012), being suggested that it could be solved through the enlargement of the sand area in the Folk trigon, as posteriorly adopted in the MeshAtlantic project (Mata Chacón et al., 2013). Nevertheless, some problems persist, namely the misrepresentation of some sediment types in level 4, for the respective biological zones, for example the circalittoral could be represented by two types of sand (i.e. sand and muddy sand) and mud (i.e. sandy mud and fine mud) while the deep circalittoral is only represented by one type of sand and mud. This led to a different resolution between the habitat types of the level 4, for the different biological zones. In the present work, this issue could be observed by the presence of two circalittoral sand habitats, namely “A5.25: Circalittoral sand” (represented in the Table 13 by their level 5 EUNIS habitat, “A5.25_PT32”) and “A5.26: Circalittoral muddy sand”, against only one for the deep circalittoral, “A5.27: Deep circalittoral sand”.

The implementation of EUNIS in the study area was successful, despite the problems described, and confirmed that for level 5 of this system, the Atlantic South European habitats are not well represented (Galparsoro et al., 2012; Henriques et al., 2015). This led to suggest six new habitats for EUNIS, the inclusion of which should only be done after the scientific consensus between the European Environment Agency and the regional research groups and institutions of the concerned region (Galparsoro et al., 2012, 2015). Nevertheless, it is considered that the separation of habitats based on only the most characteristic species could result in an exaggerated list of EUNIS habitats. Thus, it is acknowledged that the new habitats proposed here could be aggregated, as facies, of some habitat already proposed for the EUNIS.

4.8 Contributions to the environmental status (ES) assessment in the scope of the Marine Strategy Framework Directive (MSFD)

The MSFD is a European commission directive claiming that the Member States should obtain or maintain good environmental status (GES) of their marine waters by 2020 (European Commission, 2008). For this, the ES assessment of the marine national waters should be realized through eleven descriptors embracing several criteria (European Commission, 2017). This work assessed the possible descriptors and criteria through the direct use of the data produced in this thesis, Descriptor 1. Biological Diversity and 6. Sedimentary Integrity. The data collected however could be relevant for the assessment of the other nine descriptors (European Commission, 2011; Galparsoro et al., 2015).

For Descriptor 1, the evaluation of the ES was performed through the marine biological valuation (MBV) approach, resulting in a map where the values of this indicator were presented for each of the EUNIS level 5 habitat types described in the study area. An overall good quality status was achieved for this descriptor. These results were not compared to reference threshold values for the ES assessment, as suggested by the European Commission (2017) due to their lack for the study area. Therefore, the final ES was assessed for the whole study area, following a methodology used in Borja et al. (2011). In fact, the results here obtained could be used to define the reference values for future work conducted in the Portuguese shelf north of Nazaré canyon. A particularity of the approach used here to calculate the MBV was the use of biogeographical ecological subzones that could be meaningfully compared, following the recommendation of Derous (2007). In this work, these subzones corresponded to the identified EUNIS level 5 habitats, as recommended by the European Commission (2017) for the ES assessment. According to what is known, this was the first time that this approach was followed anywhere. Despite its quality, the limitations of the MBV are well-known: i) subjectivity, primarily related to the choice of the assessment questions by the researcher, as also as the selection of the ecological important and habitat-forming species. These features have nevertheless a positive side, that is the addition of some flexibility to this methodology (Derous, 2007; Pascual et al., 2011); ii) lack of reference values for each assessment question and total valuation, meaning that the biological values of the different subzones instead of being related to an intrinsic condition of the subzone, resulted from the comparison between each other (Derous, 2007). Thus, the study area will always have subzones with the highest and lowest ES level, i.e. very high and very low, respectively. Furthermore, for the present study, some other issues were relevant: i) related to the MBV map, showing blank spaces in areas of rock substrate or, due to the modeling constrains, some of the samples that contributed to the calculation of the MBV of a subzone could not be spatially coincident with the respective area in the map; ii) although acknowledging that for the MBV is an important measure, the method reliability was not evaluated, given that only macrofauna benthic data was used. The combined use of other types of biological data should permit to evaluate reliability. Despite these constrains, it is considered that the assessment and mapping works using the MBV are valuable outputs that should be used by the national authorities in the ES assessment in the scope of the MSFD, when integrated with the evaluation of the other biological available data, as namely indicated by Cochrane et al. (2010).

In MAMAOT (2012), the MBV was calculated for the whole Portuguese shelf in broad subzones selected under a bathymetric criterion, and for the subzones spatially coincident with the present study area, a high or very high MBV was obtained. More recently, Gomes et al., (2018) also conducted a study evaluating the MBV for the whole Portuguese shelf using a different approach, dividing the study area in a grid to obtain the subzones. This approach seems to fit well if the study aim is integrating the MBV for diverse biological taxa, as already demonstrated by other authors (Derous et al. 2007b). The division of the subzones in classification schemes, as was done in the present study, based on the relation of the physical environment and the marine biota, makes particularly sense in the case of the soft sediments macrofauna as the distribution of this biotic component mirrors well the physical features, as stated in Derous (2007), and proved in other sections of the present work. The different approaches used by Gomes et al. (2018) and in this study make comparisons difficult. However, the subzones with the higher MBV values in Gomes et al. (2018), for this study area, coincide generally with that obtained in this study, despite of solely based in macrofaunal data.

Concerning descriptor 6, the indicators AMBI and M-AMBI were used for the evaluation of the ES. The ES obtained were high and good for AMBI and M-AMBI, respectively. The European Commission (2017) stated that, for this descriptor, the evaluation should be done separately for each habitat. In the present work this was not possible given the recommendation by Borja et al. (2008) that M-AMBI should include at least 50 samples, a number not achieved by some of the habitats in the study area. Following the criteria outlined by Borja and Rodríguez (2010), AMBI and M-AMBI are considered highly reliable. In the ES assessment for descriptor 6 for the Portuguese shelf presented in MAMAOT (2012), despite the indicators were the same, the methodologies were different from those used here. In the present study, AMBI was used as in Borja et al. (2011), for the indicator of the presence of particularly sensitive and/or tolerant species. The AMBI results per sample presented here (0.38 – 2.8) were in line with those obtained by Borja et al. (2011) (0.22- 3.41) for the Basque country (Spain) continental shelf. M-AMBI, was also used in MAMAOT (2012), although using depth classes in the calculation. The mean M-AMBI value obtained in the present work (0.70) was inside the range of that obtained in MAMAOT (2012) (0.51 – 0.83) for areas of the Portuguese shelf that are in part coincident with the study area of the present work, although lower than 0.83 the mean M-AMBI obtained by Borja et al. (2011), for the Basque country (Spain) continental shelf.

For the criteria used in the present work, as in the MAMAOT (2012) for the same areas, the GES was achieved. It is acknowledged, that the total ES assessment in the scope of the MSFD should not use only one biological data type. However, the assessments using certain types of data should be done by the experts on that scientific field. Finally, the lack of threshold reference values, in the case of the descriptor 1, and methodological issues (explained above) for the descriptor 6 do not allowed the assessment of the ES for each habitat type as stablished by the European Commission (2017).

Chapter 5. Final Remarks

The main aims initially proposed in the formulation of this thesis were achieved. The present study permitted to detail the benthic soft sediment habitats and their associated communities in the section of the Portuguese continental shelf north of Nazaré canyon, presenting a complete workflow that permitted, for example, producing communities distribution maps from original collected data. In this thesis, remote sensing data, collected using an acoustic ground discrimination system (AGDS), and the traditional point sample environmental and macrofaunal data, undertaken using a grab sampler, were collected and combined. Unfortunately, the acoustic data that should discriminate the soft sediment types, and therefore be used as environmental proxy in the distribution models (DM), revealed to be contaminated by depth, jeopardizing its use in this study.

The study area presented sediments, ranging from mud to gravel, confirming the results obtained in previous studies. Using a spatial interpolation technique, maps of environmental variables were produced, such as fines, sand, gravel, kurtosis and depth, showing, once more, that this approach is an accurate way to obtain continuous data layers of the ocean seafloor.

The spatial distribution of macrofauna primary and derived variables were characterized, as well as their relationship to the sedimentary data and depth. This was accomplished by developing distribution models (DM), based on a range of regression type models, evaluating which permitted to obtain the higher prediction accuracy. Also, these models accuracy were compared, in a process rarely done, with models where the predictions of the biological indices were obtained through the direct spatial interpolation using geostatistical methods.

Seven macrofauna communities were identified in the study area and used in community distribution models (CDM) relating their spatial distribution to the sediment parameters and depth. Combining the outputs of these models with the continuous environmental maps produced, allowed to create maps of the probability of presence of each community and, through their combination, a map showing the distribution of the most probable benthic community in the study area, according to what is known, produced for the first time anywhere. This map was used then to produce a thematic map of the benthic habitats classified accordingly to the European Nature Information System (EUNIS) and derive the environmental status (ES) assessment of the study area in the scope of the Marine Strategy Framework Directive (MSFD), showing its usefulness as a marine ecosystem studies tool. Despite their utility, it is important to notice that the models and distribution maps produced do not represent an absolute observed truth, but, a view of what they try to explain. Therefore, it is considered that these results are not immutable, rigid and fully explanatory, being always amenable to improvement.

The benthic maps produced in this work, both the environmental and the biological, are valuable tools suitable for a range of purposes in the context of ecosystem management, such as: monitoring, non-indigenous species control, spatial planning or climate change studies.

Chapter 6. References

6.1 Webography

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Annexes

Table 1 – Geographic coordinates and environmental variables per sampling site. Legend: Sed. Class. = Sediment Classification; FG = Fine Gravel; VCS = Very Coarse Sand; CS = Coarse Sand; MS = Medium Sand; FS = Fine Sand; VFS = Very Fine Sand; M = Mud; C = Coarse Sediment; MxS = Mixed Sediment; S = Sand; mS = Muddy Sand; sM = Sandy Mud; M2010 = MeshAtlantic 2010; M2011 = MeshAtlantic 2011; A = ACOSHELF.

Sites	Longitude	Latitude	Depth (m)	Fines (%)	Sand (%)	Gravel (%)	Median (ϕ)	Sorting	Kurtosis	Sed. Class. (Wentworth)	Sed. Class. (Folk-MeshAtlantic)	Survey
1a	-9.10997	39.73923	49.2	5.62	94.38	0.00	2.67	1.07	11.78	FS	S	M2010
1b	-9.22768	39.73925	100.5	12.17	87.83	0.00	2.65	1.48	5.67	FS	mS	M2010
1c	-9.31238	39.73665	125.9	82.94	17.06	0.00	5.58	1.44	4.67	M	sM	M2010
1d	-9.44013	39.73855	137.5	35.46	64.39	0.15	3.54	2.14	1.70	VFS	mS	M2010
2a	-9.05893	39.7786	24.3	1.30	98.70	0.00	2.60	0.62	31.30	FS	S	M2010
2b	-9.17035	39.7787	74.4	15.69	84.31	0.00	2.62	1.69	4.18	FS	mS	M2010
2c	-9.28032	39.77752	117.6	27.59	72.41	0.00	3.51	1.85	2.09	VFS	mS	M2010
2d	-9.39438	39.77704	130.8	40.84	59.16	0.00	3.72	1.98	1.27	VFS	mS	M2010
2e	-9.4795	39.778	139.7	21.02	78.98	0.00	3.47	1.68	2.85	VFS	mS	M2010
3a	-9.08132	39.80933	47.5	4.18	95.82	0.00	2.54	0.98	15.85	FS	S	M2010
3b	-9.22955	39.80973	100.5	16.10	83.90	0.00	2.74	1.63	3.99	FS	mS	M2010
3c	-9.32893	39.80982	124.1	87.14	12.86	0.00	5.70	1.30	6.73	M	sM	M2010
3d	-9.43795	39.80972	133.3	61.30	38.66	0.03	4.73	2.77	2.09	M	sM	M2010
r1	-9.47492	39.8465	136.4	24.98	75.02	0.00	3.47	1.74	2.24	VFS	mS	M2010
r2	-9.1742	39.85012	78.4	7.08	92.92	0.00	2.59	1.23	9.50	FS	S	M2010
4a	-9.02145	39.87914	28.9	0.18	99.82	0.00	1.66	0.73	7.43	MS	S	M2010
4b	-9.07012	39.87793	52.5	0.35	47.78	51.87	-1.07	0.91	17.00	FG	C	M2010
4c	-9.17255	39.87848	80.1	4.08	95.92	0.00	2.54	1.03	13.95	FS	S	M2010
4d	-9.23323	39.8755	103	32.19	67.81	0.00	3.08	2.02	1.58	VFS	mS	M2010
4e	-9.33178	39.87737	121.9	47.20	52.80	0.00	3.85	2.16	1.20	VFS	mS	M2010
4f	-9.48053	39.87865	138.5	23.46	76.54	0.00	3.27	1.85	2.47	VFS	mS	M2010
5a	-9.0419	39.90703	44.9	1.27	98.73	0.00	2.38	0.74	20.22	FS	S	M2010
5b	-9.11943	39.90942	67.9	0.48	55.79	43.72	-0.78	1.06	13.14	VCS	C	M2010
5c	-9.28152	39.90675	113.1	61.52	38.48	0.00	4.74	2.06	1.47	M	sM	M2010
5d	-9.41947	39.91017	130.6	49.66	50.32	0.03	3.95	3.14	1.31	VFS	mS	M2010
6a	-8.98142	39.93812	20.4	0.30	99.70	0.00	1.54	0.74	11.06	MS	S	M2010
6b	-9.05087	39.93844	52.7	0.73	26.69	72.58	-1.98	1.09	16.15	FG	C	M2010
6c	-9.17168	39.94113	88.4	1.09	81.07	17.84	-0.24	1.20	14.14	VCS	C	M2010
6d	-9.2316	39.93705	102.5	10.85	86.22	2.93	0.82	2.14	5.13	CS	mS	M2010
6e	-9.33163	39.9375	122.3	65.76	33.91	0.33	4.95	2.15	2.69	M	sM	M2010
6f	-9.48007	39.93912	139.4	47.84	52.16	0.00	3.82	3.15	1.34	VFS	mS	M2010
7a	-8.94133	40.00882	16.6	1.58	98.42	0.00	2.64	0.72	19.82	FS	S	M2010
7b	-9.03937	40.00948	54	0.13	38.26	61.61	-1.30	0.88	9.89	FG	C	M2010
7c	-9.12237	40.00782	78.3	0.42	63.24	36.34	-0.65	1.02	13.75	VCS	C	M2010
7d	-9.23012	40.00675	100.2	3.19	55.63	41.18	-0.81	1.44	18.43	VCS	C	M2010
7e	-9.32942	40.00903	125.6	24.12	75.88	0.00	2.98	2.05	2.39	FS	mS	M2010
7f	-9.41998	40.00857	134.3	48.11	51.89	0.00	3.80	3.15	1.29	VFS	mS	M2010
8a	-8.99955	40.03937	44.4	0.19	60.56	39.24	-0.72	0.97	10.00	VCS	C	M2010
8b	-9.0825	40.03783	69	0.61	62.35	37.04	-0.70	0.90	29.26	VCS	C	M2010
8c	-9.17458	40.0384	99.5	67.76	32.20	0.05	5.04	2.30	2.20	M	sM	M2010
8d	-9.2795	40.03945	110.9	2.93	97.07	0.00	0.79	1.27	14.58	CS	S	M2010
8e	-9.3786	40.03917	133.7	19.18	80.82	0.00	3.30	1.63	3.06	VFS	mS	M2010
9a	-8.9506	40.0685	27.1	1.86	98.14	0.00	2.60	0.76	19.66	FS	S	M2010
9b	-9.02142	40.0691	56.8	0.06	26.64	73.30	-1.77	1.18	3.69	FG	C	M2010
9c	-9.1228	40.0694	84.3	1.07	84.30	14.63	-0.26	1.23	12.75	VCS	C	M2010
9d	-9.23067	40.06692	101.2	21.93	78.05	0.03	2.65	2.22	2.30	FS	mS	M2010
9e	-9.3303	40.06835	127.7	25.45	74.55	0.00	3.21	2.06	2.15	VFS	mS	M2010
9f	-9.44187	40.0664	140.8	15.62	84.38	0.00	3.03	1.61	3.76	VFS	mS	M2010
10a	-9.01128	40.1394	51.8	0.00	55.92	44.08	-0.81	1.06	3.49	VCS	C	M2010
10b	-9.08143	40.13987	74.2	1.62	98.38	0.00	2.52	0.76	22.38	FS	S	M2010
10c	-9.17418	40.13754	106.3	92.14	7.86	0.00	5.82	1.09	13.56	M	M	M2010
10d	-9.27938	40.13962	118.2	9.27	90.73	0.00	2.69	1.38	6.46	FS	S	M2010
10e	-9.3813	40.13895	135.5	16.04	83.96	0.00	3.21	1.55	3.73	VFS	mS	M2010
11a	-8.94097	40.16837	29.3	0.91	99.09	0.00	2.56	0.53	42.02	FS	S	M2010
11b	-9.03253	40.1703	62	0.83	99.17	0.00	2.53	0.50	52.66	FS	S	M2010
11c	-9.12085	40.17027	90.6	5.40	94.60	0.00	2.53	1.14	11.22	FS	S	M2010
11d	-9.23143	40.16839	111.7	13.54	86.46	0.00	2.60	1.70	4.35	FS	mS	M2010
11f	-9.4423	40.16825	145	12.67	87.33	0.00	3.03	1.45	4.80	VFS	mS	M2010
12a	-8.98058	40.20692	47.6	0.84	99.16	0.00	2.02	0.74	18.12	FS	S	M2010
12b	-9.08145	40.20973	78.2	2.36	97.64	0.00	2.55	0.73	28.75	FS	S	M2010

