METHODOLOGY FOR POSITIONING A GROUP OF GREEN ARTIFICIAL REEF BASED ON A DATABASE MANAGEMENT SYSTEM, APPLIED IN THE ESTUARY OF ARES-BETANZOS (NW IBERIAN PENINSULA)

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ABSTRACT

The Galician coast, and particularly its estuaries are ecosystems with a large biological production which require protection against the strong human pressure they suffer. Sustainability in fishing, shell fishing and recreational activities makes it advisable to develop measures such as the implementation of green artificial reefs (AR), which promote wealth and biodiversity in areas that stand out due to their productive capacity.

This document proposes a database management system (DBMS) to determine the position of the AR groups, based on geographic information systems (GIS) combined with high resolution numerical modelling and the development of computational algorithms. This system will be capable of analysing a large amount of spatial information regarding socio-economic and environmental factors that affect their installation.

The methodology considered in the DBMS takes into account ***production factors*** and ***economic factors related to construction and maintenance***. This combination allows for the identification of the best locations for the functional development of the AR group with low implementation costs. The DBMS is applied to the Ria of Ares-Betanzos leading to the definition of the most suitable places for installing AR groups in this area.

Key words: Green Artificial Reef; Database Management System; Coastal Dynamics

1. INTRODUCTION

Management of coastal areas has become an important concern for society due to the impact of human activities on the quality of the environment and of the water, and the need to optimise the aquaculture strategy (Bacher et al, 2003). These issues are of particular importance in Galicia (NW Spain) where the coastal areas, and especially its estuaries, have been recognized for their enormous uniqueness and importance as a support for population, productive activities, biological diversity and source of resources (Carral et al, 2018a).

Currently, the estuaries face the challenge of solving deep environmental and socio-economic problems. The estuaries are high-capacity ecosystems that function as areas for breeding and rearing marine organisms, many of them with a high economic value; thus, it is of great interest to know the biological resources available in these ecosystems, their internal dynamics and how to take advantage of them, protect them and foster them effectively.

At the same time, one of the recommended measures to redress the loss of structural complexity of the communities, the decrease of breeding areas and the alteration of trophic networks is the implantation of artificial reefs (AR) in the environment (Seaman *et al*., 1989; Pickering, *et al*., 1998; Barnabé, et al., 2000; Haround and Herrera, 2000 and Whitmarsh, *et al*., 2008); however, for their proper functioning it is utterly necessary to take into account the possible impacts that these structures could have on the aquatic environment (Sanders and Ruiz, 2007; Thiony *et al*., 2011).

The placement of AR seeks to imitate some of the characteristics of a natural reef (OSPAR, 1996) in order to obtain benefits such as: the **conservation of resources** by reducing the pressure on existing reefs, the **restoration of the substrate** due to the settlement of communities of invertebrates and algae in the AR, the **improvement in fishing production** and even new applications such as **nautical tourism** and the **recreational use of the sea** (Seaman, 2002; ;Seaman, 2007; Pears and Williams, 2005).

The goal of the PROARR Research Project is to design production and protection modules for the construction of artificial reef groups adapted to the characteristics of the Galician Region. As a result, green AR production and protection modules have been developed, with the purpose of acting as agents for repopulating marine ecosystems and recovering artisan fishery (Carral et al, 2018a). The modules resulting from the project have been patented (Fig. 2) (Carral et al, 2018b), and the estuary of Ares-Betanzos has been designated as the coastal area for the installation of an experimental reef group (Carral et al, 2018a).

Fig. 1. Location of the Ares - Betanzos estuaries in the NE region of Spain. Source: Own

The estuary of Ares-Betanzos is located between the estuaries of A Coruña and Ferrol covering an area of roughly 72 km^2. It is the largest of the six estuaries located between Cape Finisterre and Cape Prior, on the Northwest coast of the Iberian Peninsula (Fig. 1). It is a double estuary system (Asensio-Amor&Grajal-Blanco, 1981), with a volume of 0,75 km^3 and a length of 19 km, consisting of two branches: i) Ares, with the estuary of the river Eume and ii) Betanzos with the estuary of the river Mandeo.

The drainage of the Eume River located in the north part of the estuary (roadstead of Ares and Redes), with an average discharge of 16.5 m^3/s, is an important determinant of the hydrographic conditions in the area (Prego et al, 1999): (Sánchez Mata et al, 1999). In addition, the rivers Mandeo, Mendo and Lambre discharge through the Betanzos marsh using the tidal channels, with an average annual flow of 14.1 m^{3}s^{-1}. The two sectors converge in an area of confluence that is freely connected to the Atlantic Ocean through a 40m deep and 4km wide NW oriented mouth (Fig. 4).

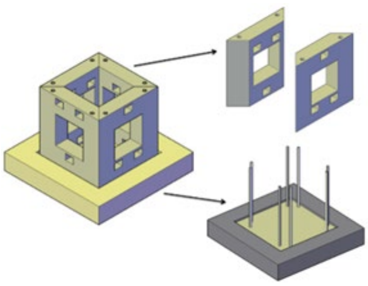

Fig. 2- Artificial Reef Module PROARR. Source: Own

Previous studies in the Ria de Ares-Betanzos have focused on the diversity and productivity of phytoplankton (Blanco, 1985; Mariño et al., 1985; Bode y Varela, 1998), nutrient distributions (Prego et al, 1999) and the physical-chemical structure of the benthic environment (Sanchez-Mata et al., 1999) or the relationship between tidal circulation and ecosystem metabolism (Villegas-Ríos et al., 2011). The latter authors implemented a 2-D model to integrate the physical, chemical and biological data and estimate the flows between the internal and external parts of the Ria. They concluded that, *in comparison with the Rias Baixas, tidal circulation in the Ria de Ares-Betanzos is positive even in upwelling and downwelling conditions as a result of the greater importance of river flows* (Villegas-Ríos et al., 2011). In Lamas et al, (2019) the hydrodynamic improvement of the PROARR modules is studied. In Rodríguez-Guerreiro et al (2019) the temporal pattern of the biological development of an AR located in this Ria was studied.

2. METHODOLOGY AND OBJECTIVES

The goal of the present investigation is to identify the most appropriate areas for the installation of an AR group in the Ria of Ares and Betanzos. To this end, a **database management system (DBMS)** is developed, based on a **geographic information system (GIS), combined** with a high-resolution numerical modelling and the development of computational algorithms capable of analysing a large amount of spatial information related to socio-economic and environmental factors affecting the installation of an AR.

The methodology developed to determine the position of AR groups is based on the consideration of *production factors* grouped by types of conditions: ***excluding factors, functional factors*** (bathymetric, geomorphological, technical) and *the* ***economic factors*** *of construction and maintenance* (table 1). This combination allows the identification of the best places for the functional development of the AR with low implementations costs.

Excluding production factors will be those that are related to the restrictive use within each area, i.e., taken into consideration (protected natural areas, areas in use by maritime transport / anchorage, areas for aquaculture / mussel farming). The individual consideration of each of the indicated functions precludes the implementation of the AR group in the areas in which one of these activities takes place, as shown in the exclusion flow diagram (Fig. 3).

Functional production factors will be those that allow the full development of the functions assigned to the AR, as defined by Carral et al (2018a). *The degree of compliance with the established target benefits will act as a measure of this adequacy*. In any case, the consideration of the functional factors will allow to classify each zone according to its possibilities to reach the established objective benefits.

From the consideration of these latter functional factors, there is a classification into **bathymetric** (depth), **geomorphological** (nature of the bottom) and **technical** (magnitude of the currents that supplies the nutrients to the AR) factors, since all of these are factors that condition the productivity of the AR.

An adequate magnitude of the water velocity and an appropriate hydrodynamic pattern lead to an increase in the contribution and renewal of favourable nutrients for the larval settlement (Perkol-Finckel el al., 2007) (Piedracoba et al, 2014), along with a reduction in the sedimentation. Sedimentation is inversely related to the movement of water, and it has been observed that a high rate of sedimentation is detrimental to the life of the reef, inhibiting, among other factors, the exchange of nutrients and dissolved gases (Smith et al., 1971; Aller y Dodge, 1974; Loya, 1976; Bak, 1978).

Finally, we must take into account **economic factors** that will affect the installation due to the costs of implementation and conservation of the AR group.

Table 1 - Factors to be considered for the development of the green AR positioning methodology. Source: Own

Types of factors for green AA	**PRODUCTION**			
	FACTORS PRODUCTION		**ECONOMIC**	
	EXCLUDING	FUNCTIONAL	CAPEX	OPEX
Type of factors	Maritime Traffic Anchoring areas Conservation Area Aquaculture Planning	Bathymetric, Geomorphological, Technical	Conception & Definition Design & Development Manufacturing Installation	Scientific Supervision Exploitation Costs
Model	**EXCLUIDING CHART FLOW DIAGRAM**	**NUMERICAL MODEL**		

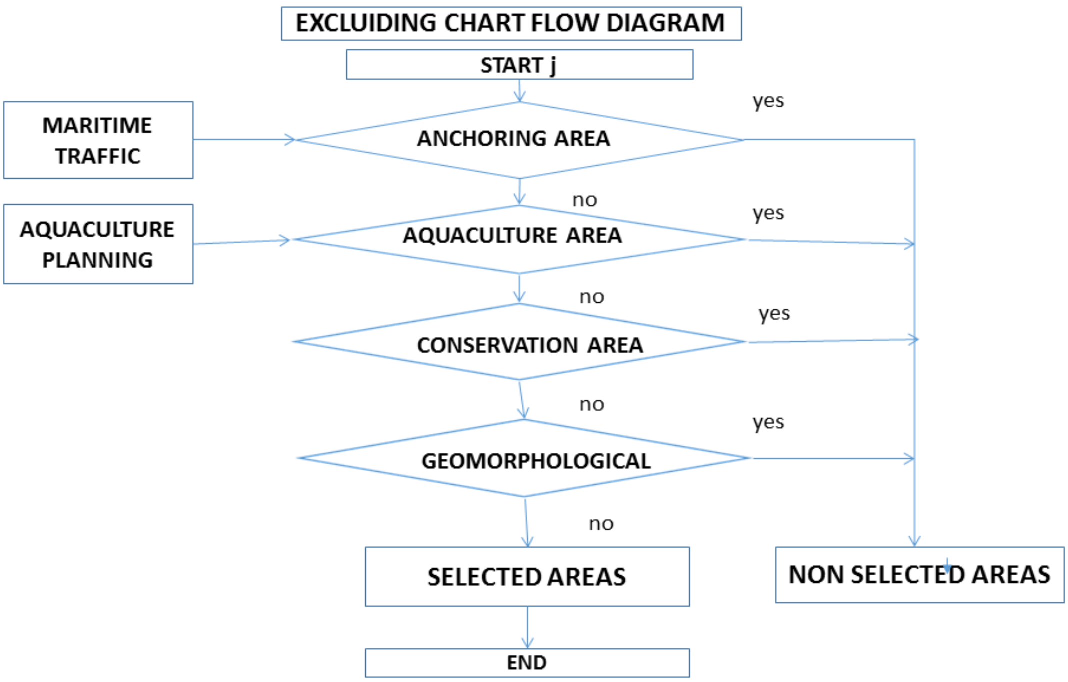

Fig. 3 - Flow chart for the application of exclusion criteria. Source: Own

In order to carry out an appropriate analysis of the established factors and thus determine the most suitable area for the positioning of an AR group in the Ria of Ares-Betanzos, it is necessary to generate and analyse a large amount of information, which is obtained through two procedures: i) collection of existing information; ii) implementation of high-resolution numerical models that are simulated during characteristic scenarios following specific methodologies. The resulting information is incorporated into a GIS (Geographic Information System), and several computational algorithms are developed allowing the manipulation of the data generated and computation of various parameters of interest. In this way, a powerful tool (DBMS) is made available leading to an informed decision-making process when defining the optimum location to install an AR group.

The specific methodologies used for the analysis of the different factors are presented in sections 3 and 4. Section 5 presents the process carried out for the implementation of the developed DBMS, as well as the results obtained, which are synthesized in the most relevant conclusions in section 6.

3. SOCIOECONOMIC AND HYDROMORPHOLOGICAL CHARACTERISTICS

3.1. Use of the coastline

The specific characteristics of a coastal area may condition or even restrict the installation of an AR. In this context, the Galician rias are characterized by their great economic, social and environmental importance, which is associated with the presence of numerous uses with which the operation of an AR must not interfere.

Among the existing uses, mussel farming is of particular relevance representing one of the most notorious characteristics of the Galician coast, since the Galician Rias develop 40% of the European mussel culture and 15% of the world production of blue mussels (Labarta et al., 2004). The Ria de Ares-Betanzos supports the production of 147 mussel rafts concentrated mainly along the southern margin (Duarte et al, 2014) (Fig. 2), which produce 10,000 tonnes of blue mussel Mytitlus Galloprovinciallis per year (Labarta et al., 2004).

These mussel rafts affect the hydrodynamics of the rias, since they are built out of eucalyptus beams attached to floats which are anchored to the sea bottom with concrete blocks. Each raft has a maximum surface of 20 m x 25 m (500 m^2) and contains up to 500 ropes with a length of between 6 and 12 m (Labarta et al., 2004). The distance between neighbouring rafts within an AR group crop is about 100 m. In the case of coastal ecosystems, several studies have investigated the influence of water circulation on the their production capacity (Grant et al, 1998; Grant y Bacher, 2001). According to Shi et al. (2011), the aquaculture facility in the Sungo Bay (China) can cause a reduction of 40% in the average surface current, decreasing the exchange of water with the adjacent areas.

Therefore, understanding the hydrodynamics of the Ria de Ares-Betanzos and the influence of aquaculture facilities on the circulation of water and *vice versa* has important applications for the determination of the location of the AR groups.

However, the Galician rias are characterized by the presence of many other activities along the coast, as well as numerous areas of great environmental value. In this study, the following uses are considered excluding factors (Section 2): **i) areas of special environmental protection (LIC and ZEPA areas); ii) bivalve (mussel) reserves; iii) mussel raft polygons; iv) shellfish banks; v) fishing grounds; vi) aquaculture areas; vii) fish shelters; vii) maritime ferry routes and sea motorways; ix) maritime traffic; x) shipwrecks.**

All the currently available information regarding the aforementioned uses is incorporated into the DBMS for its analysis. In this sense, an area is considered valid for AR installation when it does not interfere from the point of view of spatial occupation with the existing uses considered as excluding ones, and therefore represent an incompatibility with the presence of ARs. Thus, it must be pointed out that the present study does not consider excluding uses those that can be easily compatible with an AR, so that their normal operation also allows for the operation of AR groups, as it is the case for the large anchoring areas of the ports of Ferrol and A Coruña that exist in the Ria.

3.2. Morphological characteristics

In addition to the socio-economic and environmental aspects, there are a number of factors that may limit the functionality of ARs, such as the morphological characteristics. Within them, the aspects that are considered as fundamental characteristics that condition the operation and maintenance of an AR are: i) the depth and ii) the nature of the bottom, both being in close relationship.

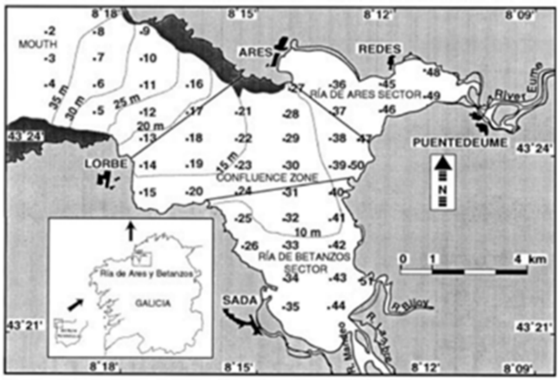

Fig. 4 -Areas of the Rias de Ares-Betanzos with indication of dimensions and depths. The latter range between 2 and 43 m. Four geographic sectors have been outlined in the study area. The Ares sector, in the main part of the estuary, is 5 km long and 2 km wide with depths of 2 to 6 m. To the south of this area, in the *Betanzos sector*, which is sheltered from the south-west winds by the Bergantiños plateau and from the north and north-west winds by the Faladoira mountain range, is 7 km long and 5 km wide with depths ranging from 2 to 12 m. The area of *confluence* of the rivers, has a depth ranging between 10 - 20 m, with a smooth bottom as a result of the sedimentary contribution of the rivers. The mouth of the Ria, which is

open to the continental shelf, is flanked on the margins by a reduced base rock and has a bottom made up of sedimentary sand with a depth of 43 m. Source: (Sánchez Mata et al, 1999)

The substrate of the sedimentary bottom of the Ria de Ares-Betanzos is distributed by three main factors: the system of water circulation within the estuary, the bathymetry and the balance of oceanic and continental flow to which the estuary is subjected to (Sánchez Mata et al, 1999).