Sites	Longitude	Latitude	Depth (m)	Fines (%)	Sand (%)	Gravel (%)	Median (ϕ)	Sorting	Kurtosis	Sed. Class. (Wentworth)	Sed. Class. (Folk-MeshAtlantic)	Survey
12c	-9.17093	40.20895	102.2	0.06	86.31	13.62	0.50	0.55	15.90	CS	C	M2010
12d	-9.28	40.20718	120.1	12.27	87.69	0.04	2.40	1.75	4.49	FS	mS	M2010
12e	-9.3806	40.20822	133	24.76	74.83	0.40	3.19	2.40	2.07	VFS	mS	M2010
13a	-8.9002	40.2784	20.4	0.58	99.42	0.00	2.57	0.55	26.46	FS	S	M2010
13b	-8.99347	40.27982	58.4	0.62	99.38	0.00	2.47	0.58	28.10	FS	S	M2010
13c	-9.0827	40.27825	80.6	2.87	97.13	0.00	2.55	0.80	25.11	FS	S	M2010
13d	-9.17075	40.27892	103.4	27.36	72.64	0.00	2.72	2.11	1.97	FS	mS	M2010
13f	-9.41808	40.27878	142	21.72	66.63	11.65	1.15	2.90	2.11	MS	MxS	M2010
14a	-8.96047	40.30807	54.1	0.55	69.04	30.41	-0.60	1.20	10.08	VCS	C	M2010
14b	-9.02993	40.30822	67.5	1.81	98.19	0.00	2.53	0.69	31.48	FS	S	M2010
14c	-9.12193	40.30875	90.4	7.17	92.83	0.00	2.63	1.19	9.84	FS	S	M2010
14d	-9.2308	40.31014	113.8	44.29	55.71	0.00	3.64	2.50	1.48	VFS	mS	M2010
15a	-8.8905	40.33883	27.4	0.20	99.80	0.00	2.44	0.60	10.91	FS	S	M2010
15b	-8.99038	40.33857	63.2	0.32	50.39	49.29	-0.98	0.94	19.92	VCS	C	M2010
15c	-9.08023	40.33955	79.4	1.56	98.44	0.00	2.54	0.68	30.18	FS	S	M2010
15d	-9.17133	40.33927	102.7	16.43	83.57	0.00	2.80	1.64	3.80	FS	mS	M2010
15e	-9.28045	40.33892	123.8	2.78	82.09	15.12	-0.47	1.42	18.77	VCS	C	M2010
15f	-9.37885	40.33922	130.6	3.43	94.97	1.60	0.57	1.27	19.65	CS	S	M2010
16a	-8.85845	40.40955	21.2	1.95	98.05	0.00	2.52	0.85	14.79	FS	S	M2010
16b	-8.94513	40.40845	52.5	0.00	83.20	16.80	-0.14	0.98	2.63	VCS	C	M2010
16c	-9.03047	40.4054	66.5	1.74	74.04	24.22	-0.51	1.46	11.19	VCS	C	M2010
16d	-9.1205	40.40762	86.6	4.98	62.58	32.43	-0.46	1.91	9.04	VCS	C	M2010
16e	-9.23023	40.40867	121	54.30	45.70	0.00	4.31	2.17	1.38	M	sM	M2010
17a	-8.90072	40.44063	43.2	0.36	74.77	24.87	-0.33	1.04	9.96	VCS	C	M2010
17b	-8.99085	40.43889	60.8	0.08	49.76	50.16	-0.99	1.21	3.38	VCS	C	M2010
17c	-9.08092	40.43917	78.1	0.92	76.58	22.50	-0.45	1.10	19.31	VCS	C	M2010
17d	-9.18415	40.43902	102.2	1.14	98.86	0.00	1.29	0.98	14.15	MS	S	M2010
17f	-9.37813	40.439	140	1.68	81.14	17.18	0.34	1.29	11.97	CS	C	M2010
18a	-8.84075	40.47878	22.3	0.25	99.43	0.32	1.31	0.67	16.81	MS	S	M2010
18b	-8.94977	40.47935	53.8	0.29	72.67	27.04	0.33	0.99	8.19	CS	C	M2010
18c	-9.02993	40.47947	68.5	0.01	99.99	0.00	2.21	0.60	3.91	FS	S	M2010
18d	-9.12083	40.47833	82.1	0.68	99.32	0.00	1.55	0.81	14.72	MS	S	M2010
18e	-9.22833	40.47825	121.7	29.64	70.36	0.00	2.76	2.54	1.74	FS	mS	M2010
19a	-8.90062	40.54987	46.5	0.30	84.76	14.94	0.39	1.00	7.76	CS	C	M2010
19b	-8.99135	40.5477	67.8	0.71	74.22	25.07	-0.13	1.27	7.88	VCS	C	M2010
19c	-9.0798	40.54793	84.5	1.22	79.55	19.24	-0.47	1.19	18.51	VCS	C	M2010
19d	-9.16	40.5488	101	1.65	98.35	0.00	2.51	0.62	43.91	FS	S	M2010
20a	-8.8411	40.57927	33.1	0.04	86.62	13.34	0.20	0.89	3.82	CS	C	M2010
20b	-8.92975	40.57985	54.2	0.14	80.20	19.66	0.24	1.00	5.10	CS	C	M2010
20c	-9.03102	40.57927	77.1	0.21	67.60	32.19	-0.60	0.88	13.12	VCS	C	M2010
20d	-9.12103	40.57993	82.4	1.31	98.68	0.01	2.50	0.58	47.10	FS	S	M2010
20e	-9.2305	40.58032	136.4	6.24	48.19	45.57	-0.70	1.88	8.59	VCS	MxS	M2010
21a	-8.90027	40.61927	47.8	0.77	76.05	23.18	0.01	0.99	18.76	CS	C	M2010
21b	-8.99105	40.62043	69.3	0.34	73.73	25.93	-0.23	1.07	8.21	VCS	C	M2010
21c	-9.08148	40.61972	88.5	1.39	98.61	0.00	2.47	0.68	30.54	FS	S	M2010
21d	-9.16933	40.6175	120.5	3.15	96.71	0.14	0.49	1.29	18.42	CS	S	M2010
22a	-8.8322	40.68087	34.1	0.08	98.79	1.13	0.19	0.69	10.06	CS	S	M2010
22b	-8.92947	40.68082	61.5	0.59	67.89	31.52	-0.44	1.06	13.77	VCS	C	M2010
22c	-9.02975	40.68044	77.8	0.14	65.60	34.26	-0.46	0.98	6.52	VCS	C	M2010
22d	-9.1221	40.67793	102.7	3.30	96.70	0.00	2.52	0.84	23.53	FS	S	M2010
22e	-9.22993	40.6789	148.1	23.80	65.81	10.39	1.21	2.92	2.03	MS	MxS	M2010
23a	-8.7759	40.70908	21	0.07	98.71	1.21	1.13	0.75	6.67	MS	S	M2010
23b	-8.85122	40.7105	37	0.02	60.16	39.82	-0.65	0.73	4.68	VCS	C	M2010
23c	-8.99232	40.71088	69.9	0.25	63.07	36.67	-0.46	1.04	7.49	VCS	C	M2010
23d	-9.08193	40.71003	91.9	1.98	98.02	0.00	2.51	0.69	34.77	FS	S	M2010
23e	-9.16945	40.7117	127.3	3.29	87.61	9.10	0.06	1.48	14.39	CS	C	M2010
24a	-8.83003	40.74972	33.1	0.16	78.79	21.05	-0.17	0.91	8.05	VCS	C	M2010
24b	-8.94048	40.74859	54	0.03	37.00	62.97	-1.46	0.83	4.45	FG	C	M2010
24c	-9.03083	40.74803	79	0.18	64.97	34.85	-0.64	0.87	12.72	VCS	C	M2010
24d	-9.10752	40.74762	105.5	2.69	97.31	0.00	2.52	0.78	27.51	FS	S	M2010
24e	-9.23037	40.7496	154	9.58	90.10	0.32	2.01	1.73	5.09	FS	S	M2010
25a	-8.73982	40.8315	21.4	2.03	97.97	0.00	2.62	0.78	18.89	FS	S	M2010
25b	-8.82913	40.82957	43	0.14	72.96	26.90	-0.46	0.87	9.41	VCS	C	M2010
25c	-8.90957	40.8286	54.7	0.25	17.44	82.31	-2.00	0.89	13.50	FG	C	M2010
25f	-9.23027	40.83045	142.2	15.01	84.98	0.01	2.67	1.79	3.58	FS	mS	M2010
26a	-8.7926	40.8592	37.2	0.55	51.07	48.39	-0.93	1.35	7.44	VCS	C	M2010
26d	-9.06728	40.85907	100	3.15	96.85	0.00	2.52	0.84	22.94	FS	S	M2010
27a	-8.73158	40.88913	22.7	2.20	97.80	0.00	2.59	0.79	20.06	FS	S	M2010