The sedimentary structure of the Rias shows a high content of white and black sands with signs of zinc silt. The distribution of clay content is determined by the bathymetry of the two internal estuaries, characterized mainly by silt and clay at depths below 10 m and a high content of organic matter and negative redox potentials in the central area with abundant sand. The middle ría with depths between 20-30 m, and the outer ría with more than 30 m, are mainly composed by gravel and sand (Fig. 9) (Sánchez Mata et al, 1999)
For the consideration of the morphological factors, on the one hand, the information currently available regarding the bathymetric characteristics of the area is incorporated into the DBMS, for which the nautical charts of this area provided by the Instituto Hidrográfico de la Marina (IHM) are used, as well as topographic data provided by the Sociedade para o Desenvolvemento Comarcal de Galicia (SITGA, Xunta de Galicia). In this context, the operating limits are established at approximately 10 - 25 m depth in LAT (Lowest Astronomical Tide) conditions, without however a fixed criterion of limits that totally restrict the installation of an AR. On the other hand, in relation to the nature of the bottom, the distribution of the sediment types is analysed considering the information provided by the IHM together with studies of high-spatial resolution (Troncoso & Urgorri 1993). This information is also included in the DBMS for further analysis. In this sense, although as in the case of the conditions related to the bathymetric configuration, there are no fixed limitations for the installation of an AR, to ensure its stability the most suitable areas are those with a mainly sandy bottom, and rocky bottoms should be avoided as much as possible.

3.3. Hydrodynamic characteristics

The circulation of water bodies in the Galician Rias has been investigated by numerous authors (Prego & Fraga 1992). The structure of the body of water within the estuaries has a highly variable profile in response to variations in the river discharge, wind, tide (Sánchez Mata et al, 1999), and even waves in its more exposed outer area, close to the mouth. In this context, the importance of the different forcing factors can vary greatly amongst estuaries, as well as between the different areas within it (Carballo et al., 2009a; Iglesias et al., 2012), and even within the same area depending on the season (Iglesias & Carballo, 2009; Iglesias & Carballo, 2011).

The hydrography of the Ria de Ares-Betanzos is normal (Prego & Fraga, 1992) with a partially stratified mix of waters in two levels: a higher level and a lower level with higher salinity (Bowden, 1980), and a gradual transition from inland waters to marine waters (Pethick, 1984; Carter, 1988). According to McLusky (1989) the study area is a *euhaline* estuary with annual salinities of bottom waters ranging between 31 and 37 PSU (Mora et al, 1994, 1996.).

The **general system of water circulation** of this ria is characterized by an important input of groundwater that penetrates through the bottom from the open ocean (North Atlantic central water). The initial movement is towards the east, where the mass of water diverges in two currents. One of them is parallel to the coast towards the south of the estuary, in the direction of the ria / marsh of the Mandeo River, where marine and continental water mix. Then, it goes to the north and finally flows out dragging along sedimentary particles from the Eume estuary in Pontedeume (Duarte et al., 2014). The second current remains in the mouth of the ria, generating a cyclonic vortex due to the bathymetric disturbances in the area, dragging the sediments towards a nearby sedimentary area and depositing the coarse heterogeneous materials in the area of exterior oceanic influence (Sánchez Mata et al, 1999).

The phenomenon of upwelling is seen seasonally through the effects of the upwelling and downwelling events. The first in seasons of prevailing northern wind which, by means of the Ekman pumping, produces an **upwelling** in the bottom of the estuaries and an exit of the superficial waters as compensation (**positive residual circulation**) (Duarte et al., 2014). During the **downwelling** season, in which the southern winds prevail, there is an inversion of this circulation pattern, with Ekman pumping forcing surface water to enter the platform which is compensated with an outflow through the bottom layer (Piedracoba et al., 2005; Carballo et al., 2009b). Nevertheless, upwelling and downwelling are also common outside their characteristic seasons (Iglesias et al., 2008). The Ria de Ares-Betanzos, (Fig. 1), which is 4 to 7 times smaller than the Rias Baixas and oriented in a different way, shows a low influence of the upwelling effect on its bottom and, on the contrary, tidal circulation has a greater impact. Consequently, this ria has a larger circulation flow that that of the Rias Baixas (Alvarez-Salgado et al., 2011).

Sanchez – Mata et al. (1999) considers that tidal currents are more important within the estuary than wind currents or those induced by waves, determining near surface velocities of up to 0.89 ms^{-1} with a tidal range of 4.14 m. In further studies, peak velocities are estimated to be of a significantly less intensity; in particular Piedracoba et al (2014) estimate the maximum values at approx. 0.10 - 0.12 ms^{-1}.

The prevailing winds in the area under study are from north to east in spring and summer and from south to south-west in winter and autumn (Fig. 1). Field observations establish that northern storms have components that can disturb bottom sediments in the entire area, with the exception of the innermost parts of the estuary (Sánchez Mata et al, 1999).

Based on the previous research presented, in this paper several high-resolution models are implemented so that an exhaustive analysis of the hydrodynamics can be carried out in the different study areas of interest, so that those with greater potential for installation of an AR can be selected. As it has been shown, the hydrodynamics of the Galician rias are the result of the complex interaction of diverse forcings (tide, contribution of oceanic and continental waters, wind and, in certain situations, waves), which are considered by the implemented models as current generating forcing agents.

To this end, various finite difference codes are implemented. First, the numerical model DELFT3D FLOW (Deltares, 2010) that solves the Navier Stokes equations under the Shallow Waters and Boussinesq assumptions, coupled to the transport equation. This model allows the calculation of the circulation induced by all the aforementioned forcings. However, in the case of waves, it needs information on the spatial distribution of the radiation tensor resulting from the existing wave field under specific conditions. To do this, the SWAN spectral model (Booij et al., 1999) is also implemented for the wave propagation from deep water to the Ria.

The implementation of the DELFT3D model is done in its 2DH form, considering a 50 x 50 m computational mesh within the Ria (and therefore within the possible areas of interest), progressively increasing its size towards the oceanic limits located approximately 15 km from the mouth of the estuary at a depth of around 80 m (Figure 5). In relation to the SWAN model, two meshes are used: a coarse mesh for propagating the wave field from deep water towards the mouth of the Ria, and a high-resolution mesh within the Ria with the same characteristics as the computational mesh used in the DELFT3D model (Figure 6). Finally, the bathymetric and topographic characteristics incorporated within the DBMS are used to interpolate the depth values to the numerical meshes.

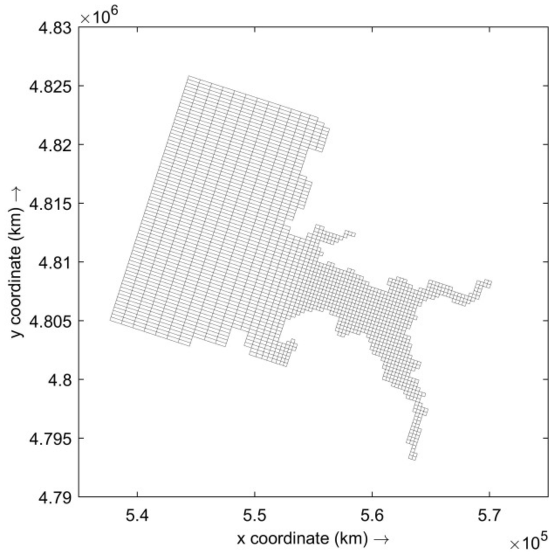

Fig. 5 - FLOW3D numerical model grid. Only 1 in 3 grid lines are shown for clarity.. Source: own

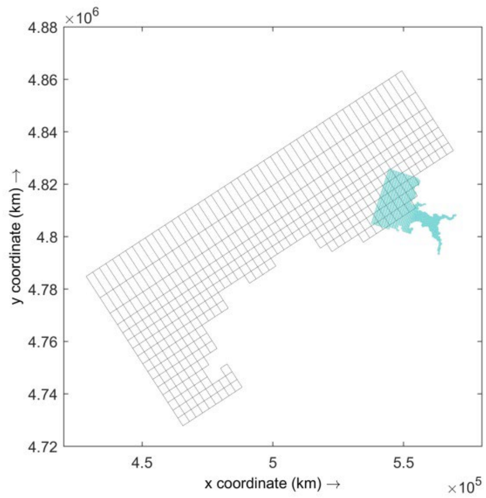

Fig. 6 -SWAN numerical model grids. Only 1 in 3 grid lines are shown for clarity.

The developed models are used to analyse the hydrodynamics of the Ria de Ares-Betanzos in three case studies: i) induced circulation in a situation of average conditions in the absence of wind and waves (Case A); ii) wind-induced circulation (Case B); iii) wave-induced circulation (Case C). The specific forcings that are considered in each case are as follows.

In Case A, the existing hydrodynamic conditions are determined considering the action of the tide during a complete cycle of average spring-neap tides, as well as the existence of annual average fresh water discharges and oceanic water mass with average thermohaline characteristics. The tide is introduced in the model considering the main tidal harmonics determined at the oceanic limit of the numerical mesh (Table 2); the characteristics of the ocean mass are obtained from the Villano-Sisargas buoy; finally, freshwater discharges are established according to previous studies (Prego et al., 1999; Sanchez-Mata el al., 1999) (Table 3).

Table 2. Main tidal constituents in the outer boundary limit of the hydrodynamic grid

Harmonic Constant	Amplitude (m)	Phase (°)
A0	2.2078	-
2SM	0.0116	289.39
Q1	0.0207	267.23
P1	0.0225	63.18
O1	0.0614	71.97
K2	0.1157	114.31
N2	0.2507	66.79
M2	1.1805	86.39
S2	0.4134	116.97

Table 3. Freshwater discharges and thermohaline conditions in Case A

Parameter	Outer boundary	Mandeo river	Eume river
Temperature (º)	16.0	13.3	11.7°
Salinity (ppt)	35.5	1	1
Q_m (m^3s^{-1})	-	14.1 $m3s^{-1}$	16.5 $m3s^{-1}$

For the hydrodynamic analysis two specific situations are considered: the situation with the greatest magnitude of the current velocity during i) spring tides, V_s, and ii) neap tides, V_n. In Case B, the wind-induced circulation is studied, considering the action of N winds favourable to the existence of upwelling processes (Duarte et al., 2014) and strong winds of 10 ms^{-1} according to previous studies in the Galician Rias (Iglesias & Carballo, 2010).

Finally, in case C, wave-induced currents are studied taking into consideration the conditions to which the Ria de Ares-Betanzos is more exposed (waves with a NW direction) and which in turn provide greater energy [spectral significant wave height, H_{m0} = 3.27 m; energy period T_e = 9.11 s] (Carballo et al., 2014).

As in the case of the previous conditions, the resulting information is incorporated into the DBMS for analysis. In this sense, although there are no established limits of the current velocity for the correct operation of an AR, it is estimated that its appropriate functioning requires the existence of velocities of 0.05 – 0.08 ms^{-1} in the case of an AR with holes that are suitable for low speeds, and greater than 0.08 ms^{-1} in the case of an AR with holes suitable for high velocities.

4. ANALYSIS OF ECONOMIC FACTORS

4.1 Procedure

The economic benefits obtained from a natural environment are commonly presented in terms of several components that, taken together, constitute the total economic value (Turner and Adger, 1996); (Ledoux and Turner, 2002). This concept also applies to the development of AR functions in the case under study (Whitmarsh et al., 2008), with the additional requirement that the production must be environmentally sustainable (Table 4). So that for each possible location Xj some benefits will correspond, which, for the case of a green AR, Carral et al, (2018a) classifies as **direct**, **indirect**, **liabilities** DB_{ij},IB_{ij}, PB_{ij} (Table 4), including among them those related to the use of inert materials derived from the recycling of waste from maritime industries (Ferreño et al, 2013). As an indirect effect, the reduction in the environmental impact of related industries in the maritime sector should be considered, while it extends the passive effects by incorporating sustainability in the activity of the canning industry.

Table 4 - Shows the type of benefits derived from the generic implementation of green AR and the benefits derived from the proposed reef type (PROARR). In each case, establishing a basic distinction between direct use, indirect use and passive use values. Source: Own elaboration based on (Carral et al, 2018a).

Location	Benefits	**Direct -DBij**	**Indirect - IBij**	**Passive - PBij**
	Definition	Immediately derived from the production and consolidation of the AA, so that the product can be obtained or enjoyed directly	Those that provide support for other economic activities or are a consequence of the effect on other components of the marine environment	Derived from the conservation of marine heritage and its availability for use by future generations
	Green AR	-Extractive uses (artisan fishing and aquaculture) -Receive uses (surfing, diving, sport fishing) - Recycling of inert materials	-Fishing production through the protection of the marine habitat (plant substrate) -Diversification of overexploited fisheries - Protection of seaboard and coastline -Improvement in water quality by renewing nutrients -Reduction in the environmental impact of related maritime industries	- Increase in biodiversity - conservation of the marine habitat, being preserved for use by generation - Sustainability of the industrial activities of maritime industries
Xj	PROARR	-Extractive uses (artisan fishing and aquaculture) -Receive uses (surfing, diving, sport fishing) -Recycling of inert materials, waste from the maritime industries	-Fishing production through the protection of the marine habitat (plant substrate) -Diversification of overexploited fisheries -Improvement in water quality by renewing nutrients -Reduction in the environmental impact of the canning industry and the production of concrete aggregates	- Increase in biodiversity - Conservation of the marine habitat, being preserved for use by generation -Sustainability in the activity of the canning industry

From the consideration of the generic benefits indicated, the general expression (1) is proposed, which includes the total benefits derived from the implementation of a green AR as a consideration of the direct, indirect and passive benefits (Table 4)

$$Total\ Benefit\ Fj = Direct\ Benefit + Indirect\ Benefit + Passive\ Benefit \quad (1)$$

The very great difficulty to evaluate the passive and indirect benefits is clear, so when considering the immediate benefits derived from the production and consolidation of the AR, formula (2) is used (Carral et al, 2018a) which allows an estimation of the beneficial factors based on considering the direct factors that should be taken into account when implementing a green AR in a location "Xj" and considering the type of purpose and activity (Bi Ci) (2).

$$Direct\ Benefit\ DBj = \sum_i^j A_{ij} B_{ij} C_{ij} \quad (2)$$

In this expression the coefficients A_{ij} **– type of AA** – (Conventional or Green), $\mathbf{B_{ij}}$ – type of purpose (extractive, recreational, derived from the use of inert materials and substitution of component materials) and the specific benefit C_{ij} **- benefit derived from each type of activity** (artisan fishing, aquaculture, surfing, diving, sport fishing, reuse of materials and recycling of materials), will be indicated by the contents of table 5

Table 5 contains the coefficients of formula (2) relative to the direct benefits derived from the implementation of AR group depending on the type of reef used and the purpose pursued. Source: Own

	Conventional AR			**Green AR**		
i	$\mathbf{A_i}$	$\mathbf{B_i}$	$\mathbf{C_i}$	$\mathbf{A_i}$	$\mathbf{B_i}$	$\mathbf{C_i}$
1	1	Extractive-1	Artisan Fishing	1	Extractive-1	Artisan Fishing
2			Aquaculture			Aquaculture
3		Recreative-1	Surfing		Recreative-1	Surfing
4			Diving			Diving
5			Sport Fishing			Sport Fishing
6	0	Substitution of materials-1	Reuse		Substitution of materials-1	Reuse
7			Recycling			Recycling

There are methodologies to address some of these benefit valuation problems (Pickering et al., 1998); (Milton and Holland, 2000), but additional techniques may be needed to broaden the scope of the evaluation so that the multiple objectives that ARs can potentially achieve are recognized. In recent years, there has been considerable progress in the application of multicriteria analysis to fisheries management (Mardle and Pascoe, 1999; Mardle et al, 2004), and within this multi-criteria analysis it may be useful for the AR socio-economic effects to the bio-economic effects (Whitmarsh et al., 2008) as a result of including the additional requirement of its environmentally sustainable production. In any case, the coefficients that weigh each of the possible effects will be obtained through experimentation

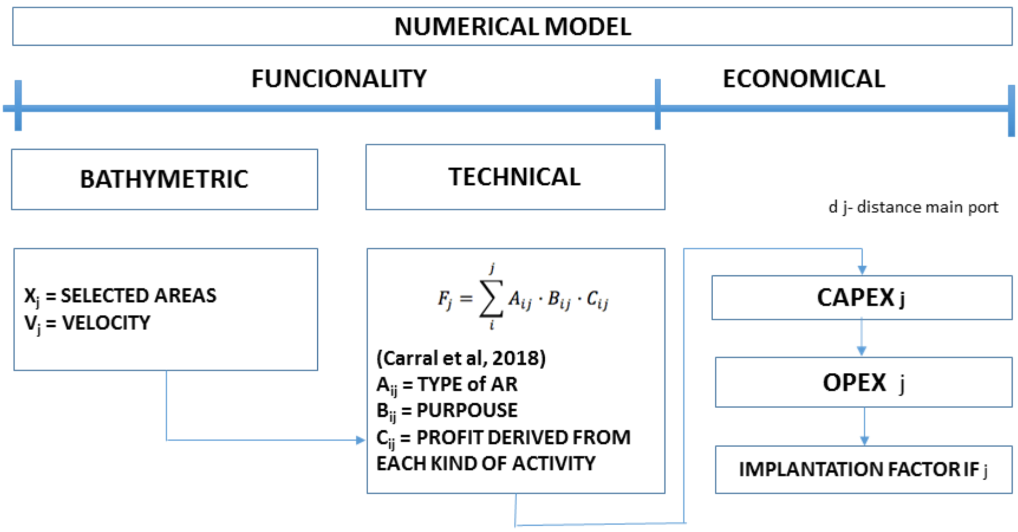

Fig. 7- Consideration of functional and economic implementation factors. Source: Prepared by the authors

4.2 Economic factors - construction and exploitation costs

For each location Xj there will be corresponding installation (CAPEX) and operation (OPEX) costs that will depend on the distance to the chosen site from the base port (dj), as well as the existing depth (hj) that will condition the installation. So, based on the gross benefits derived from that location, if we discount the CAPEX and OPEX costs, we will obtain the net benefits derived from the chosen location (Fig. 7).