Sites	Longitude	Latitude	Depth (m)	Fines (%)	Sand (%)	Gravel (%)	Median (ϕ)	Sorting	Kurtosis	Sed. Class. (Wentworth)	Sed. Class. (Folk-MeshAtlantic)	Survey
27b	-8.82948	40.88854	45.5	0.90	47.84	51.26	-1.05	1.55	4.88	FG	C	M2010
27d	-9.03012	40.88862	84.9	1.14	65.46	33.40	-0.63	1.19	18.58	CS	C	M2010
27f	-9.23282	40.88973	143.8	25.42	74.58	0.00	2.91	2.25	1.99	FS	mS	M2010
28a	-8.79093	40.91837	38	0.01	81.17	18.82	-0.41	0.74	4.91	VCS	C	M2010
28b	-8.87123	40.92135	52.4	0.36	34.27	65.37	-1.81	1.04	11.16	FG	C	M2010
28c	-8.96493	40.91827	70.9	1.52	52.99	45.49	-0.87	1.27	18.57	VCS	C	M2010
28d	-9.0514	40.91985	96.7	16.63	83.37	0.00	2.62	1.70	4.00	FS	mS	M2010
28e	-9.17277	40.91992	135	7.52	92.46	0.01	1.40	1.73	6.57	MS	S	M2010
M4G	-8.84827	40.83055	45	0.01	47.78	52.21	-1.08	0.87	3.75	FG	C	M2011
M5G	-8.83942	40.91913	44.2	0.15	79.44	20.42	-0.52	0.58	41.15	VCS	C	M2011
M6G	-8.77145	40.85992	33.1	2.93	97.07	0.00	2.63	0.91	14.32	FS	S	M2011
M7G	-8.79163	40.7997	34	0.00	87.80	12.20	0.71	0.86	3.24	CS	C	M2011
M9G	-8.8694	40.92977	49.55	0.94	98.93	0.13	2.50	0.59	33.89	FS	S	M2011
M10G	-8.85998	40.89005	49.77	1.52	98.48	0.00	2.20	0.85	16.65	FS	S	M2011
M1MG	-9.05848	41.0323	102.8	72.91	27.02	0.07	5.25	2.18	3.05	M	sM	M2011
M2MG	-9.0435	41.02162	98.6	8.08	91.85	0.07	2.56	1.35	7.93	FS	S	M2011
M3MG	-8.90362	40.9677	61.6	1.59	28.90	69.51	-1.58	1.34	15.13	FG	C	M2011
M4MG	-8.98923	40.9853	81.5	0.30	13.40	86.30	-1.85	0.90	18.09	FG	C	M2011
M5MG	-8.82298	40.85175	40.9	0.23	99.77	0.00	2.38	0.66	9.56	FS	S	M2011
M6MG	-8.77672	40.86802	33	3.37	96.61	0.02	2.71	0.90	14.84	FS	S	M2011
M7MG	-8.8528	40.86857	51.8	0.66	37.75	61.59	-1.21	1.08	20.76	FG	C	M2011
M8MG	-8.8887	40.95078	58	3.29	96.71	0.00	2.50	0.90	19.66	FS	S	M2011
M9MG	-8.86905	40.77625	41.7	0.04	66.01	33.96	-0.21	0.94	3.63	VCS	C	M2011
M10MG	-8.86752	40.89062	55.1	1.29	35.25	63.46	-1.35	1.22	19.49	FG	C	M2011
M11MG	-9.00748	40.8431	75.5	0.49	53.63	45.88	-0.85	0.95	18.14	VCS	C	M2011
M12MG	-8.98848	40.83895	72	0.06	67.08	32.86	-0.54	0.81	7.41	VCS	C	M2011
M14MG	-8.94198	40.81072	58.3	0.20	52.71	47.09	-0.90	0.96	9.53	VCS	C	M2011
M15MG	-8.82195	40.80253	36.5	0.00	76.57	23.43	0.26	1.00	2.45	CS	C	M2011
M16MG	-8.81962	40.81735	38	0.04	57.66	42.30	-0.64	1.05	3.40	VCS	C	M2011
M17MG	-9.03468	40.93487	91.4	8.51	91.49	0.00	2.56	1.32	8.31	FS	S	M2011
M18MG	-9.0442	40.8914	92.3	1.99	98.00	0.01	2.51	0.74	26.99	FS	S	M2011
M20MG	-9.02075	40.8706	83.5	4.39	46.14	49.47	-0.98	1.78	11.41	VCS	C	M2011
M21MG	-8.9691	40.97087	75	2.38	41.41	56.22	-1.17	1.45	16.93	FG	C	M2011
M22MG	-8.90235	40.94152	60.8	0.20	58.79	41.01	-0.79	0.76	21.24	VCS	C	M2011
M23MG	-8.82047	40.89332	41.4	0.07	52.79	47.14	-0.93	0.85	9.70	VCS	C	M2011
M24MG	-8.82032	40.8734	39.7	0.83	99.17	0.00	2.47	0.67	20.77	FS	S	M2011
M25MG	-8.76737	40.82057	27.6	0.07	98.67	1.26	0.92	0.76	6.37	CS	S	M2011
M26MG	-8.78913	40.75783	27.2	0.00	82.31	17.69	0.32	0.98	2.45	CS	C	M2011
M27MG	-8.892	40.8338	50.3	0.02	40.60	59.38	-1.23	0.85	4.87	FG	C	M2011
M28MG	-8.79005	40.90257	36.3	0.00	71.97	28.03	-0.49	0.91	4.06	VCS	C	M2011
M29MG	-8.8346	40.76987	35.8	0.00	95.85	4.15	0.60	0.77	3.25	CS	S	M2011
M31MG	-8.98578	40.91965	75.5	0.74	43.11	56.15	-1.18	1.13	15.71	FG	C	M2011
M32MG	-8.85425	41.00078	51.2	0.34	40.20	59.45	-1.31	0.99	13.14	FG	C	M2011
M33MG	-8.81877	41.02472	44.7	0.64	46.77	52.59	-1.10	1.06	16.39	FG	C	M2011
M34MG	-8.78687	40.9863	39	0.00	51.42	48.58	-0.94	0.92	3.18	VCS	C	M2011
M35MG	-8.70897	40.98758	21.4	5.34	94.66	0.00	2.71	1.24	7.32	FS	S	M2011
M36MG	-8.72133	40.94273	22.7	1.83	98.17	0.00	2.71	0.78	15.87	FS	S	M2011
M37MG	-8.85343	40.93903	48.4	1.06	98.91	0.03	2.46	0.69	23.75	FS	S	M2011
M38MG	-8.79462	40.94102	37.7	0.35	99.58	0.07	1.47	0.85	8.14	MS	S	M2011
M39MG	-8.75392	40.85358	25.1	2.01	97.99	0.00	2.61	0.84	14.62	FS	S	M2011
M40MG	-8.74352	40.90671	25.9	1.21	98.79	0.00	2.44	0.81	13.41	FS	S	M2011
M41MG	-8.86688	40.80747	43.4	0.04	69.23	30.74	-0.14	0.99	3.28	VCS	C	M2011
M42MG	-8.75497	40.78768	21.9	0.00	97.24	2.76	0.76	0.82	3.15	CS	S	M2011
M43MG	-8.74222	40.75663	15	0.01	99.89	0.10	1.18	0.79	4.27	MS	S	M2011
M44MG	-9.00797	41.05492	91.2	3.95	11.63	84.41	-1.43	1.75	16.73	FG	C	M2011
M46MG	-8.87532	41.05409	57	0.54	18.90	80.56	-1.57	0.82	34.20	FG	C	M2011
M48MG	-9.03475	41.1063	96.8	93.44	6.46	0.09	5.85	1.05	17.98	M	M	M2011
M49MG	-8.95107	41.10489	73	66.61	33.37	0.02	4.99	1.74	2.01	M	sM	M2011
M50MG	-8.857	41.1058	51.8	6.74	93.26	0.00	3.15	1.31	5.85	VFS	S	M2011
M51MG	-8.78788	41.10553	37.7	25.32	74.61	0.08	3.65	1.61	2.60	VFS	mS	M2011
M52MG	-8.70407	41.10513	23.1	16.06	83.92	0.02	3.51	1.55	3.88	VFS	mS	M2011
A23	-9.0583	41.18822	96.86	97.80	2.20	0.00	5.95	0.58	54.35	M	M	A
A24	-8.9547	41.18932	64.31	50.39	49.61	0.00	4.02	1.77	1.07	M	sM	A
A25	-8.85653	41.1893	47.25	4.11	67.57	28.32	-0.42	1.67	11.50	VCS	C	A
A26	-8.76115	41.18663	28.86	1.03	98.97	0.00	1.30	0.81	26.29	MS	S	A
A27	-8.73453	41.05828	24.3	0.38	60.72	38.90	-0.55	0.98	12.79	VCS	C	A
A28	-8.84485	41.05723	48.41	0.50	92.94	6.56	0.35	0.87	19.50	CS	C	A
A31	-9.1669	41.05938	134.59	35.11	61.08	3.81	3.23	2.65	1.89	VFS	mS	A

Sites	Longitude	Latitude	Depth (m)	Fines (%)	Sand (%)	Gravel (%)	Median (ɸ)	Sorting	Kurtosis	Sed. Class. (Wentworth)	Sed. Class. (Folk-MeshAtlantic)	Survey
A39	-8.8145	40.78837	29.25	0.01	76.18	23.81	0.38	0.95	2.98	CS	C	A
A40	-8.91717	40.79043	45.15	0.04	41.48	58.48	-1.23	0.89	4.53	FG	C	A
A41	-9.00173	40.78838	68.55	0.37	58.64	40.98	-0.66	1.11	8.77	VCS	C	A
A42	-9.10512	40.78797	99.56	5.96	94.04	0.00	2.56	1.10	12.79	FS	S	A
A45	-9.10952	40.64932	90.94	1.57	98.43	0.00	2.50	0.61	44.27	FS	S	A
A46	-9.03727	40.65323	74.1	0.50	61.39	38.11	-0.60	1.12	10.63	VCS	C	A
A47	-8.93452	40.653	49.88	0.19	61.24	38.57	-0.57	1.02	6.69	VCS	C	A
A48	-8.85485	40.65492	35.1	0.14	46.91	52.95	-1.10	0.95	7.07	FG	C	A
A51	-8.93712	40.51558	48.45	0.00	81.35	18.65	-0.06	0.96	2.67	VCS	C	A
A52	-9.06107	40.51638	73.84	0.49	61.90	37.61	-0.76	0.91	27.01	VCS	C	A
A53	-9.17898	40.5322	100.27	6.13	93.75	0.12	2.27	1.51	6.79	FS	S	A
A58	-9.06212	40.38093	69.32	3.41	96.59	0.00	2.51	0.99	14.24	FS	S	A
A59	-8.9685	40.38057	54.9	0.36	85.62	14.02	-0.30	0.88	16.56	VCS	C	A
A60	-8.87727	40.37962	24.11	2.16	97.68	0.16	2.46	0.92	13.08	FS	S	A
A61	-8.93815	40.24642	32.1	0.84	99.00	0.16	2.41	0.71	18.59	FS	S	A
A62	-9.06507	40.24807	68.85	1.44	98.56	0.00	2.54	0.62	38.13	FS	S	A
A63	-9.14217	40.25097	91.57	9.33	90.67	0.00	2.65	1.32	7.53	FS	S	A
A67	-9.11965	40.11367	82.69	3.16	96.83	0.01	2.57	0.85	21.19	FS	S	A
A68	-8.99877	40.11393	42.34	0.03	37.39	62.58	-1.51	0.90	4.62	FG	C	A
A69	-8.93432	40.11357	20.66	1.46	98.54	0.00	2.59	0.72	19.93	FS	S	A
A70	-9.01765	39.97787	38.7	0.58	57.15	42.27	-0.80	1.07	16.03	VCS	C	A
A71	-9.10967	39.97757	67.93	0.68	53.33	45.99	-0.84	1.04	16.80	VCS	C	A
A72	-9.23547	39.97802	98.7	11.53	88.47	0.00	2.78	1.57	4.68	FS	mS	A
A73	-9.37717	39.97723	125.51	31.96	68.04	0.00	3.42	2.15	1.86	VFS	mS	A
A74	-9.38342	39.8449	123.67	68.99	31.01	0.00	5.09	2.17	2.85	M	sM	A
A77	-9.0835	39.84553	48.19	0.47	49.54	49.99	-1.00	1.08	13.38	VCS	C	A
A78	-9.12985	39.7096	49.24	6.66	93.34	0.00	2.84	1.14	9.01	FS	S	A
A79	-9.18463	39.70548	90.3	4.53	95.47	0.00	2.61	1.01	13.67	FS	S	A
A80	-9.30005	39.71205	119.92	85.90	14.10	0.00	5.67	1.29	5.97	M	sM	A

Table 2 – Complete list of the macrofauna with total abundance (A) and occurrence per species (O). Legend: * = subphylum Crustacea.

Phylum	Class	Family	Species name	A	O
Annelida	Clitellata	Oligochaeta n.i.	Oligochaeta n.i.	399	46
Annelida	Clitellata	Tubificidae	*Tubificoides benedii* (Udekem, 1855)	1	1
Annelida	Polychaeta	Lumbrineridae	*Abyssoninoe hibernica* (McIntosh, 1903)	27	18
Annelida	Polychaeta	Polynoidae	*Acholoe squamosa* (Delle Chiaje, 1827)	2	2
Annelida	Polychaeta	Acrocirridae	Acrocirridae n.i.	1	1
Annelida	Polychaeta	Acrocirridae	*Acrocirrus frontifilis* (Grube, 1860)	32	10
Annelida	Polychaeta	Nephtyidae	*Aglaophamus agilis* (Langerhans, 1880)	24	14
Annelida	Polychaeta	Ampharetidae	*Ampharete finmarchica* (M. Sars, 1865)	232	53
Annelida	Polychaeta	Ampharetidae	*Ampharete octocirrata* (Sars, 1835)	1	1
Annelida	Polychaeta	Ampharetidae	Ampharetidae n.i.	1	1
Annelida	Polychaeta	Ampharetidae	*Amphicteis gunneri* (M. Sars, 1835)	15	8
Annelida	Polychaeta	Pectinariidae	*Amphictene auricoma* (O.F. Müller, 1776)	15	6
Annelida	Polychaeta	Sabellidae	*Amphiglena mediterranea* (Leydig, 1851)	4	2
Annelida	Polychaeta	Terebellidae	*Amphitrite cirrata* (Müller, 1771 in 1776)	5	1
Annelida	Polychaeta	Pilargidae	*Ancistrosyllis groenlandica* McIntosh, 1879	3	3
Annelida	Polychaeta	Spionidae	*Aonides oxycephala* (Sars, 1862)	706	68
Annelida	Polychaeta	Cirratulidae	*Aphelochaeta marioni* (Saint-Joseph, 1894)	25	18
Annelida	Polychaeta	Cirratulidae	*Aphelochaeta* sp. Blake, 1991	184	29
Annelida	Polychaeta	Cirratulidae	*Aphelochaeta* sp.1 Blake, 1991	4	3
Annelida	Polychaeta	Cirratulidae	*Aphelochaeta* sp.2 Blake, 1991	2	2
Annelida	Polychaeta	Cirratulidae	*Aphelochaeta* sp.4 Blake, 1991	2	1
Annelida	Polychaeta	Aphroditidae	*Aphrodita aculeata* Linnaeus, 1758	2	2
Annelida	Polychaeta	Onuphidae	*Aponuphis bilineata* (Baird, 1870)	278	58
Annelida	Polychaeta	Onuphidae	*Aponuphis brementi* (Fauvel, 1916)	39	17
Annelida	Polychaeta	Onuphidae	*Aponuphis grubii* (Marenzeller, 1886)	54	18
Annelida	Polychaeta	Onuphidae	*Aponuphis juvenile* sp.1	6	6
Annelida	Polychaeta	Onuphidae	*Aponuphis juvenile* sp.2	6	4
Annelida	Polychaeta	Oenonidae	*Arabella iricolor* (Montagu, 1804)	1	1
Annelida	Polychaeta	Archiannelida n.i.	Archiannelida n.i.	41	5
Annelida	Polychaeta	Paraonidae	*Aricidea (Acmira) assimilis* Tebble, 1959	41	14
Annelida	Polychaeta	Paraonidae	*Aricidea (Acmira) catherinae* Laubier, 1967	14	8
Annelida	Polychaeta	Paraonidae	*Aricidea (Acmira) cerrutii* Laubier, 1966	25	12
Annelida	Polychaeta	Paraonidae	*Aricidea (Acmira) laubieri* Hartley, 1981	20	13
Annelida	Polychaeta	Paraonidae	*Aricidea (Acmira) lopezi* Berkeley & Berkeley, 1956	6	5
Annelida	Polychaeta	Paraonidae	*Aricidea (Acmira) simonae* Laubier & Ramos, 1974	4	3
Annelida	Polychaeta	Paraonidae	*Aricidea (Aricidea) pseudoarticulata* Hobson, 1972	168	39
Annelida	Polychaeta	Paraonidae	*Aricidea (Aricidea) wassi* Pettibone, 1965	31	15
Annelida	Polychaeta	Paraonidae	*Aricidea (Strelzovia) bifurcata* Aguirrezabalaga & Gil, 2009	1	1
Annelida	Polychaeta	Paraonidae	*Aricidea (Strelzovia) roberti* Hartley, 1984	120	35
Annelida	Polychaeta	Paraonidae	*Aricidea neosuecica* Hartman, 1965 sensu Laubier & Ramos, 1974	1	1
Annelida	Polychaeta	Paraonidae	*Aricidea* sp.1 Webster, 1879	1	1
Annelida	Polychaeta	Terebellidae	*Artacama proboscidea* Malmgren, 1866	2	2
Annelida	Polychaeta	Ampharetidae	*Auchenoplax worsfoldi* Jirkov & Leontovich, 2013	47	16
Annelida	Polychaeta	Sabellidae	*Bispira volutacornis* (Montagu, 1804)	4	2
Annelida	Polychaeta	Spionidae	*Boccardiella ligerica* (Ferronnière, 1898)	1	1
Annelida	Polychaeta	Spionidae	*Boccardiella* sp. Blake & Kudenov, 1978	2	1
Annelida	Polychaeta	Flabelligeridae	*Brada villosa* (Rathke, 1843)	9	4
Annelida	Polychaeta	Capitellidae	*Capitella capitata tripartita* Hartman, 1961	3	2
Annelida	Polychaeta	Capitellidae	*Capitella* sp. Blainville, 1828	2	2
Annelida	Polychaeta	Cirratulidae	*Caulleriella alata* (Southern, 1914)	29	8
Annelida	Polychaeta	Cirratulidae	*Caulleriella bioculata* (Keferstein, 1862)	63	22
Annelida	Polychaeta	Capitellidae	cf. *Capitellethus* sp. Chamberlin, 1919	2	2
Annelida	Polychaeta	Capitellidae	cf. *Pseudoleiocapitella* sp. Harmelin, 1964	1	1
Annelida	Polychaeta	Cirratulidae	*Chaetozone carpenteri* McIntosh, 1911	55	22
Annelida	Polychaeta	Cirratulidae	*Chaetozone gibber* Woodham & Chambers, 1994	96	22
Annelida	Polychaeta	Cirratulidae	*Chaetozone* sp.	11	8
Annelida	Polychaeta	Cirratulidae	*Chaetozone* sp.2	33	13
Annelida	Polychaeta	Cirratulidae	*Chaetozone zetlandica* McIntosh, 1911	34	12
Annelida	Polychaeta	Maldanidae	*Chirimia biceps* (M. Sars, 1861)	39	19
Annelida	Polychaeta	Amphinomidae	*Chloeia venusta* Quatrefages, 1866	5	5
Annelida	Polychaeta	Cirratulidae	Cirratulidae n.i.	1	1
Annelida	Polychaeta	Cirratulidae	*Cirratulus cirratus* (O. F. Müller, 1776)	1	1
Annelida	Polychaeta	Cirratulidae	*Cirriformia* sp.	1	1
Annelida	Polychaeta	Cirratulidae	*Cirriformia tentaculata* (Montagu, 1808)	8	6
Annelida	Polychaeta	Paraonidae	*Cirrophorus branchiatus* Ehlers, 1908	6	6
Annelida	Polychaeta	Paraonidae	*Cirrophorus furcatus* (Hartman, 1957)	2	2

Phylum	Class	Family	Species name	A	O
Annelida	Polychaeta	Maldanidae	*Clymenella torquata* (Leidy, 1855)	3	2
Annelida	Polychaeta	Maldanidae	*Clymenura* sp.	4	3
Annelida	Polychaeta	Capitellidae	*Dasybranchus caducus* (Grube, 1846)	4	2
Annelida	Polychaeta	Onuphidae	*Diopatra micrura* Pires, Paxton, Quintino & Rodrigues, 2010	25	3
Annelida	Polychaeta	Syllidae	*Dioplosyllis cirrosa* Gidholm, 1962	3	2
Annelida	Polychaeta	Flabelligeridae	*Diplocirrus glaucus* (Malmgren, 1867)	69	28
Annelida	Polychaeta	Spionidae	*Dipolydora flava* (Claparède, 1870)	10	4
Annelida	Polychaeta	Spionidae	*Dipolydora giardi* (Mesnil, 1896)	1	1
Annelida	Polychaeta	Dorvilleidae	Dorvilleidae n.i.	1	1
Annelida	Polychaeta	Oenonidae	*Drilonereis filum* (Claparède, 1868)	16	11
Annelida	Polychaeta	Sphaerodoridae	*Ephesiella abyssorum* (Hansen, 1878)	1	1
Annelida	Polychaeta	Phyllodocidae	*Eteone* sp. Savigny, 1818	7	4
Annelida	Polychaeta	Sabellidae	*Euchone rubrocincta* (Sars, 1862)	4	3
Annelida	Polychaeta	Maldanidae	*Euclymene droebachiensis* (Sars, 1872)	29	11
Annelida	Polychaeta	Maldanidae	*Euclymene lombricoides* (Quatrefages, 1866)	4	1
Annelida	Polychaeta	Maldanidae	*Euclymene oerstedi* (Claparède, 1863)	30	11
Annelida	Polychaeta	Maldanidae	*Euclymene* sp.	10	1
Annelida	Polychaeta	Maldanidae	*Euclymene* sp. A	40	15
Annelida	Polychaeta	Maldanidae	*Euclymeninae* sp. A	2	2
Annelida	Polychaeta	Phyllodocidae	*Eulalia bilineata* (Johnston, 1840)	1	1
Annelida	Polychaeta	Phyllodocidae	*Eulalia mustela* Pleijel, 1987	412	62
Annelida	Polychaeta	Phyllodocidae	*Eulalia* sp.1	3	3
Annelida	Polychaeta	Phyllodocidae	*Eumida bahusiensis* Bergstrom, 1914	2	2
Annelida	Polychaeta	Phyllodocidae	*Eumida sanguinea* (Örsted, 1843)	421	68
Annelida	Polychaeta	Nereididae	*Eunereis longissima* Johnston, 1840	49	35
Annelida	Polychaeta	Eunicidae	*Eunice harassii* Audouin & Milne Edwards, 1833	1	1
Annelida	Polychaeta	Eunicidae	*Eunice* sp.	1	1
Annelida	Polychaeta	Eunicidae	*Eunice vittata* (Delle Chiaje, 1828)	40	23
Annelida	Polychaeta	Eunicidae	*Eunicidae juvenile*	1	1
Annelida	Polychaeta	Terebellidae	*Eupolymnia nebulosa* (Montagu, 1818)	5	5
Annelida	Polychaeta	Syllidae	*Eurysyllis tuberculata* Ehlers, 1864	150	31
Annelida	Polychaeta	Syllidae	*Exogone (Exogone) naidina* Örsted, 1845	3	1
Annelida	Polychaeta	Oweniidae	*Galathowenia oculata* (Zachs, 1923)	112	31
Annelida	Polychaeta	Lumbrineridae	*Gallardoneris iberica* Martins, Carrera-Parra, Quintino & Rodrigues, 2012	49	16
Annelida	Polychaeta	Glyceridae	*Glycera alba* (O.F. Müller, 1776)	23	15
Annelida	Polychaeta	Glyceridae	*Glycera celtica* O'Connor, 1987	9	5
Annelida	Polychaeta	Glyceridae	*Glycera dayi* O'Connor, 1987	35	19
Annelida	Polychaeta	Glyceridae	*Glycera gigantea* Quatrefages, 1866	5	5
Annelida	Polychaeta	Glyceridae	*Glycera lapidum* Quatrefages, 1866	825	94
Annelida	Polychaeta	Glyceridae	*Glycera mimica* Hartman, 1965	3	2
Annelida	Polychaeta	Glyceridae	*Glycera oxycephala* Ehlers, 1887	53	17
Annelida	Polychaeta	Glyceridae	*Glycera tridactyla* Schmarda, 1861	158	20
Annelida	Polychaeta	Glyceridae	*Glycera unicornis* Lamarck, 1818	30	18
Annelida	Polychaeta	Goniadidae	*Glycinde nordmanni* (Malmgren, 1866)	74	22
Annelida	Polychaeta	Goniadidae	*Glycinde* sp.	1	1
Annelida	Polychaeta	Goniadidae	*Goniada maculata* Örsted, 1843	39	24
Annelida	Polychaeta	Goniadidae	*Goniadella gracilis* (Verrill, 1873)	518	74
Annelida	Polychaeta	Hesionidae	*Gyptis propinqua* Marion & Bobretzky, 1875	276	44
Annelida	Polychaeta	Hesionidae	*Gyptis rosea* Marion, 1875	1	1
Annelida	Polychaeta	Syllidae	*Haplosyllis spongicola* (Grube, 1855)	3	2
Annelida	Polychaeta	Polynoidae	*Harmothoe antilopes* McIntosh, 1876	5	5
Annelida	Polychaeta	Polynoidae	*Harmothoe fraserthomsoni* McIntosh, 1897	50	19
Annelida	Polychaeta	Polynoidae	*Harmothoe glabra* (Malmgren, 1866)	12	8
Annelida	Polychaeta	Polynoidae	*Harmothoe goreensis* Augener, 1918	8	8
Annelida	Polychaeta	Polynoidae	*Harmothoe* sp.	1	1
Annelida	Polychaeta	Hesionidae	Hesionidae n.i.	5	3
Annelida	Polychaeta	Phyllodocidae	*Hesionura elongata* (Southern, 1914)	7896	54
Annelida	Polychaeta	Serpulidae	*Hydroides elegans* (Haswell, 1883)	1	1
Annelida	Polychaeta	Serpulidae	*Hydroides norvegica* Gunnerus, 1768	101	26
Annelida	Polychaeta	Phyllodocidae	*Hypereteone foliosa* (Quatrefages, 1865)	1	1
Annelida	Polychaeta	Ampharetidae	*Isolda pulchella* Müller in Grube, 1858	23	7
Annelida	Polychaeta	Sabellidae	*Jasmineira elegans* Saint-Joseph, 1894	65	28
Annelida	Polychaeta	Sigalionidae	*Labioleanira yhleni* (Malmgren, 1867)	43	21
Annelida	Polychaeta	Lacydoniidae	*Lacydonia miranda* Marion & Bobretzky, 1875	1	1
Annelida	Polychaeta	Pectinariidae	*Lagis koreni* Malmgren, 1866	170	20
Annelida	Polychaeta	Terebellidae	*Lanice conchilega* (Pallas, 1766)	74	27
Annelida	Polychaeta	Spionidae	*Laonice bahusiensis* Söderström, 1920	119	34
Annelida	Polychaeta	Capitellidae	*Leiocapitella dollfusi* (Fauvel, 1936)	4	3
Annelida	Polychaeta	Maldanidae	*Leiochone leiopygos* (Grube, 1860)	28	13

Phylum	Class	Family	Species name	A	O
Annelida	Polychaeta	Lumbrineridae	*Lumbrinerides amoureuxi* Miura, 1981	8	8
Annelida	Polychaeta	Lumbrineridae	*Lumbrineris futilis* Kinberg, 1865	13	9
Annelida	Polychaeta	Lumbrineridae	*Lumbrineris luciliae* Martins, Carrera-Parra, Quintino & Rodrigues, 2012	4	2
Annelida	Polychaeta	Lumbrineridae	*Lumbrineris lusitanica* Martins, Carrera-Parra, Quintino & Rodrigues, 2012	270	63
Annelida	Polychaeta	Lumbrineridae	*Lumbrineris* sp.	1	1
Annelida	Polychaeta	Sabellariidae	*Lygdamis muratus* (Allen, 1904)	1	1
Annelida	Polychaeta	Eunicidae	*Lysidice ninetta* Audouin & H Milne Edwards, 1833	1	1
Annelida	Polychaeta	Eunicidae	*Lysidice unicornis* (Grube, 1840)	6	5
Annelida	Polychaeta	Ampharetidae	*Lysippe labiata* Malmgren, 1866	24	8
Annelida	Polychaeta	Acrocirridae	*Macrochaeta* sp.	1	1
Annelida	Polychaeta	Magelonidae	*Magelona alleni* Wilson, 1958	124	30
Annelida	Polychaeta	Magelonidae	*Magelona filiformis* Wilson, 1959	441	40
Annelida	Polychaeta	Magelonidae	*Magelona johnstoni* Fiege, Licher & Mackie, 2000	2804	44
Annelida	Polychaeta	Magelonidae	*Magelona lusitanica* Mortimer, Gil & Fiege, 2011	5	3
Annelida	Polychaeta	Magelonidae	*Magelona minuta* Eliason, 1962	111	25
Annelida	Polychaeta	Magelonidae	*Magelona wilsoni* Glémarec, 1966	17	13
Annelida	Polychaeta	Spionidae	*Malacoceros fuliginosus* (Claparède, 1870)	2	1
Annelida	Polychaeta	Maldanidae	*Maldane glebifex* Grube, 1860	7	6
Annelida	Polychaeta	Maldanidae	Maldanidae n.i.	2	2
Annelida	Polychaeta	Polynoidae	*Malmgrenia andreapolis* McIntosh, 1874	10	7
Annelida	Polychaeta	Polynoidae	*Malmgrenia arenicolae* (de Saint Joseph, 1888)	1	1
Annelida	Polychaeta	Polynoidae	*Malmgrenia castanea* (McIntosh, 1876)	5	3
Annelida	Polychaeta	Polynoidae	*Malmgrenia darbouxi* Pettibone, 1993	17	9
Annelida	Polychaeta	Polynoidae	*Malmgrenia lilianae* Petttibone, 1993	1	1
Annelida	Polychaeta	Polynoidae	*Malmgrenia ljungmani* (Malmgren, 1867)	399	59
Annelida	Polychaeta	Polynoidae	*Malmgrenia lunulata* (Delle Chiaje, 1830)	10	9
Annelida	Polychaeta	Polynoidae	*Malmgrenia mcintoshi* (Tebble & Chambers, 1982)	20	4
Annelida	Polychaeta	Eunicidae	*Marphysa bellii* (Audouin & Milne Edwards, 1833)	19	12
Annelida	Polychaeta	Eunicidae	*Marphysa kinbergi* McIntosh, 1910	1	1
Annelida	Polychaeta	Capitellidae	*Mediomastus fragilis* Rasmussen, 1973	5931	97
Annelida	Polychaeta	Ampharetidae	*Melinna cristata* (M. Sars, 1851)	1	1
Annelida	Polychaeta	Ampharetidae	*Melinna palmata* Grube, 1870	2	1
Annelida	Polychaeta	Ampharetidae	*Melinna* sp.1	1	1
Annelida	Polychaeta	Chaetopteridae	*Mesochaetopterus sagittarius* (Claparède, 1870)	342	36
Annelida	Polychaeta	Maldanidae	*Microclymene tricirrata* Arwidsson, 1906	8	6
Annelida	Polychaeta	Nephtyidae	*Micronephthys minuta* (Théel, 1879)	1	1
Annelida	Polychaeta	Nephtyidae	*Micronephthys* sp.	3	3
Annelida	Polychaeta	Hesionidae	*Microphthalmus similis* Bobretzky, 1870	5	3
Annelida	Polychaeta	Hesionidae	*Microphthalmus* sp.	1	1
Annelida	Polychaeta	Spionidae	*Microspio mecznikowianus* (Claparède, 1869)	3	1
Annelida	Polychaeta	Cirratulidae	*Monticellina heterochaeta* Laubier, 1961	196	40
Annelida	Polychaeta	Cirratulidae	*Monticellina* sp.	2	2
Annelida	Polychaeta	Syllidae	*Myrianida brachycephala* (Marenzeller, 1874)	13	6
Annelida	Polychaeta	Oweniidae	*Myriochele danielsseni* Hansen, 1878	38	5
Annelida	Polychaeta	Phyllodocidae	*Mysta picta* (Quatrefages, 1866)	3	3
Annelida	Polychaeta	Terebellidae	*Neoamphitrite figulus* (Dalyell, 1853)	4	3
Annelida	Polychaeta	Nephtyidae	*Nephtys assimilis* Örsted, 1843	42	24
Annelida	Polychaeta	Nephtyidae	*Nephtys cirrosa* Ehlers, 1868	124	26
Annelida	Polychaeta	Nephtyidae	*Nephtys hombergii* Savigny in Lamarck, 1818	39	18
Annelida	Polychaeta	Nephtyidae	*Nephtys incisa* Malmgren, 1865	30	15
Annelida	Polychaeta	Nephtyidae	*Nephtys kersivalensis* McIntosh, 1908	114	43
Annelida	Polychaeta	Nephtyidae	*Nephtys* sp.	8	5
Annelida	Polychaeta	Nereididae	*Nereis zonata* Malmgren, 1867	7	6
Annelida	Polychaeta	Lumbrineridae	*Ninoe armoricana* Glémarec, 1968	12	9
Annelida	Polychaeta	Onuphidae	*Nothria britannica* (McIntosh, 1903)	2	1
Annelida	Polychaeta	Onuphidae	*Nothria* sp.	9	4
Annelida	Polychaeta	Capitellidae	*Notomastus latericeus* Sars, 1851	205	72
Annelida	Polychaeta	Syllidae	*Odontosyllis fulgurans* (Audouin & Milne Edwards, 1833)	1	1
Annelida	Polychaeta	Syllidae	*Odontosyllis gibba* Claparède, 1863	5	4
Annelida	Polychaeta	Opheliidae	*Ophelia celtica* Amoureux & Dauvin, 1981	46	7
Annelida	Polychaeta	Opheliidae	*Ophelia neglecta* Schneider, 1892	4	3
Annelida	Polychaeta	Opheliidae	*Ophelia roscoffensis* Augener, 1910	9	7
Annelida	Polychaeta	Opheliidae	*Ophelina minima* Hartmann-Schröder, 1974	5	1
Annelida	Polychaeta	Orbiniidae	*Orbinia sertulata* (Savigny, 1822)	2	2
Annelida	Polychaeta	Oweniidae	*Owenia fusiformis* Delle Chiaje, 1844	331	27
Annelida	Polychaeta	Hesionidae	*Oxydromus flexuosus* (Delle Chiaje, 1827)	6	5
Annelida	Polychaeta	Hesionidae	*Oxydromus pallidus* Claparède, 1864	145	38
Annelida	Polychaeta	Syllidae	*Palposyllis prosostoma* Hartmann-Schröder, 1977	15	9
Annelida	Polychaeta	Paraonidae	*Paradoneis armata* Glémarec, 1966	9	4