4.2.1 CAPEX

The capital costs will derive from the consideration of several components; **conception and definition**, **design and development**, **prefabrication and installation** (table 6).

$$CAPEX = Conception\ and\ Definition + Design\ and\ Development + Manufacturing\ Costs + Installing\ Costs \quad (3)$$

$$CAPEX = C1 + C2 + C3 + C4 \quad (4)$$

Table 6. It contains the components related to the CAPEX for the installation of the AR group. Source: own

Costs Components - CAPEX			
C1	C2	C3	C4
CONCEPTION AND DEFINITION	**DESIGN AND DEVELOPMENT**	**MANUFACTURING**	**INSTALLING**
-Design AR Group -C11 economic feasibility study **(C_{efs})** -C12 law factors **(C_{taxes})**	**-Engineering project** -C2 detailed engineering **(C_{de})**	-C31- AR. Production **($CAR_{production}$)** -C32- AR. Protection **($CAR_{protection}$)**	-C41Terrestrial Transport **(Cet)** -C42 Operation at the Base Port **(Coh)** -C43Maritime Transport **(Cmt)** -C44 Descent **(Cach)**

-C13 entry design of AR group **(C_{hs}, C_{bs}, C_{chs})**			-C45 Signalling **(Cs)**
VARIABLES			
-Area AR group -Number of Modules **(NAR_{pr}, NAR_{pt})**		-Materials Cost **(C_{mc})** -Direct labour Cost **(C_{dlc})** -Activity Cost **(C_a)**	-Manufacturing area -Port distance **dbase-port** **-dj port –anchoring** **- Hj - depth**

Conception and definition

Corresponding to the costs incurred in the initial phases of the project, we must consider; the study of *economic viability (C11)*, *legal factors (C12)* and *the design of each AR group (C13)*. The latter should include the hydrodynamic characterization of the study area as well as biological and geomorphological studies

$$C1 = C11 + C12 + C13 \quad (5)$$

where each of the components will be broken down according to the expressions (6), (7) and (8) that consider the costs of the economic feasibility study (C_{efs}), the occupation rates (C_{taxes}), $C_{hydrodynamic\ study}$ (C_{hs}), $C_{biological\ study}$ (Cbs) and $C_{characterization\ of\ seabed}$ (C_{chs})

$$C11 = C_{efs} \quad (6)$$

$$C12 = C_{taxes} * Area\ Polygon \quad (7)$$

$$C13 = C_{hs} + C_{bs} + C_{chs} \quad (8)$$

Design and Development

This must include the detailed engineering required for the definition of the AR groups including production and protection modules and the complete logistic study ($C_{detailed\ engineering}$)

$$C2 = C_{detailed\ engineering} \quad (9)$$

Manufacturing cost

This will correspond to the manufacturing costs of the production modules (C31) and protection (C32)

$$C3 = C31 + C32 \quad (10)$$

$$C31 = CAR_{production} * NAR_{production} \quad (11)$$

$$C32 = CAR_{protection} * NAR_{protection} \quad (12)$$

Where NAR_{pr} is the number of production AR and NAR_{pt} the number of AR intended for protection.

There are two different approaches in the supply chain, one based on the existence of a central place specialized in the construction of modules and the corresponding transport to each coastal space in which rehabilitation is considered, and a second option with the production in the local port area next to the area that is to be rehabilitated.

In relation to the corresponding costs (C31, C32) these will depend on the chosen strategy, with one set of values for the construction in a centralized inland location (C311, C312) and a different set of values in the case of construction at the port that is the base of operations (C321, C322). $C_{materials}$ refers to the concrete and concrete reinforcement, while in the case of a protection AA $C'_{materials}$ it also includes the cost of the corresponding steel. The cost of materials (Cm), the cost of direct labour (C_{dl}) and the indirect costs (C_{ac}) and industrial profit (b)

$$C311 = (C_m + C_{d\,l} + C_{a\,c})(1+b) \quad (13)$$

$$C312 = \left(C'_m + C_{d\,l} + C_{a\,c}\right)(1+b) \quad (14)$$

Depending on the strategies considered, we must take into account differentiated direct costs and activity costs, as well as the incorporation of the costs of occupation of the port surface that the port manager charges (C_{port})

$$C321 = \left(C_m + C_{d\,l} + C_{a\,c} + C_{port}\right)(1+b) \quad (15)$$

$$C322 = \left(C'_m + C_{d\,l} + C_{a\,c} + C_{port}\right)(1+b) \quad (16)$$

Installation cost

This corresponds with the fourth stage in the process of construction of the AR group.

$$C4 = C41 + C42 + C43 + C44 + C45 \quad (17)$$

The components are terrestrial transport (C41), the costs of handling at the origin and at the base port (C42), maritime transport (C43), the cost of submerging the modules (C44) together with the cost of signalling the AR groups at the surface (C45).

$$C41 = C_t.d_{base-port}\left(NAR_{pr} + NAR_{pt}\right) \quad (18)$$

$$C42 = C_c\left(NAR_{pr} + NAR_{pt}\right) \quad (19)$$

$$C43 = C_{tm}.d_{port-anchoring}\left(NAR_{pr} + NAR_{pt}\right) \quad (20)$$

$$C44 = C_{fc}.h_j.\left(NAR_{pr} + NAR_{pt}\right) \quad (21)$$

$$C45 = C_{signaling} \quad (22)$$

These expressions have the following coefficients, C_t - unit cost of terrestrial transport, C_c - cost of the crane on land and C_{fc} - floating crane, C_{tm} - unit cost of maritime transport, where $d_{base-port}$ and $d_{port-anchoring}$ are the distances between the place of manufacture of the modules, the base port and the final anchoring location. In each case the duration of the use of the floating crane for anchoring the modules will depend on the depth of each area (h_j). $C_{signalling}$ the signalling and beaconing of each affected AR group of the number of existing AR groups in the study area.

4.2.2 OPEX

Operating costs will derive from the consideration of several components; scientific supervision and exploitation.

$$OPEX = Scientific\ Supervision + Exploitation\ Costs \quad (23)$$

$$OPEX = C5 + C6 \quad (24)$$

Table 7. It contains the components related to the OPEX for the installation of the AR group. Source: Own

Costs components - OPEX	
C5	C6
SCIENTIFIC SUPERVISION	EXPLOITING
-C51 Divers costs (C_{diving}) -C52 Biology Laboratory Costs ($C_{biology\ laboratory}$)	-C61 Preventive maintenance -C62 Corrective maintenance
Variables	
-Number of samples -Number of divers	-AR group distance (dj) -

Scientific Supervision costs

This will correspond to the costs derived from the monitoring of the evolution of the AR carried out by biologists, and is related to the costs derived from the immersions for the collection of samples (C51) and the corresponding characterization works in the laboratory (C52) (table 7)

$$C5 = C51 + C52 \ (25)$$

$$C51 = C_{diving} \cdot N_{inspection} \cdot N_{number\ of\ divers} \ (26)$$

$$C52 = C_{biology\ laboratory} \cdot N_{number\ of\ samples} \ (27)$$

Where $N_{inspections}$ – is the number of inspections to be carried out. $N_{number\ of\ divers}$ – the number of inspections per year to be carried out and CAR_{diving} the cost of each dive.

$C_{biology\ laboratory}$ – cost per sample from the biology laboratory and $N_{number\ of\ samples}$ – the number of samples collected in a year

Exploiting costs

Whether the maintenance is preventive or replacive, the expression of this cost item will be composed of the costs of the materials to be replaced (CMm), its transport cost affected by the distance to be travelled between the base port and the location of the AR group (C_{Mtm}. $D_{port-anchoring}$) and direct and indirect labour (Cd l, Ca c) (Castro-Santos et al, 2016); (Castro-Santos et al, 2017)

$$C6 = C61 + C62 = \left(CM_{tm}.d_{port-anchoring} + CM_m + C_{d\,l} + C_{a\,c}\right) \quad (28)$$

5. RESULTS AND DISCUSSION

5.1. Procedure description

The selection of the appropriate locations for the installation of the AR is done through the DBMS that contains all the information that was collected and generated (Section 3). In the same way, the management system incorporates a series of computational algorithms that allow easy manipulation and the determination of parameters of interest facilitating the decision-making process (Sections 3 and 4). To this end, the selection of the locations is made in three differentiated phases (Phases I, II and III), through which the possible valid areas for the installation of an AR group are filtered. Below, we describe the phases carried out and the results obtained.

5.2. Phase I: Excluding and morphological factors

In this initial phase, the locations are selected based on two requirements. First, they are not affected by excluding factors, that is, the installation of an AR in these areas is not incompatible with the development of existing coastal uses. Secondly, they fulfil the functional conditions related to the morphological characteristics, that is, the depth and type of sea bottom are appropriate. As a result of the integration of these two factors, a total of six areas (1-6) located approximately in the middle part of the estuary meeting these requirements are identified. The locations of these areas, together with the distribution of the considered uses, as well as the morphological characteristics analysed are shown in Figures 8 and 9, respectively.

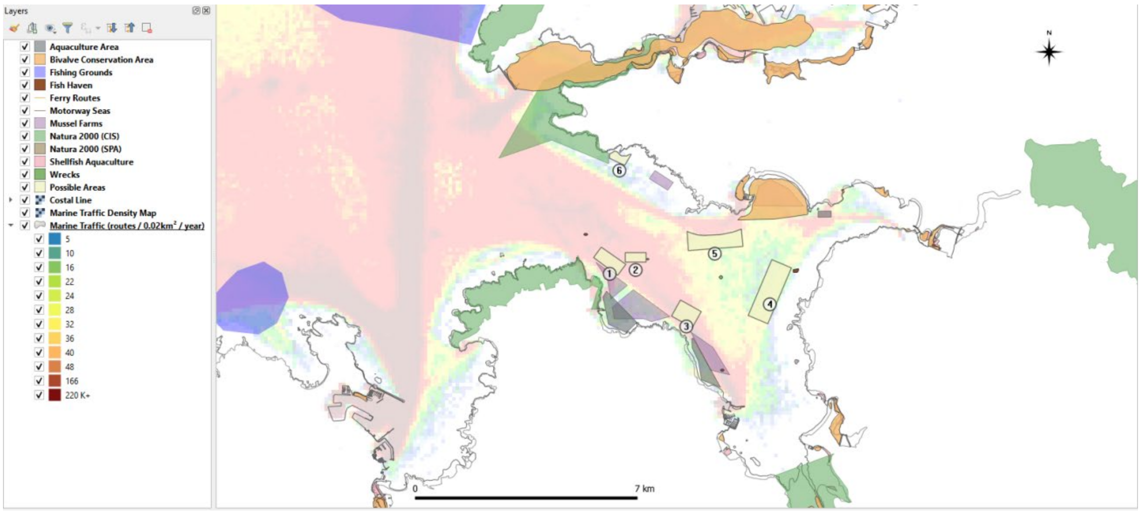

Fig. 8 - Areas selected after first step and coastal uses in the Ria de Ares-Betanzos (DBMS view).

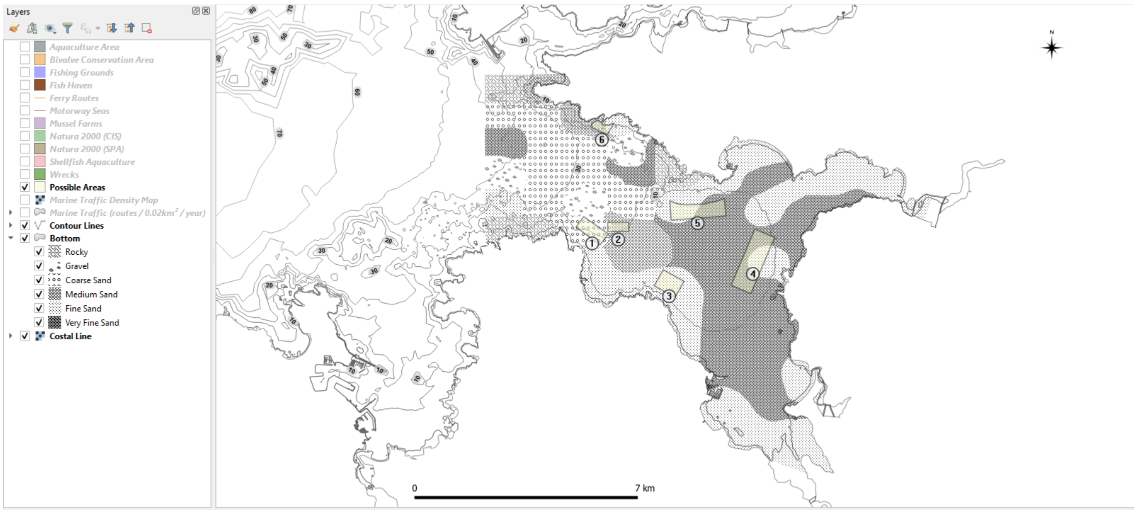

Fig. 9 - Areas selected after first step and morphological characteristics of the Ria de Ares-Betanzos (DBMS view).

Within the selected areas, it should be mentioned that, while areas 1 and 2 are close to the limit established as adequate depth for the operation of an AR with these characteristics, they are considered based on the explicit indication provided by the Regional Authority (Xunta de Galicia) due to their special interest resulting from their proximity to the Port of Lorbé.

On the other hand, in spite of the fact that the selected areas do not currently present any limitation in relation to a potential interference with the existing uses, or derived from their morphological characteristics, a possible intensification of an existing activity in the future, or morphological variations in the medium or long term due to sediment transport processes, could result in an interference amongst uses (Álvarez et al., 2017). In order to be able to evaluate such interferences or restrictions, Table 8 shows the distance of the selected areas to the current uses located within less than 1 km, as well as the density of the existing maritime traffic. Similarly, Table 9 shows the most relevant morphological characteristics, and more specifically, the depth range and composition of the sediment of the bottom in the previously selected areas.

Table 8. Distance from the areas selected to coastal uses located at less than 1 km

Zone	Uses of the coastal zones		
	Distance	Uses	Marine Traffic Density
1	76 m 428 m 700 m	Mussel farms Natura 2000 (CIS) Aquaculture area	High
2	25 m 560	Wrecks Mussel farms	Very high
3	130 m 350 m	Mussel farms Aquaculture area	High
4	76 m	Wrecks	Low
5	286 m	Bivalve conservation area	Medium/High
6	10 m	Natura 2000 (CIS)	Low

Table 9. Morphological characteristics of the areas selected

Zone	Depth (m)	% Grain size class
1	18-23	100 % Coarse sand
2	19-22	100 % Medium sand
3	10-14	100 % Fine sand
4	10-12	31 % Fine sand 69 % Very fine sand
5	10.5-16	50 % Fine sand 50 % Very fine sand
6	10-19	21 % Medium sand 89 % Fine sand

From the information presented in Tables 8 y 9, it can be seen that zones 1, 2, 3 and 5 present a potential interference with maritime traffic. In order to analyse this possible interference in more detail, the fishermen's association of the Ports of Ares and Lorbé was consulted, since they are the main users. Based on the information provided, zone 5 is considered as not appropriate for the installation of an AR. Zones 1-4 and 6 are therefore retained for further analysis.

Finally, it is important to take into consideration that the information presented in Tables 8 y 9 as well as any other information contained within the DBMS can be used by the Regional Authority for the final decision-making.

5.3. Phase II: Hydrodynamic factors

The numerical results obtained in the three case studies (A, B and C) (Section 3) are incorporated into the DBMS and used to analyse the areas that were selected in Phase I. Figures 10 and 11 show the distribution of the velocity field in the Ria de Ares-Betanzos in Case A (average conditions in the absence of wind and waves), for the situation of greater magnitude of the velocity of the currents during spring tides and neap tides, respectively, which corresponds to the situations defined (Section 3) for obtaining the parameters V_s and V_n.