Phylum	Class	Family	Species name	A	O
Annelida	Polychaeta	Paralacydoniidae	*Paralacydonia paradoxa* Fauvel, 1913	23	19
Annelida	Polychaeta	Terebellidae	*Paramphitrite tetrabranchia* Holthe, 1976	5	3
Annelida	Polychaeta	Phyllodocidae	*Paranaitis kosteriensis* (Malmgren, 1867)	7	6
Annelida	Polychaeta	Syllidae	*Parapionosyllis brevicirra* Day, 1954	12	5
Annelida	Polychaeta	Syllidae	*Parapionosyllis cabezali* Parapar, San Martín & Moreira, 2000	14	7
Annelida	Polychaeta	Spionidae	*Paraprionospio pinnata* (Ehlers, 1901)	27	16
Annelida	Polychaeta	Sabellidae	*Parasabella* sp.	1	1
Annelida	Polychaeta	Syllidae	*Parexogone hebes* (Webster & Benedict, 1884)	1	1
Annelida	Polychaeta	Syllidae	*Parexogone* sp.	1	1
Annelida	Polychaeta	Pectinariidae	*Petta pusilla* Malmgren, 1866	2	2
Annelida	Polychaeta	Pholoidae	*Pholoe synophthalmica* Claparède, 1868	1	1
Annelida	Polychaeta	Phyllodocidae	*Phyllodoce lineata* (Claparède, 1870)	8	6
Annelida	Polychaeta	Phyllodocidae	*Phyllodoce longipes* Kinberg, 1866	16	10
Annelida	Polychaeta	Phyllodocidae	*Phyllodoce maculata* (Linnaeus, 1767)	3	3
Annelida	Polychaeta	Phyllodocidae	*Phyllodoce rosea* (McIntosh, 1877)	27	13
Annelida	Polychaeta	Phyllodocidae	*Phyllodoce* sp.	1	1
Annelida	Polychaeta	Pilargidae	Pilargidae n.i.	1	1
Annelida	Polychaeta	Sigalionidae	*Pisione guanche* San Martín, López & Núñez, 1999	1	1
Annelida	Polychaeta	Sigalionidae	*Pisione inkoi* Martinez, Aguirrezabalaga & Adarraga, 2008	1	1
Annelida	Polychaeta	Sigalionidae	*Pisione parapari* Moreira, Quintas & Troncoso, 2000	2766	38
Annelida	Polychaeta	Sigalionidae	*Pisione remota* (Southern, 1914)	1211	64
Annelida	Polychaeta	Terebellidae	*Pista cristata* (Müller, 1776)	206	43
Annelida	Polychaeta	Terebellidae	*Pista lornensis* (Pearson, 1969)	7	6
Annelida	Polychaeta	Syllidae	*Plakosyllis brevipes* Hartmann-Schröder, 1956	57	22
Annelida	Polychaeta	Nereididae	*Platynereis dumerilii* (Audouin & Milne Edwards, 1834)	2	2
Annelida	Polychaeta	Hesionidae	*Podarkeopsis capensis* (Day, 1963)	8	8
Annelida	Polychaeta	Poecilochaetidae	*Poecilochaetus serpens* Allen, 1904	66	37
Annelida	Polychaeta	Terebellidae	*Polycirrus haematodes* (Claparède, 1864)	10	1
Annelida	Polychaeta	Terebellidae	*Polycirrus medusa* Grube, 1850	227	61
Annelida	Polychaeta	Spionidae	*Polydora ciliata* (Johnston, 1838)	9	3
Annelida	Polychaeta	Spionidae	*Polydora cornuta* Bosc, 1802	3	2
Annelida	Polychaeta	Polygordiidae	*Polygordius appendiculatus* Fraipont, 1887	6447	73
Annelida	Polychaeta	Sabellidae	*Potamilla torelli* (Malmgren, 1866)	58	13
Annelida	Polychaeta	Maldanidae	*Praxillella affinis* (M. Sars in G.O. Sars, 1872)	1	1
Annelida	Polychaeta	Maldanidae	*Praxillella gracilis* (M. Sars, 1861)	3	2
Annelida	Polychaeta	Maldanidae	*Praxillella praetermissa* (Malmgren, 1865)	2	2
Annelida	Polychaeta	Maldanidae	*Praxillura longissima* Arwidsson, 1906	1	1
Annelida	Polychaeta	Spionidae	*Prionospio aluta* Maciolek, 1985	6	6
Annelida	Polychaeta	Spionidae	*Prionospio ehlersi* Fauvel, 1928	101	24
Annelida	Polychaeta	Spionidae	*Prionospio fallax* Söderström, 1920	427	40
Annelida	Polychaeta	Spionidae	*Prionospio multibranchiata* Berkeley, 1927	115	30
Annelida	Polychaeta	Spionidae	*Prionospio pulchra* Imajima, 1990	26	12
Annelida	Polychaeta	Spionidae	*Prionospio* sp.	541	56
Annelida	Polychaeta	Spionidae	*Prionospio* sp.2	1	1
Annelida	Polychaeta	Spionidae	*Prionospio steenstrupi* Malmgren, 1867	70	14
Annelida	Polychaeta	Syllidae	*Prosphaerosyllis campoyi* (San Martín, Acero, Contonente & Gomez, 1982)	1	1
Annelida	Polychaeta	Dorvilleidae	*Protodorvillea kefersteini* (McIntosh, 1869)	2071	73
Annelida	Polychaeta	Hesionidae	*Psamathe fusca* Johnston, 1836	308	51
Annelida	Polychaeta	Phyllodocidae	*Pseudomystides limbata* (Saint-Joseph, 1888)	88	28
Annelida	Polychaeta	Spionidae	*Pseudopolydora antennata* (Claparède, 1869)	40	11
Annelida	Polychaeta	Ampharetidae	*Pterolysippe vanelli* (Fauvel, 1936)	12	7
Annelida	Polychaeta	Capitellidae	*Pulliella* sp.	216	41
Annelida	Polychaeta	Polynoidae	*Robertianella* sp.	2	1
Annelida	Polychaeta	Sabellariidae	*Sabellaria spinulosa* (Leuckart, 1849)	7	5
Annelida	Polychaeta	Sabellariidae	Sabellariidae n.i.	1	1
Annelida	Polychaeta	Sabellidae	Sabellidae n.i.	2	2
Annelida	Polychaeta	Saccocirridae	*Saccocirrus papillocercus* Bobretzky, 1872	234	4
Annelida	Polychaeta	Syllidae	*Salvatoria* sp.	34	11
Annelida	Polychaeta	Ampharetidae	*Samytha sexcirrata* (M. Sars, 1856)	6	3
Annelida	Polychaeta	Onuphidae	*Sarsonuphis bihanica* (Intes and le Loeuff, 1975)	424	31
Annelida	Polychaeta	Scalibregmatidae	*Scalibregma celticum* Mackie, 1991	21	13
Annelida	Polychaeta	Scalibregmatidae	*Scalibregma inflatum* Rathke, 1843	11	8
Annelida	Polychaeta	Dorvilleidae	*Schistomeringos neglecta* (Fauvel, 1923)	28	10
Annelida	Polychaeta	Dorvilleidae	*Schistomeringos rudolphi* (Delle Chiaje, 1828)	12	10
Annelida	Polychaeta	Spionidae	*Scolelepis (Parascolelepis) tridentata* (Southern, 1914)	24	10
Annelida	Polychaeta	Spionidae	*Scolelepis (Scolelepis) cantabra* (Rioja, 1918)	2	2
Annelida	Polychaeta	Spionidae	*Scolelepis (Scolelepis) squamata* (O.F. Muller, 1806)	47	8
Annelida	Polychaeta	Spionidae	*Scolelepis bonnieri* (Mesnil, 1896)	6	5
Annelida	Polychaeta	Spionidae	*Scolelepis* sp.	35	2

Phylum	Class	Family	Species name	A	O
Annelida	Polychaeta	Lumbrineridae	*Scoletoma impatiens* (Claparède, 1868)	1	1
Annelida	Polychaeta	Lumbrineridae	*Scoletoma* sp.	1	1
Annelida	Polychaeta	Lumbrineridae	*Scoletoma* sp.1	1	1
Annelida	Polychaeta	Lumbrineridae	*Scoletoma* sp.2	1	1
Annelida	Polychaeta	Orbiniidae	*Scoloplos (Scoloplos) armiger* (Müller, 1776)	31	15
Annelida	Polychaeta	Orbiniidae	*Scoloplos typicus* (Eisig, 1914)	5	4
Annelida	Polychaeta	Serpulidae	Serpulidae n.i.	5	5
Annelida	Polychaeta	Sigalionidae	*Sigalion mathildae* Audouin & Milne Edwards in Cuvier, 1830	54	24
Annelida	Polychaeta	Sigalionidae	*Sigalion squamosus* Delle Chiaje, 1830	1	1
Annelida	Polychaeta	Pilargidae	*Sigambra parva* (Day, 1963)	3	2
Annelida	Polychaeta	Ampharetidae	*Sosane sulcata* Malmgren, 1866	1	1
Annelida	Polychaeta	Syllidae	*Sphaerosyllis bulbosa* Southern, 1914	601	52
Annelida	Polychaeta	Syllidae	*Sphaerosyllis hystrix* Claparède, 1863	71	30
Annelida	Polychaeta	Syllidae	*Sphaerosyllis* sp.	174	14
Annelida	Polychaeta	Syllidae	*Sphaerosyllis taylori* Perkins, 1981	71	20
Annelida	Polychaeta	Spionidae	*Spio decoratus* Bobretzky, 1870	113	29
Annelida	Polychaeta	Spionidae	*Spio filicornis* (Müller, 1776)	3347	63
Annelida	Polychaeta	Chaetopteridae	*Spiochaetopterus solitarius* (Rioja, 1917)	58	28
Annelida	Polychaeta	Spionidae	Spionidae n.i.	7	5
Annelida	Polychaeta	Spionidae	*Spiophanes bombyx* (Claparède, 1870)	568	65
Annelida	Polychaeta	Spionidae	*Spiophanes kroyeri* Grube, 1860	117	38
Annelida	Polychaeta	Serpulidae	*Spiraserpula massiliensis* (Zibrowius, 1968)	3	2
Annelida	Polychaeta	Serpulidae	*Spirobranchus lamarcki* (Quatrefages, 1866)	33	5
Annelida	Polychaeta	Serpulidae	*Spirobranchus triqueter* (Linnaeus, 1758)	126	6
Annelida	Polychaeta	Sternaspidae	*Sternaspis scutata* Ranzani, 1817	4	4
Annelida	Polychaeta	Sigalionidae	*Sthenelais limicola* (Ehlers, 1864)	70	25
Annelida	Polychaeta	Terebellidae	*Streblosoma bairdi* (Malmgren, 1866)	1	1
Annelida	Polychaeta	Syllidae	*Streptodonta pterochaeta* (Southern, 1914)	38	15
Annelida	Polychaeta	Syllidae	*Streptosyllis bidentata* Southern, 1914	15	9
Annelida	Polychaeta	Syllidae	*Syllidae juvenile*	2	2
Annelida	Polychaeta	Syllidae	*Syllides convolutus* Webster & Benedict, 1884	3	2
Annelida	Polychaeta	Syllidae	*Syllides edentatus* Westheide, 1974	1	1
Annelida	Polychaeta	Hesionidae	*Syllidia armata* Quatrefages, 1866	21	13
Annelida	Polychaeta	Syllidae	*Syllis garciai* (Campoy, 1982)	409	53
Annelida	Polychaeta	Syllidae	*Syllis gerlachi* (Hartmann-Schröder, 1960)	2	2
Annelida	Polychaeta	Syllidae	*Syllis licheri* Ravara, San Martín & Moreira, 2004	116	31
Annelida	Polychaeta	Syllidae	*Syllis mercedesae* Lucas, San Martín & Parapar, 2012	10	2
Annelida	Polychaeta	Syllidae	*Syllis parapari* San Martín & López, 2000	1	1
Annelida	Polychaeta	Syllidae	*Syllis pontxioi* San Martín & López, 2000	72	21
Annelida	Polychaeta	Syllidae	*Syllis pulvinata* (Langerhans, 1881)	3	3
Annelida	Polychaeta	Syllidae	*Synmerosyllis lamelligera* (Saint-Joseph, 1886)	49	14
Annelida	Polychaeta	Terebellidae	Terebellidae juvenile	3	3
Annelida	Polychaeta	Terebellidae	Terebellidae n.i.	4	3
Annelida	Polychaeta	Trichobranchidae	*Terebellides stroemii* Sars, 1835	62	22
Annelida	Polychaeta	Echiuridae	*Thalassema thalassemum* (Pallas, 1766)	3	3
Annelida	Polychaeta	Cirratulidae	*Tharyx* sp.	6	4
Annelida	Polychaeta	Trichobranchidae	*Trichobranchus roseus* (Malm, 1874)	2	2
Annelida	Polychaeta	Trichobranchidae	*Trichobranchus* sp.	1	1
Annelida	Polychaeta	Syllidae	*Trypanosyllis (Trypanosyllis) coeliaca* Claparède, 1868	162	27
Annelida	Polychaeta	Syllidae	*Xenosyllis scabra* (Ehlers, 1864)	11	4
Arthropoda*	Hexanauplia	Scalpellidae	*Scalpellum scalpellum* (Linnaeus, 1767)	4	2
Arthropoda*	Hexanauplia	Archaeobalanidae	*Semibalanus balanoides* (Linnaeus, 1767)	2	2
Arthropoda	Insecta	Insecta n.i.	Insecta n.i.	1	1
Arthropoda*	Malacostraca	Melitidae	*Abludomelita gladiosa* (Bate, 1862)	10	2
Arthropoda*	Malacostraca	Melitidae	*Abludomelita obtusata* (Montagu, 1813)	15	9
Arthropoda*	Malacostraca	Mysidae	*Acanthomysis longicornis* (Milne Edwards, 1837)	1	1
Arthropoda*	Malacostraca	Acidostomatidae	*Acidostoma obesum* (Bate & Westwood, 1861)	2	1
Arthropoda*	Malacostraca	Alpheidae	*Alpheus glaber* (Olivi, 1792)	12	9
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca armoricana* Bellan-Santini & Dauvin, 1981	45	14
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca brevicornis* (Costa, 1853)	232	40
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca calypsonis* Bellan-Santini & Kaim-Malka, 1977	4	2
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca dalmatina* Karaman, 1975	10	5
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca diadema* (Costa, 1853)	5	5
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca heterodactyla* Schellenberg, 1925	11	2
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca pectenata* Reid, 1951	10	6
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca pseudosarsi* Bellan-Santini & Kaim-Malka, 1977	10	8
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca ruffoi* Bellan-Santini & Kaim-Malka, 1977	10	7
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca sarsi* Chevreux, 1888	5	4
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca* sp.	5	5