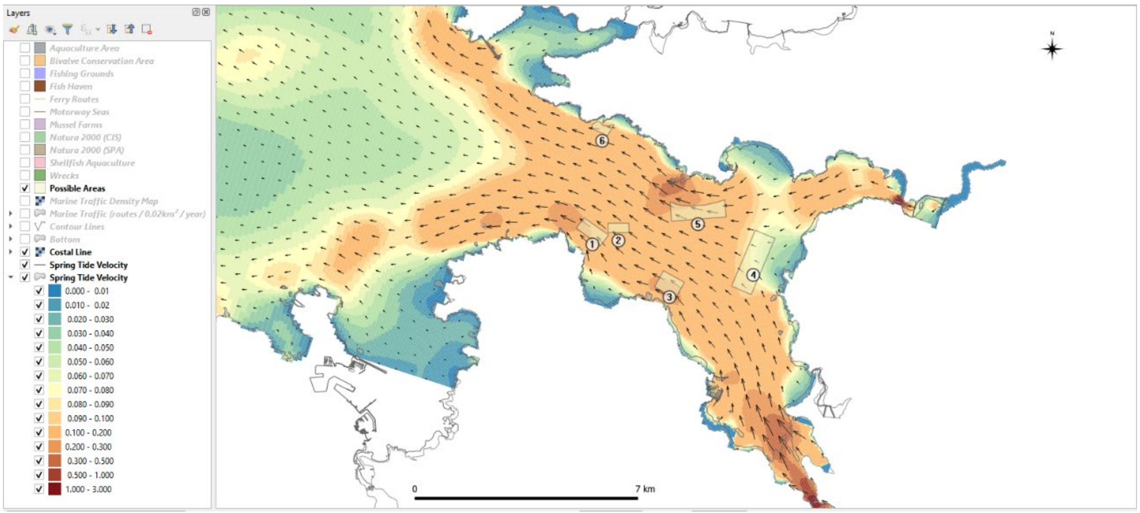

Fig. 10 - Magnitude and direction of peak velocities in the Ría de Ares-Betanzos during spring tides (approximately at mid-ebb) under mean conditions (Case A) (DBMS view).

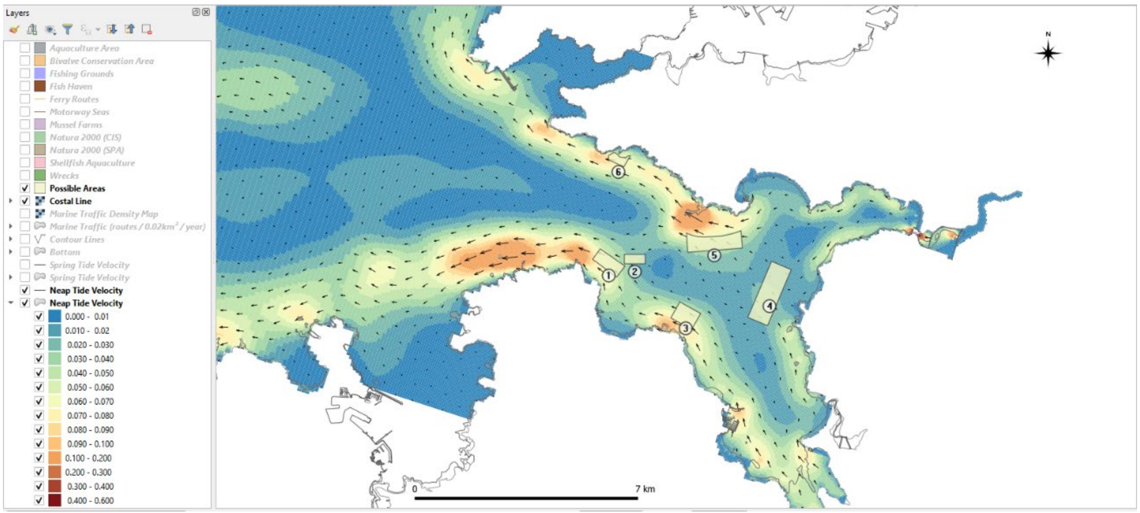

Fig. 11 - Magnitude and direction of peak velocities in the Ría de Ares-Betanzos during neap tides (approximately at mid-ebb) under mean conditions (Case A) (DBMS view).

The situation of greater magnitude of the currents in average conditions is obtained approximately at mid ebb tide. In general terms, it can be established that the magnitude of the velocity increases gradually towards the upper part of the estuary, where velocities of up to 1 ms^{-1} occur in the narrowest and shallowest sections, which in any case are very localized and do not correspond to the areas of interest for the installation of an AR (Section 5.2). In addition, the velocity of the currents tends to present higher values in the vicinity of closed contours (coastal limits), which is probably the result of the lower depth, in contrast to the more central channel of greater depth. This situation becomes more evident during neap tides (Figure 11). As for the middle Ria, where the previously selected zones are located, it presents maximum current magnitudes between 0.2 ms^{-1} in spring tides and 0.1 ms^{-1} in neap tides, results that are coherent with those previously obtained in this Ria as presented in Section 3 (Piedracoba et al., 2005).

In relation to the action of the wind (Case B) and waves (Case C), the circulation induced by these forcings acting solely is presented in Figures 12 y 13, respectively.

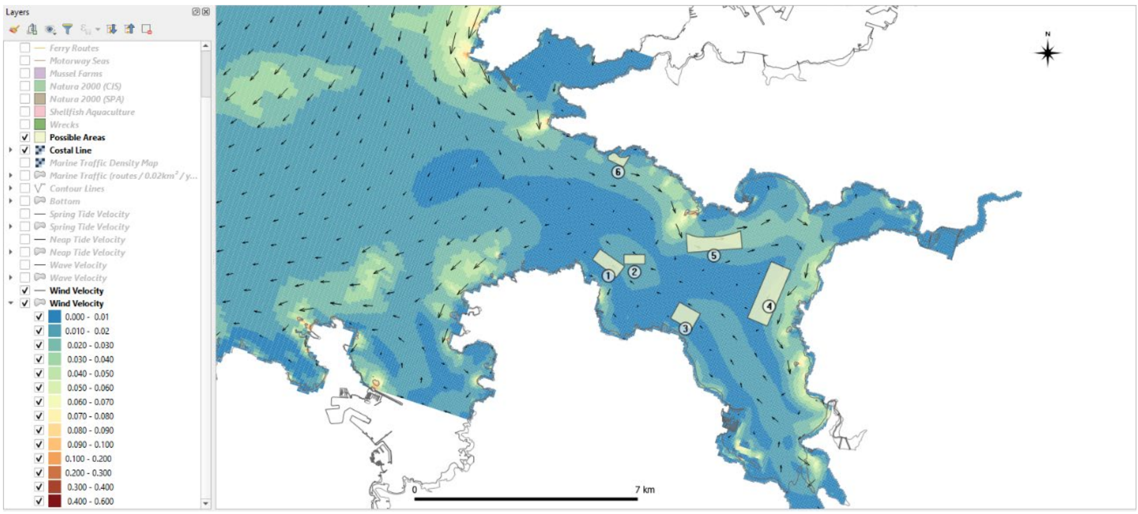

Fig. 12- Wind-induced circulation in the Ría de Ares-Betanzos (Case B) (DBMS view).

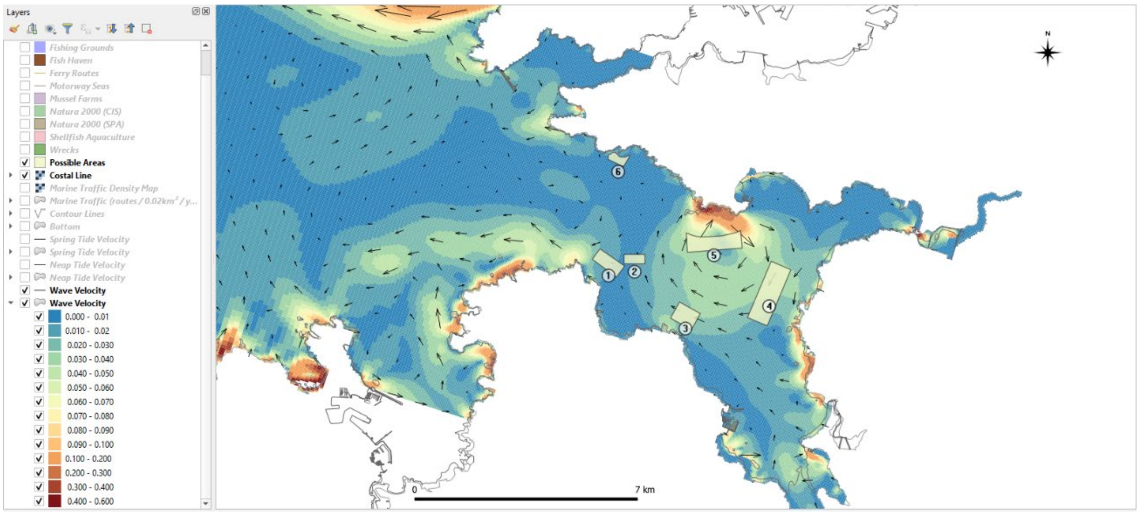

Fig. 13- Wave-induced circulation in the Ría de Ares-Betanzos (Case C) (DBMS view).