Phylum	Class	Family	Species name	A	O
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca spinimana* Chevreux, 1900	94	13
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca spinipes* Boeck, 1861	68	26
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca tenuicornis* Lilljeborg, 1855	14	8
Arthropoda*	Malacostraca	Ampeliscidae	*Ampelisca typica* (Bate, 1856)	25	8
Arthropoda*	Malacostraca	Amphilochidae	*Amphilochus spencebatei* (Stebbing, 1876)	3	3
Arthropoda*	Malacostraca	Ampithoidae	*Ampithoe gammaroides* (Bate, 1856)	1	1
Arthropoda*	Malacostraca	Paguridae	*Anapagurus hyndmanni* (Bell, 1846)	11	7
Arthropoda*	Malacostraca	Paguridae	*Anapagurus laevis* (Bell, 1846)	16	14
Arthropoda*	Malacostraca	Paguridae	*Anapagurus pusillus* Henderson, 1888	3	3
Arthropoda*	Malacostraca	Mysidae	*Anchialina agilis* (G.O. Sars, 1877)	10	5
Arthropoda*	Malacostraca	Maeridae	*Animoceradocus semiserratus* (Bate, 1862)	76	18
Arthropoda*	Malacostraca	Anthuridae	Anthuridae n.i.	6	1
Arthropoda*	Malacostraca	Aoridae	*Aora spinicornis* Afonso, 1976	9	5
Arthropoda*	Malacostraca	Calliopiidae	*Apherusa bispinosa* (Bate, 1857)	300	30
Arthropoda*	Malacostraca	Calliopiidae	*Apherusa cirrus* (Bate, 1862)	1	1
Arthropoda*	Malacostraca	Calliopiidae	*Apherusa jurinei* Milne Edwards, 1830	4	4
Arthropoda*	Malacostraca	Amphilochidae	*Apolochus neapolitanus* (Della Valle, 1893)	2	1
Arthropoda*	Malacostraca	Apseudidae	*Apseudopsis latreillii* (Milne Edwards, 1828)	21	8
Arthropoda*	Malacostraca	Argissidae	*Argissa hamatipes* (Norman, 1869)	7	6
Arthropoda*	Malacostraca	Arcturidae	*Astacilla dilatata* Sars, 1882	4	3
Arthropoda*	Malacostraca	Arcturidae	*Astacilla* sp.	2	2
Arthropoda*	Malacostraca	Atelecyclidae	*Atelecyclus rotundatus* (Olivi, 1792)	4	3
Arthropoda*	Malacostraca	Alpheidae	*Athanas nitescens* (Leach, 1813 [in Leach, 1813-1814])	1	1
Arthropoda*	Malacostraca	Atylidae	*Atylus vedlomensis* (Bate & Westwood, 1862)	34	15
Arthropoda*	Malacostraca	Aoridae	*Autonoe spiniventris* Della Valle, 1893	51	30
Arthropoda*	Malacostraca	Bathyporeiidae	*Bathyporeia elegans* Watkin, 1938	21	6
Arthropoda*	Malacostraca	Bathyporeiidae	*Bathyporeia gracilis* Sars, 1891	25	5
Arthropoda*	Malacostraca	Bathyporeiidae	*Bathyporeia guilliamsoniana* (Bate, 1857)	6	3
Arthropoda*	Malacostraca	Bathyporeiidae	*Bathyporeia nana* Toulmond, 1966	1	1
Arthropoda*	Malacostraca	Bathyporeiidae	*Bathyporeia pelagica* (Bate, 1856)	9	1
Arthropoda*	Malacostraca	Bathyporeiidae	*Bathyporeia pilosa* Lindström, 1855	7	1
Arthropoda*	Malacostraca	Bathyporeiidae	*Bathyporeia sarsi* Watkin, 1938	13	6
Arthropoda*	Malacostraca	Bathyporeiidae	*Bathyporeia tenuipes* Meinert, 1877	34	15
Arthropoda*	Malacostraca	Bodotriidae	*Bodotria scorpioides* (Montagu, 1804)	93	10
Arthropoda*	Malacostraca	Diastylidae	*Brachydiastylis resima* (Krøyer, 1846)	1	1
Arthropoda*	Malacostraca	Callianassidae	*Callianassa subterranea* (Montagu, 1808)	59	24
Arthropoda*	Malacostraca	Nannastacidae	*Campylaspis glabra* Sars, 1878	44	12
Arthropoda*	Malacostraca	Caprellidae	*Caprella lilliput* Krapp-Schickel & Ruffo, 1987	78	12
Arthropoda*	Malacostraca	Caprellidae	*Caprella penantis* Leach, 1814	1	1
Arthropoda*	Malacostraca	Cheirocratidae	*Cheirocratus assimilis* (Lilljeborg, 1852)	4	1
Arthropoda*	Malacostraca	Cheirocratidae	*Cheirocratus sundevalli* (Rathke, 1843)	371	39
Arthropoda*	Malacostraca	Cirolanidae	*Conilera cylindracea* (Montagu, 1804)	9	4
Arthropoda*	Malacostraca	Anthuridae	*Cortezura* sp.	10	4
Arthropoda*	Malacostraca	Corystidae	*Corystes cassivelaunus* (Pennant, 1777)	1	1
Arthropoda*	Malacostraca	Crangonidae	*Crangon crangon* (Linnaeus, 1758)	8	5
Arthropoda*	Malacostraca	Sphaeromatidae	*Cymodoce truncata* Leach, 1814	49	12
Arthropoda*	Malacostraca	Oedicerotidae	*Deflexilodes subnudus* (Norman, 1889)	1	1
Arthropoda*	Malacostraca	Diastylidae	*Diastylis bradyi* Norman, 1879	133	24
Arthropoda*	Malacostraca	Diogenidae	*Diogenes pugilator* (Roux, 1829)	35	12
Arthropoda*	Malacostraca	Dulichiidae	*Dulichia* sp.	3	2
Arthropoda*	Malacostraca	Leucosiidae	*Ebalia granulosa* H. Milne Edwards, 1837	5	5
Arthropoda*	Malacostraca	Leucosiidae	*Ebalia nux* A. Milne-Edwards, 1883	10	8
Arthropoda*	Malacostraca	Leucosiidae	*Ebalia tuberosa* (Pennant, 1777)	2	2
Arthropoda*	Malacostraca	Leucosiidae	*Ebalia tumefacta* (Montagu, 1808)	10	7
Arthropoda*	Malacostraca	Entoniscidae	Entoniscidae n.i.	1	1
Arthropoda*	Malacostraca	Bodotriidae	*Eocuma dimorphum* Fage, 1928	1	1
Arthropoda*	Malacostraca	Bodotriidae	*Eocuma dollfusi* Calman, 1907	2	2
Arthropoda*	Malacostraca	Hippolytidae	*Eualus cranchii* (Leach, 1817 [in Leach, 1815-1875])	1	1
Arthropoda*	Malacostraca	Cirolanidae	*Eurydice naylori* Jones & Pierpoint, 1997	70	25
Arthropoda*	Malacostraca	Cirolanidae	*Eurydice pulchra* Leach, 1815	6	4
Arthropoda*	Malacostraca	Cirolanidae	*Eurydice spinigera* Hansen, 1890	17	8
Arthropoda*	Malacostraca	Majidae	*Eurynome spinosa* Hailstone, 1835	2	2
Arthropoda*	Malacostraca	Eusiridae	*Eusirus longipes* Boeck, 1861	1	1
Arthropoda*	Malacostraca	Galatheidae	*Galathea intermedia* Lilljeborg, 1851	233	35
Arthropoda*	Malacostraca	Galatheidae	*Galathea strigosa* (Linnaeus, 1761)	1	1
Arthropoda*	Malacostraca	Nuuanuidae	*Gammarella fucicola* (Leach, 1814)	21	4
Arthropoda*	Malacostraca	Photidae	*Gammaropsis maculata* (Johnston, 1828)	16	7
Arthropoda*	Malacostraca	Photidae	*Gammaropsis sophiae* (Boeck, 1861)	7	5
Arthropoda*	Malacostraca	Mysidae	*Gastrosaccus sanctus* (Van Beneden, 1861)	108	3

Phylum	Class	Family	Species name	A	O
Arthropoda*	Malacostraca	Gnathiidae	*Gnathia oxyuraea* (Lilljeborg, 1855)	12	8
Arthropoda*	Malacostraca	Goneplacidae	*Goneplax rhomboides* (Linnaeus, 1758)	12	9
Arthropoda*	Malacostraca	Dexaminidae	*Guernea (Guernea) coalita* (Norman, 1868)	175	34
Arthropoda*	Malacostraca	Mysidae	*Haplostylus normani* (G.O. Sars, 1877)	70	24
Arthropoda*	Malacostraca	Phoxocephalidae	*Harpinia antennaria* Meinert, 1890	61	16
Arthropoda*	Malacostraca	Phoxocephalidae	*Harpinia truncata* Sars, 1891	1	1
Arthropoda*	Malacostraca	Haustoriidae	*Haustorius arenarius* (Slabber, 1769)	1	1
Arthropoda*	Malacostraca	Mysidae	*Heteromysis (Heteromysis) formosa* Smith, 1873	2	1
Arthropoda*	Malacostraca	Lysianassidae	*Hippomedon denticulatus* (Bate, 1857)	30	20
Arthropoda*	Malacostraca	Hyperiidae	*Hyperia* sp.	2	2
Arthropoda*	Malacostraca	Janiridae	*Ianiropsis breviremis* (Sars, 1883)	8	4
Arthropoda*	Malacostraca	Liljeborgiidae	*Idunella excavata* (Schecke, 1973)	31	8
Arthropoda*	Malacostraca	Liljeborgiidae	*Idunella longirostris* (Chevreux, 1920)	12	8
Arthropoda*	Malacostraca	Liljeborgiidae	*Idunella picta* (Norman, 1889)	5	2
Arthropoda*	Malacostraca	Iphimediidae	*Iphimedia minuta* G.O. Sars, 1882	1	1
Arthropoda*	Malacostraca	Bodotriidae	*Iphinoe serrata* Norman, 1867	1	1
Arthropoda*	Malacostraca	Bodotriidae	*Iphinoe trispinosa* (Goodsir, 1843)	64	18
Arthropoda*	Malacostraca	Isaeidae	*Isaea montagui* Milne Edwards, 1830	1	1
Arthropoda*	Malacostraca	Janiridae	*Janira maculosa* Leach, 1814	3	2
Arthropoda*	Malacostraca	Ischyroceridae	*Jassa falcata* (Montagu, 1808)	3	3
Arthropoda*	Malacostraca	Laomediidae	*Jaxea nocturna* Nardo, 1847	2	2
Arthropoda*	Malacostraca	Lysianassidae	*Lepidepecreum longicornis* (Bate & Westwood, 1862)	4	2
Arthropoda*	Malacostraca	Corophiidae	*Leptocheirus hirsutimanus* (Bate, 1862)	59	7
Arthropoda*	Malacostraca	Corophiidae	*Leptocheirus pectinatus* (Norman, 1869)	50	13
Arthropoda*	Malacostraca	Corophiidae	*Leptocheirus tricristatus* (Chevreux, 1887)	4	3
Arthropoda*	Malacostraca	Mysidae	*Leptomysis gracilis* (G.O. Sars, 1864)	2	2
Arthropoda*	Malacostraca	Leucothoidae	*Leucothoe incisa* (Robertson, 1892)	182	55
Arthropoda*	Malacostraca	Leucothoidae	*Leucothoe lilljeborgi* Boeck, 1861	3	2
Arthropoda*	Malacostraca	Leucothoidae	*Leucothoe procera* Bate, 1857	3	3
Arthropoda*	Malacostraca	Liljeborgiidae	*Liljeborgia pallida* (Bate, 1857)	2	2
Arthropoda*	Malacostraca	Polybiidae	*Liocarcinus holsatus* (Fabricius, 1798)	1	1
Arthropoda*	Malacostraca	Polybiidae	*Liocarcinus pusillus* (Leach, 1816)	29	20
Arthropoda*	Malacostraca	Lophogastridae	*Lophogaster typicus* M. Sars, 1857	2	2
Arthropoda*	Malacostraca	Lysianassidae	*Lysianassa insperata* (Lincoln, 1979)	7	7
Arthropoda*	Malacostraca	Maeridae	*Maera grossimana* (Montagu, 1808)	6	2
Arthropoda*	Malacostraca	Maeridae	*Maera inaequipes* (Costa, 1857)	1	1
Arthropoda*	Malacostraca	Maeridae	*Maerella tenuimana* (Bate, 1862)	2	2
Arthropoda*	Malacostraca	Megaluropidae	*Megaluropus agilis* Hoeck, 1889	51	19
Arthropoda*	Malacostraca	Photidae	*Megamphopus cornutus* Norman, 1869	119	32
Arthropoda*	Malacostraca	Euphausiidae	*Meganyctiphanes norvegica* (M. Sars, 1857)	3	3
Arthropoda*	Malacostraca	Melitidae	*Melita valesi* Karaman, 1955	9	2
Arthropoda*	Malacostraca	Phoxocephalidae	*Metaphoxus fultoni* (Scott, 1890)	41	12
Arthropoda*	Malacostraca	Phoxocephalidae	*Metaphoxus pectinatus* (Walker, 1896)	1	1
Arthropoda*	Malacostraca	Stenothoidae	*Metopella* sp.	48	12
Arthropoda*	Malacostraca	Paguridae	*Michelopagurus atlanticus* (Bouvier, 1922)	1	1
Arthropoda*	Malacostraca	Aoridae	*Microdeutopus armatus* Chevreux, 1886	17	6
Arthropoda*	Malacostraca	Aoridae	*Microdeutopus chelifer* (Bate, 1862)	2	2
Arthropoda*	Malacostraca	Janiridae	*Microjaera anisopoda* Bocquet & Levi, 1955	86	12
Arthropoda*	Malacostraca	Microprotopidae	*Microprotopus longimanus* Chevreux, 1887	1	1
Arthropoda*	Malacostraca	Oedicerotidae	*Monoculodes carinatus* (Bate, 1857)	23	14
Arthropoda*	Malacostraca	Munididae	*Munida tenuimana* Sars, 1872	1	1
Arthropoda*	Malacostraca	Munnidae	*Munna kroyeri* Goodsir, 1842	1	1
Arthropoda*	Malacostraca	Mysidae	*Mysideis insignis* (G.O. Sars, 1864)	1	1
Arthropoda*	Malacostraca	Cirolanidae	*Natatolana gallica* (Hansen, 1905)	2	2
Arthropoda*	Malacostraca	Cirolanidae	*Natatolana* sp.	7	5
Arthropoda*	Malacostraca	Nebaliidae	*Nebalia troncosoi* Moreira, Cacabelos & Dominguez, 2003	12	4
Arthropoda*	Malacostraca	Callianassidae	*Necallianassa truncata* (Giard & Bonnier, 1890)	106	27
Arthropoda*	Malacostraca	Atylidae	*Nototropis falcatus* (Metzger, 1871)	25	15
Arthropoda*	Malacostraca	Atylidae	*Nototropis swammerdamei* (Milne Edwards, 1830)	2	2
Arthropoda*	Malacostraca	Oedoceratidae	Oedoceratidae n.i.	1	1
Arthropoda*	Malacostraca	Lysianassidae	*Orchomene similis* (Chevreux, 1912)	48	7
Arthropoda*	Malacostraca	Maeridae	*Othomaera othonis* (Milne Edwards, 1830)	357	34
Arthropoda*	Malacostraca	Paguridae	*Pagurus chevreuxi* (Bouvier, 1896)	8	7
Arthropoda*	Malacostraca	Paguridae	*Pagurus cuanensis* Bell, 1846	1	1
Arthropoda*	Malacostraca	Paguridae	*Pagurus excavatus* (Herbst, 1791)	1	1
Arthropoda*	Malacostraca	Pandalidae	*Pandalina brevirostris* (Rathke, 1843)	6	6
Arthropoda*	Malacostraca	Caprellidae	*Pariambus typicus* (Krøyer, 1884)	173	22
Arthropoda*	Malacostraca	Oedicerotidae	*Perioculodes longimanus* (Bate & Westwood, 1868)	52	32
Arthropoda*	Malacostraca	Crangonidae	*Philocheras bispinosus bispinosus* (Hailstone, 1835)	31	17

Phylum	Class	Family	Species name	A	O
Arthropoda*	Malacostraca	Crangonidae	*Philocheras trispinosus* (Hailstone in Hailstone & Westwood, 1835)	6	5
Arthropoda*	Malacostraca	Photidae	*Photis longicaudata* (Bate & Westwood, 1862)	7	3
Arthropoda*	Malacostraca	Caprellidae	*Phtisica marina* Slabber, 1769	11	8
Arthropoda*	Malacostraca	Porcellanidae	*Pisidia longicornis* (Linnaeus, 1767)	2	1
Arthropoda*	Malacostraca	Polybiidae	*Polybius henslowii* Leach, 1820	5	4
Arthropoda*	Malacostraca	Oedicerotidae	*Pontocrates altamarinus* (Bate & Westwood, 1862)	20	7
Arthropoda*	Malacostraca	Oedicerotidae	*Pontocrates arenarius* (Bate, 1858)	27	15
Arthropoda*	Malacostraca	Portunidae	*Portumnus latipes* (Pennant, 1777)	1	1
Arthropoda*	Malacostraca	Processidae	*Processa modica modica* Williamson in Williamson & Rochanaburanon, 1979	5	5
Arthropoda*	Malacostraca	Processidae	*Processa nouveli holthuisi* Al-Adhub & Williamson, 1975	42	17
Arthropoda*	Malacostraca	Eriopisidae	*Psammogammarus caecus* Karaman, 1955	89	18
Arthropoda*	Malacostraca	Caprellidae	*Pseudolirius kroyeri* (Haller, 1897)	1	1
Arthropoda*	Malacostraca	Caprellidae	*Pseudoprotella phasma* (Montagu, 1804)	1	1
Arthropoda*	Malacostraca	Nebaliidae	*Sarsinebalia cristoboi* Moreira, Gestoso & Troncoso, 2003	317	32
Arthropoda*	Malacostraca	Nebaliidae	*Sarsinebalia urgorrii* Moreira, Gestoso & Troncoso, 2003	1	1
Arthropoda*	Malacostraca	Mysidae	*Schistomysis ornata* (G.O. Sars, 1864)	7	4
Arthropoda*	Malacostraca	Mysidae	*Schistomysis spiritus* (Norman, 1860)	2	2
Arthropoda*	Malacostraca	Ischyroceridae	*Siphonoecetes (Centraloecetes) striatus* Myers & McGrath, 1979	1	1
Arthropoda*	Malacostraca	Lysianassidae	*Socarnes erythrophthalmus* Robertson, 1892	488	24
Arthropoda*	Malacostraca	Stenothoidae	*Stenothoe marina* (Bate, 1856)	34	10
Arthropoda*	Malacostraca	Oedicerotidae	*Synchelidium haplocheles* (Grube, 1864)	1	1
Arthropoda*	Malacostraca	Oedicerotidae	*Synchelidium maculatum* Stebbing, 1906	7	7
Arthropoda*	Malacostraca	Synopiidae	*Syrrhoites pusilla* Enequist, 1949	3	2
Arthropoda*	Malacostraca	Tanaidacea n.i.	Tanaidacea n.i.	42	11
Arthropoda*	Malacostraca	Thiidae	*Thia scutellata* (Fabricius, 1793)	2	2
Arthropoda*	Malacostraca	Uristidae	*Tmetonyx similis* (Sars, 1891)	1	1
Arthropoda*	Malacostraca	Lysianassidae	*Tryphosa nana* (Krøyer, 1846)	1	1
Arthropoda*	Malacostraca	Lysianassidae	*Tryphosella sarsi* Bonnier, 1893	36	6
Arthropoda*	Malacostraca	Lysianassidae	*Tryphosites longipes* (Bate & Westwood, 1861)	7	3
Arthropoda*	Malacostraca	Unciolidae	*Unciola crenatipalma* (Bate, 1862)	4	2
Arthropoda*	Malacostraca	Upogebiidae	*Upogebia deltaura* (Leach, 1815)	11	6
Arthropoda*	Malacostraca	Upogebiidae	*Upogebia stellata* (Montagu, 1808)	1	1
Arthropoda*	Malacostraca	Urothoidae	*Urothoe brevicornis* Bate, 1862	16	2
Arthropoda*	Malacostraca	Urothoidae	*Urothoe elegans* (Bate, 1857)	14	5
Arthropoda*	Malacostraca	Urothoidae	*Urothoe grimaldii* Chevreux, 1895	22	9
Arthropoda*	Malacostraca	Urothoidae	*Urothoe marina* (Bate, 1857)	11	4
Arthropoda*	Malacostraca	Urothoidae	*Urothoe poseidonis* Reibish, 1905	5	4
Arthropoda*	Malacostraca	Urothoidae	*Urothoe pulchella* (Costa, 1853)	121	24
Arthropoda*	Malacostraca	Bodotriidae	*Vaunthompsonia cristata* Bate, 1858	2	1
Arthropoda*	Malacostraca	Oedicerotidae	*Westwoodilla caecula* (Bate, 1857)	5	4
Arthropoda*	Ostracoda	Ostracoda n.i.	Ostracoda n.i.	22	16
Arthropoda*	Pycnogonida	Ammotheidae	Ammotheidae n.i.	2	1
Chaetognatha	Chaetognatha	Chaetognatha n.i.	Chaetognatha n.i.	52	27
Chordata	Actinopteri	Callionymidae	*Callionymus lyra* Linnaeus, 1758	3	3
Chordata	Actinopteri	Gobiesocidae	*Lepadogaster candolii* Risso, 1810	3	2
Chordata	Actinopteri	Gobiidae	*Pomatoschistus minutus* (Pallas, 1770)	1	1
Chordata	Leptocardii	Branchiostomatidae	*Branchiostoma lanceolatum* (Pallas, 1774)	165	40
Cnidaria	Anthozoa	Anthozoa n.i.	Anthozoa n.i.	12	6
Cnidaria	Anthozoa	Anthozoa n.i.	Anthozoa sp.2	1	1
Cnidaria	Anthozoa	Edwardsiidae	*Edwardsia claparedii* (Panceri, 1869)	461	47
Cnidaria	Anthozoa	Edwardsiidae	*Edwardsiella carnea* (Gosse, 1856)	1	1
Cnidaria	Anthozoa	Haloclavidae	*Peachia cylindrica* (Reid, 1848)	1	1
Cnidaria	Anthozoa	Pennatulidae	*Pennatula phosphorea* Linnaeus, 1758	3	2
Cnidaria	Anthozoa	Scleractinia n.i.	Scleractinia n.i.	2	2
Cnidaria	Anthozoa	Veretillidae	*Veretillum cynomorium* (Pallas, 1766)	1	1
Cnidaria	Cnidaria	Cnidaria n.i.	Cnidaria n.i.	3	3
Cnidaria	Hydrozoa	Hydrozoa n.i.	Hydrozoa n.i.	2	2
Echinodermata	Asteroidea	Asterinidae	*Asterina gibbosa* (Pennant, 1777)	2	2
Echinodermata	Asteroidea	Astropectinidae	*Astropecten irregularis* (Pennant, 1777)	2	2
Echinodermata	Crinoidea	Antedonidae	*Antedon bifida* (Pennant, 1777)	2	1
Echinodermata	Crinoidea	Antedonidae	*Leptometra celtica* (M'Andrew & Barrett, 1857)	2	1
Echinodermata	Echinoidea	Brissidae	*Brissopsis atlantica mediterranea* Mortensen, 1913	1	1
Echinodermata	Echinoidea	Brissidae	*Brissopsis lyrifera* (Forbes, 1841)	4	4
Echinodermata	Echinoidea	Loveniidae	*Echinocardium cordatum* (Pennant, 1777)	27	19
Echinodermata	Echinoidea	Loveniidae	*Echinocardium flavescens* (O.F. Müller, 1776)	19	12
Echinodermata	Echinoidea	Loveniidae	*Echinocardium mortenseni* Thiéry, 1909	1	1
Echinodermata	Echinoidea	Echinocyamidae	*Echinocyamus pusillus* (O.F. Müller, 1776)	429	63
Echinodermata	Echinoidea	Parechinidae	*Paracentrotus lividus* (Lamarck, 1816)	12	2
Echinodermata	Echinoidea	Parechinidae	*Psammechinus miliaris* (P.L.S. Müller, 1771)	9	7