The results show that the wind is not capable of inducing a significant current velocity compared to the average scenario in absence of wind (Case A), even in the case of considering strong winds. In this sense, the resulting velocities are of approx. 0.01 ms^{-1}, one order of magnitude lower than the currents in an average situation in the absence of wind and waves (Figure 12). However, it is expected that its capacity to generate residual currents is greater than that of the tide and freshwater discharges, representing in any case the forcing agent with greater capacity to generate upwelling processes. Finally, as it might be expected, the currents induced by the waves (Case C) (Figure 13) are relevant in the outer zone of the Ria, while in the middle Ria they are of certain interest only at very specific locations being exposed to the action of the waves.

In this way, the circulation induced by the wind and waves during non-extreme events is of much less importance than the transient circulation generated by the tide, which corroborates the results obtained in recent investigations (Piedracoba et al., 2014). For this reason, the magnitude of the currents in an average situation (Case A) is used in the present work to select the locations of interest to install an AR group.

In order to analyse more accurately the magnitude of the current velocity in the areas selected in Case A, the DBMS is used to compute the average value within each area of V_s and V_n, as established in Section 3 (Table 10).

Table 10. Mean peak current velocities during spring tides, V_s, and neap tides, V_n

Zone	V_s (ms^{-1})	V_n (ms^{-1})
1	0,194	0,058
2	0,157	0,024
3	0,204	0,058
4	0,079	0,020
6	0,146	0,042

It can be seen that areas 1 and 3 present the highest flow velocity, followed by areas 2 and 6 with a slightly lower value during spring tides and a significantly lower one during neap tides; finally, area 4 has a significantly lower magnitude of velocity in both situations. In this sense, it can be observed that there is a considerable variation between the velocities reached during spring and neap tides, a situation that results from the significant differences in the tidal range, which in turn shows that the tide is the main forcing of the hydrodynamics of the Ria de Ares-Betanzos in an average situation. In accordance with the criteria established in Section 3 regarding the magnitude of the current velocity suitable for the installation of ARs, area 4 is determined as not to be appropriate for this purpose. Therefore, zones 1, 2, 3 and 6 are retained for analysis in Phase 3.

It is necessary to bear in mind that the described hydrodynamic patterns causes the transport of sediments which is responsible for the changes in the morphology of the estuary. Similarly, a detailed analysis of the wind-induced circulation and its importance in generating upwelling processes, as well as its influence on the operational capacity of ARs, requires the implementation of 3D models. This information could be used in the decision-making process, so its future inclusion in the DBMS is considered.

5.4. Phase III: Economic factors

In addition to the aforementioned factors, economic factors play a fundamental role in the selection of the most appropriate areas for installing an AR. These depend on, among other aspects, the depth of the operation (*Hj*), as well as the distance to the nearest port (*dj*), in this case Ares and Lorbé, and the total available surface available for its installation (*AR Group Area*). In the present phase 3 the costs are calculated according to the procedure presented in Section 3, through which the parameters related to the conditions contained in the DBMS are obtained (Table 11).

Table 11. Main characteristics of the areas selected for an economic analysis

Zone	Depth (m)	Area (ha)	Distance to Lorbé Port (km)	Distance to Ares Port (km)
1	18-23	39.67	1.61	4.81
2	19-22	19.49	2.01	4.02
3	10-14	43.39	2.70	4.13
6	10-19	15.71	4.86	4.28

In order to establish an economic criterion that allows us to determine the most suitable locations, we must consider the components that are dependent on the locations under study. Specifically, the CAPEX components [C11 (Area AR group), C2 (dj), C3 (dj), C43 (dj) and C44 (Hj)) and OPEX components (C51 (dj, Hj), C6 (dj)] are dependent of the AR group position variables for each zone contained in table 11 (*AR Group area*, *dj port -anchoring*, - *Hj - depth*).

For the areas under study, and considering the cost components dependent on the location together with the weighting factors that modulate the importance of each of these components, decision table 12 has been compiled. Its application shows that the options of greater interest are areas 1, 2-3 and 6 from the port of Lorbé and areas 2-3, 6 and 1 from the port of Ares (classified according to their ascending installation costs) (table 13). As a result of this third phase, zones 6 and 1 are excluded, depending on whether the base ports were Lorbé or Ares.

Table 12 - Allows the identification of areas with favourable CAPEX and OPEX costs. For each study area and based on the consideration of two base ports (Lorbé and Ares), after weighting each cost component, the areas have been classified in order, proportional to their cost (value proportional to the cost incurred, 1-low, 4-high). Source: Own

	COST COMPONENTS						
	Capex			**Opex**			
Zone	**C11 (Area)**	**C43 (dj) Lorbé/Ares**	**C44 (Hj)**	**C51 (dj) Lorbé/Ares**	**C51 (Hj)**	**C6 (dj) Lorbé/Ares**	**COST**
1	3	1/4	3.5	1/4	3.5	1/4	13
2	2	2/1	3.5	2/1	3.5	2/1	15
3	4	3/2	1	3/2	1	3/2	19
6	1	4/3	2	4/3	2	4/3	16
Weighting factor	0.1	0.3	0.2	0.2	0.1	0.1	
TOTAL							**COST Lorbé/ Ares**
1	0.3	0.3/1.2	0.7	0.2/0.8	0.35	0.1/0.4	1.65 /3.75
2	0.2	0.6/0.3	0.7	0.4/0.2	0.35	0.2/0.1	2.45 /1.85
3	0.4	0.9/0.6	0.2	0.6/0.4	0.1	0.3/0.2	2.5/1.9
6	0.1	1.2/0.9	0.4	0.8/0.6	0.2	0.4/0.3	3.1/2.5

Table 13. Finalist areas in accordance with base ports as a result of applying the DBMS tool.

PORT AREA	**Best option zone**	**Second option zone**	**Deleted zone**
Lorbé	1	2-3	6
Ares	2-3	6	1

6. CONCLUSIONS

The methodology described in the present research allows an informed decision-making for positioning AR groups based on the consideration of production factors grouped by types of conditions: excluding, functional (bathymetric, geomorphological, technical) and economic factors related to construction and maintenance.

With this in view, the selection of the appropriate locations for the installation of the AR is done through the so-called DBMS (database management system) that contains all the information that was collected and generated. In the same way, this management system incorporates a series of computational algorithms that allow easy manipulation and the determination of parameters of interest that facilitate the decision- making. In this way, the selection of the locations is made in three differentiated phases (Phase I: excluding and morphological factors, Phase II: hydrodynamic factors and Phase III: economic factors), through which the possible valid areas for the installation of an AR group are progressively filtered.

In the application to the Ria de Ares-Betanzos, from Phase I a total of six areas (1-6) emerge as possible sites for installing an AR group, being location 5 disregarded after consulting the fishermen's association of the Ports of Ares and Lorbé. By analysing through numerical modelling the hydrodynamics of this Ría, and in particular the selected areas (Phase II), it can be seen that areas 1 and 3 have the highest flow velocity, followed by areas 2 and 6 with a slightly lower value during spring tides and significantly lower during neap tides; finally, area 4 has a significantly lower magnitude of velocity in both situations. In this sense, it can be observed that there is a considerable variation between the velocities attained during spring and neap tides, a situation that results from the significant differences in the tidal range which in turn shows that the tide is the main forcing agent of the hydrodynamics of the Ria de Ares-Betanzos in an average situation. In accordance with the criteria established in Section 3 regarding the magnitude of the current velocity suitable for the installation of ARs, area 4 emerges as not appropriate for this purpose. Therefore, zones 1, 2, 3 and 6 are retained for analysis in Phase 3.

Finally, the economic factors play a fundamental role in the selection of the most suitable area to install an AR, since after determining which areas are suitable and generate similar potential benefits (those that pass phases 1 and 2), the most favourable ones will be those that present lower costs. The installation and maintenance costs depend, among other aspects, on the total area available for installation, the depth of operation and the distance to the nearest ports, in this case Ares and Lorbé. Considering the areas under study, the cost components depending on the location and the weighting factors that modulate the importance of each component, the areas that are selected as the most interesting options are areas 1, 2 and 3, using Lorbé as the base port and the areas 2, 3 and 6 in case of using Ares.

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