Phylum	Class	Family	Species name	A	O
Echinodermata	Echinoidea	Spatangidae	*Spatangus raschi* Lovén, 1869	1	1
Echinodermata	Echinoidea	Strongylocentrotidae	*Strongylocentrotus pallidus* (Sars G.O., 1872)	3	2
Echinodermata	Holothuroidea	Cucumariidae	*Cucumaria frondosa* (Gunnerus, 1767)	4	3
Echinodermata	Holothuroidea	Cucumariidae	*Ekmania barthii* (Troschel, 1846)	2	1
Echinodermata	Holothuroidea	Holothuroidea n.i.	Holothuroidea n.i.	2	2
Echinodermata	Holothuroidea	Synaptidae	*Labidoplax media* Östergren, 1905	3	2
Echinodermata	Holothuroidea	Cucumariidae	*Leptopentacta elongata* (Düben & Koren, 1846)	5	5
Echinodermata	Holothuroidea	Cucumariidae	*Leptopentacta tergestina* (M. Sars, 1857)	1	1
Echinodermata	Holothuroidea	Synaptidae	*Leptosynapta inhaerens* (O.F. Müller, 1776)	19	15
Echinodermata	Holothuroidea	Synaptidae	*Leptosynapta* sp.	3	2
Echinodermata	Holothuroidea	Cucumariidae	*Ocnus brunneus* (Forbes in Thompson, 1840)	1	1
Echinodermata	Holothuroidea	Cucumariidae	*Ocnus planci* (Brandt, 1835)	1	1
Echinodermata	Holothuroidea	Synaptidae	*Oestergrenia digitata* (Montagu, 1815)	24	14
Echinodermata	Holothuroidea	Phyllophoridae	*Thyone inermis* Heller, 1868	2	2
Echinodermata	Ophiuroidea	Amphiuridae	*Acrocnida brachiata* (Montagu, 1804)	23	15
Echinodermata	Ophiuroidea	Amphiuridae	*Amphipholis squamata* (Delle Chiaje, 1828)	20	6
Echinodermata	Ophiuroidea	Amphiuridae	*Amphiura (Amphiura) incana* Lyman, 1879	3	3
Echinodermata	Ophiuroidea	Amphiuridae	*Amphiura (Ophiopeltis) securigera* (Düben & Koren, 1846)	108	11
Echinodermata	Ophiuroidea	Amphiuridae	*Amphiura chiajei* Forbes, 1843	331	45
Echinodermata	Ophiuroidea	Amphiuridae	*Amphiura filiformis* (O.F. Müller, 1776)	196	30
Echinodermata	Ophiuroidea	Ophiuridae	*Ophiocten affinis* (Lütken, 1858)	7	4
Echinodermata	Ophiuroidea	Ophiocomidae	*Ophiopsila annulosa* (M. Sars, 1859)	1	1
Echinodermata	Ophiuroidea	Ophiocomidae	*Ophiopsila aranea* Forbes, 1843	4	4
Echinodermata	Ophiuroidea	Ophiuridae	*Ophiura albida* Forbes, 1839	38	21
Echinodermata	Ophiuroidea	Ophiuridae	*Ophiura ophiura* (Linnaeus, 1758)	11	8
Echinodermata	Ophiuroidea	Ophiuridae	*Ophiura robusta* (Ayres, 1854)	7	3
Echinodermata	Ophiuroidea	Ophiuridae	*Ophiura* sp.	32	9
Echinodermata	Ophiuroidea	Ophiurida n.i.	Ophiurida n.i.	1	1
Mollusca	Bivalvia	Semelidae	*Abra alba* (W. Wood, 1802)	128	37
Mollusca	Bivalvia	Semelidae	*Abra nitida* (O. F. Müller, 1776)	3	3
Mollusca	Bivalvia	Semelidae	*Abra prismatica* (Montagu, 1808)	14	9
Mollusca	Bivalvia	Cardiidae	*Acanthocardia aculeata* (Linnaeus, 1758)	2	1
Mollusca	Bivalvia	Anomiidae	*Anomia ephippium* Linnaeus, 1758	3	3
Mollusca	Bivalvia	Tellinidae	*Arcopagia crassa* (Pennant, 1777)	4	4
Mollusca	Bivalvia	Astartidae	*Astarte borealis* (Schumacher, 1817)	3	2
Mollusca	Bivalvia	Astartidae	*Astarte sulcata* (da Costa, 1778)	1	1
Mollusca	Bivalvia	Pinnidae	*Atrina fragilis* (Pennant, 1777)	1	1
Mollusca	Bivalvia	Cuspidariidae	*Cardiomya costellata* (Deshayes, 1835)	2	2
Mollusca	Bivalvia	Veneridae	*Chamelea gallina* (Linnaeus, 1758)	2	2
Mollusca	Bivalvia	Veneridae	*Chamelea striatula* (da Costa, 1778)	31	19
Mollusca	Bivalvia	Pectinidae	*Chlamys tigerina* (O. F. Müller, 1776)	7	5
Mollusca	Bivalvia	Veneridae	*Clausinella fasciata* (da Costa, 1778)	14	9
Mollusca	Bivalvia	Corbulidae	*Corbula gibba* (Olivi, 1792)	28	14
Mollusca	Bivalvia	Cuspidariidae	*Cuspidaria rostrata* (Spengler, 1793)	2	2
Mollusca	Bivalvia	Astartidae	*Digitaria digitaria* (Linnaeus, 1758)	31	10
Mollusca	Bivalvia	Ungulinidae	*Diplodonta rotundata* (Montagu, 1803)	11	5
Mollusca	Bivalvia	Donacidae	*Donax vittatus* (da Costa, 1778)	1	1
Mollusca	Bivalvia	Veneridae	*Dosinia exoleta* (Linnaeus, 1758)	2	2
Mollusca	Bivalvia	Veneridae	*Dosinia lupinus* (Linnaeus, 1758)	27	19
Mollusca	Bivalvia	Pharidae	*Ensis* sp.	1	1
Mollusca	Bivalvia	Psammobiidae	*Gari costulata* (Turton, 1822)	66	23
Mollusca	Bivalvia	Psammobiidae	*Gari tellinella* (Lamarck, 1818)	47	10
Mollusca	Bivalvia	Glycymerididae	*Glycymeris glycymeris* (Linnaeus, 1758)	92	22
Mollusca	Bivalvia	Glycymerididae	*Glycymeris nummaria* (Linnaeus, 1758)	3	1
Mollusca	Bivalvia	Veneridae	*Gouldia minima* (Montagu, 1803)	7	4
Mollusca	Bivalvia	Hiatellidae	*Hiatella arctica* (Linnaeus, 1767)	1	1
Mollusca	Bivalvia	Montacutidae	*Kurtiella bidentata* (Montagu, 1803)	137	26
Mollusca	Bivalvia	Cardiidae	*Laevicardium crassum* (Gmelin, 1791)	9	8
Mollusca	Bivalvia	Lasaeidae	Lasaeidae n.i.	3	3
Mollusca	Bivalvia	Limidae	*Limaria loscombi* (G. B. Sowerby I, 1823)	1	1
Mollusca	Bivalvia	Lucinidae	*Loripes* sp.	7	1
Mollusca	Bivalvia	Mactridae	*Mactra stultorum* (Linnaeus, 1758)	20	10
Mollusca	Bivalvia	Pectinidae	*Mimachlamys varia* (Linnaeus, 1758)	1	1
Mollusca	Bivalvia	Mytilidae	*Modiolus barbatus* (Linnaeus, 1758)	2	2
Mollusca	Bivalvia	Tellinidae	*Moerella distorta* (Poli, 1791)	1	1
Mollusca	Bivalvia	Tellinidae	*Moerella donacina* (Linnaeus, 1758)	40	25
Mollusca	Bivalvia	Veneridae	*Mysia undata* (Pennant, 1777)	15	10
Mollusca	Bivalvia	Nuculidae	*Nucula nitidosa* Winckworth, 1930	27	10
Mollusca	Bivalvia	Pectinidae	*Palliolum incomparabile* (Risso, 1826)	1	1

Phylum	Class	Family	Species name	A	O
Mollusca	Bivalvia	Cardiidae	*Parvicardium pinnulatum* (Conrad, 1831)	1	1
Mollusca	Bivalvia	Cardiidae	*Parvicardium scabrum* (Philippi, 1844)	3	2
Mollusca	Bivalvia	Cardiidae	*Parvicardium* sp.	3	1
Mollusca	Bivalvia	Pharidae	*Pharus legumen* (Linnaeus, 1758)	17	9
Mollusca	Bivalvia	Pharidae	*Phaxas pellucidus* (Pennant, 1777)	61	25
Mollusca	Bivalvia	Nuculidae	*Pronucula tenuis* Powell, 1927	2	1
Mollusca	Bivalvia	Nuculanidae	*Saccella commutata* (Philippi, 1844)	16	8
Mollusca	Bivalvia	Semelidae	*Scrobicularia plana* (da Costa, 1778)	1	1
Mollusca	Bivalvia	Solecurtidae	*Solecurtus scopula* (Turton, 1822)	1	1
Mollusca	Bivalvia	Mactridae	*Spisula elliptica* (Brown, 1827)	55	23
Mollusca	Bivalvia	Mactridae	*Spisula solida* (Linnaeus, 1758)	23	7
Mollusca	Bivalvia	Mactridae	*Spisula subtruncata* (da Costa, 1778)	33	13
Mollusca	Bivalvia	Montacutidae	*Tellimya ferruginosa* (Montagu, 1808)	28	19
Mollusca	Bivalvia	Montacutidae	*Tellimya* sp.	1	1
Mollusca	Bivalvia	Tellinidae	*Tellina compressa* Brocchi, 1814	32	11
Mollusca	Bivalvia	Tellinidae	*Tellina fabula* Gmelin, 1791	163	33
Mollusca	Bivalvia	Tellinidae	*Tellina pygmaea* Lovén, 1846	113	28
Mollusca	Bivalvia	Tellinidae	*Tellina serrata* Brocchi, 1814	1	1
Mollusca	Bivalvia	Tellinidae	*Tellina* sp.	1	1
Mollusca	Bivalvia	Thraciidae	*Thracia phaseolina* (Lamarck, 1818)	6	5
Mollusca	Bivalvia	Thraciidae	*Thracia villosiuscula* (MacGillivray, 1827)	255	49
Mollusca	Bivalvia	Thyasiridae	*Thyasira flexuosa* (Montagu, 1803)	44	16
Mollusca	Bivalvia	Thyasiridae	*Thyasira* sp.	27	5
Mollusca	Bivalvia	Veneridae	*Timoclea ovata* (Pennant, 1777)	9	4
Mollusca	Bivalvia	Veneridae	*Venerupis corrugata* (Gmelin, 1791)	1	1
Mollusca	Bivalvia	Veneridae	*Venus casina* Linnaeus, 1758	4	4
Mollusca	Gastropoda	Acteonidae	*Acteon tornatilis* (Linnaeus, 1758)	2	2
Mollusca	Gastropoda	Aporrhaidae	*Aporrhais pespelecani* (Linnaeus, 1758)	9	8
Mollusca	Gastropoda	Mangeliidae	*Bela decussata* (Locard, 1892)	1	1
Mollusca	Gastropoda	Caecidae	*Caecum* sp.	317	30
Mollusca	Gastropoda	Caecidae	*Caecum subannulatum* de Folin, 1870	6	3
Mollusca	Gastropoda	Drilliidae	*Crassopleura maravignae* (Bivona Ant. in Bivona And., 1838)	1	1
Mollusca	Gastropoda	Cylichnidae	*Cylichna cylindracea* (Pennant, 1777)	49	24
Mollusca	Gastropoda	Epitoniidae	*Epitonium pulchellum* (Bivona, 1832)	1	1
Mollusca	Gastropoda	Eulimidae	*Eulima glabra* (da Costa, 1778)	9	4
Mollusca	Gastropoda	Naticidae	*Euspira catena* (da Costa, 1778)	1	1
Mollusca	Gastropoda	Naticidae	*Euspira nitida* (Donovan, 1804)	79	35
Mollusca	Gastropoda	Fasciolariidae	*Fusinus rostratus* (Olivi, 1792)	1	1
Mollusca	Gastropoda	Gastropoda n.i.	Gastropoda n.i.	1	1
Mollusca	Gastropoda	Trochidae	*Gibbula* sp.	16	5
Mollusca	Gastropoda	Trochidae	*Gibbula varia* (Linnaeus, 1758)	13	4
Mollusca	Gastropoda	Hydrobiidae	*Hydrobia acuta neglecta* Muus, 1963	5	2
Mollusca	Gastropoda	Trochidae	*Jujubinus* sp.	1	1
Mollusca	Gastropoda	Eulimidae	*Melanella frielei* (Jordan, 1895)	3	1
Mollusca	Gastropoda	Eulimidae	*Melanella polita* (Linnaeus, 1758)	5	3
Mollusca	Gastropoda	Nassariidae	*Nassarius ovoideus* (Locard, 1886)	2	2
Mollusca	Gastropoda	Nassariidae	*Nassarius reticulatus* (Linnaeus, 1758)	75	34
Mollusca	Gastropoda	Nudibranchia n.i.	Nudibranchia n.i.	1	1
Mollusca	Gastropoda	Pyramidellidae	*Ondina* sp.	1	1
Mollusca	Gastropoda	Philinidae	*Philine* sp.	1	1
Mollusca	Gastropoda	Rissoidae	*Plagyostila asturiana* P. Fischer in de Folin, 1872	1	1
Mollusca	Gastropoda	Ringiculidae	*Ringicula* sp.	1	1
Mollusca	Gastropoda	Ovulidae	*Simnia* sp.	2	1
Mollusca	Gastropoda	Muricidae	*Trophon* sp.	2	2
Mollusca	Gastropoda	Pyramidellidae	*Turbonilla* sp.	2	2
Mollusca	Gastropoda	Turritellidae	*Turritella communis* Risso, 1826	2	1
Mollusca	Gastropoda	Turritellidae	*Turritella turbona* Monterosato, 1877	1	1
Mollusca	Gastropoda	Eulimidae	*Vitreolina incurva* (Bucquoy, Dautzenberg & Dollfus, 1883)	1	1
Mollusca	Polyplacophora	Leptochitonidae	*Leptochiton algesirensis* (Capellini, 1859)	1	1
Mollusca	Polyplacophora	Leptochitonidae	*Leptochiton alveolus* (M. Sars MS, Lovén, 1846)	1	1
Mollusca	Polyplacophora	Leptochitonidae	*Leptochiton asellus* (Gmelin, 1791)	7	2
Mollusca	Polyplacophora	Leptochitonidae	*Leptochiton cancellatus* (Sowerby, 1840)	12	7
Mollusca	Polyplacophora	Polyplacophora n.i.	Polyplacophora n.i.	1	1
Mollusca	Scaphopoda	Dentaliidae	*Antalis entalis* (Linnaeus, 1758)	1	1
Mollusca	Scaphopoda	Dentaliidae	*Antalis vulgaris* (da Costa, 1778)	2	2
Mollusca	Scaphopoda	Fustiariidae	*Fustiaria rubescens* (Deshayes, 1825)	2	2
Nemertea	Nemertea	Nemertea n.i.	Nemertea n.i.	2522	129
Phoronida	Phoronida n.i.	Phoronida n.i.	Phoronida n.i.	175	44
Platyhelminthes	Platyhelminthes n.i.	Platyhelminthes n.i.	Platyhelminthes n.i.	57	15

Phylum	**Class**	**Family**	**Species name**	**A**	**O**
Platyhelminthes	Turbellaria	Turbellaria n.i.	Turbellaria n.i.	10	7
Sipuncula	Phascolosomatidea	Aspidosiphonidae	*Aspidosiphon (Aspidosiphon) muelleri muelleri* Diesing, 1851	32	12
Sipuncula	Phascolosomatidea	Phascolosomatidae	*Phascolosoma (Phascolosoma) granulatum* Leuckart, 1828	1	1
Sipuncula	Sipuncula n.i.	Sipuncula n.i.	Sipuncula n.i.	18	8
Sipuncula	Sipunculidea	Golfingiidae	*Golfingia (Golfingia) elongata* (Keferstein, 1862)	20	9
Sipuncula	Sipunculidea	Golfingiidae	*Golfingia (Golfingia) vulgaris vulgaris* (de Blainville, 1827)	3	3
Sipuncula	Sipunculidea	Golfingiidae	*Golfingia* sp.	1	1
Sipuncula	Sipunculidea	Phascolionidae	*Onchnesoma magnibathum* Cutler, 1969	4	2
Sipuncula	Sipunculidea	Phascolionidae	*Onchnesoma steenstrupii steenstrupii* Koren & Danielssen, 1876	105	30
Sipuncula	Sipunculidea	Phascolionidae	*Phascolion (Phascolion) strombus strombus* (Montagu, 1804)	11	7