University of Algarve

Faculty of Sciences

Department of Marine Sciences

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Design optimisation of a marine protected area network in Algarve (Portugal)

Ricardo da Cunha Simões

Promotor: David Abecasis

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I hereby confirm that I have independently composed this Master thesis and that no other than the indicated aid and sources have been used. This work has not been presented to any other examination board.

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Executive Summary

Over the years, degradation of natural resources and wildlife has been dramatically increasing, leading to losses of biodiversity and environmental functions. As a method to hinder harmful anthropogenic activities and preserve a representative part of biodiversity, protected areas were established around the world. In the maritime environment, the term Marine Spatial Planning (MSP) proliferated, and Marine Protected Areas (MPAs) made their appearance. Several biodiversity congresses and conventions agreed that protection of biodiversity should range between 10% and 30%, with the United Nations Aichi targets 2020 establishing the 10% goal, recognised by several countries and the World Parks Congress setting the bar higher with a 30% minimum protection target. However, the number of protected areas around the globe is still approximately 4% with only half of those being marine reserves. Even inside the EU, there are still significant ecological gaps in most of the countries, and at least half of the member states are still way below the 10% Aichi target. Moreover, due to the lack of active management and poor conservation status, most of the MPAs are not considered representative or ecologically relevant and so, are named as "paper parks".

In Portugal, only 3% of the marine environment is protected, with just 0.03% being considered no-take zones. Fishing and dredging activities are still allowed in the majority of the "protected" areas, with monitoring and enforcement being the most significant deficiency of the Portuguese plan. In the Algarve, only two marine protected areas exist, despite the considerable anthropogenic pressure, mostly due to the massive influx of tourists and sea-oriented culture, with strong fish-based gastronomy and a majority of jobs related with the marine environment. This led to heavy coastal development and degradation of coastal marine environments.

Plenty of management and types of MPA's were developed, but examples showed that no-take areas or marine reserves are the most successful ones in achieving their purpose and effectively preserving a representative part of biodiversity. Nevertheless, these reserves are only truly effective when part of a well thought network system, which allows to protect different life cycles of species and multiple essential habitats and ecological processes, promoting synergistic effects between different protected areas.

To support decision making, several software that can process high quantities of data and generate multiple optimised scenarios based on the parameters provided were developed. Marxan is one of the most popular choices, due to its effectiveness in

calculating the lowest cost areas while preserving the conservation targets established by the user. Allied with MinPatch, a program developed to solve fragmentation issues by giving the users the ability to select a minimum size threshold to be used when selecting protected areas, it is possible to create coherent and adaptative MPA networks.

This project aimed to offer several proposals for marine networks in the Algarve, by creating new and optimising the already existing protected areas. To do so, data was collected from a diverse range of European and national projects such as EMODnet, RENSUB and PRESPO. Together with literature from the scientific community, it was possible to obtain data on habitats, species and fishing intensity. Based on the EUNIS classification system and a group of national experts, a hierarchization of habitats was used, grounded on their ecological relevance. Furthermore, fishing activities were ranked according to their intensity and attributed costs for both artisanal fishing and coastal fishing to provide an estimation of implementation costs. Moreover, species data was also ranked, and a special status was attributed to species under concerning conservation status.

Four different scenarios were prepared, in a regional and a smaller local scale, with two sets of conservation targets. One scenario with a fixed 30% protection for all conservation features and another scenario with variable protection, ranging from 10% to 30% based on the rankings established. After all the input data was processed, 100 models with $1x10^9$ iterations were performed for each scenario.

The outputs obtained in the regional case presented 32.29% portfolio cost and a total MPA area of 1102 km^2 in the fixed protection scenario. In the variable protection scenario, the portfolio cost was 28%, with a total MPA area of 975 km^2. The portfolio cost represents the estimated expenses one would have if activities in the area were to cease, due to the creation of the no-take zones. In both scenarios, the maximum distance between MPA's was within the existing literature recommendations.

For the local scenario, the fixed protection scenario achieved 30% cost with a total MPA area of 116 km^2. Again, in the variable protection scenario, the costs were lowered to 26.19% and the total MPA area was slightly smaller with 100 km^2.

These proposals can be interpreted as a starting point for discussion among stakeholders, offering the possibility to reach new milestones. Moreover, this framework allows constant improvement with optimised data thus fitting in an adaptative management plan. This project introduced fishing data, allied with a ranking method to establish priority habitats and species, with additional protection for cases under special conservation status. The 30% fixed protection scenario opens doors for meeting the latest agreements in the scientific community, proven to be compatible to some point with sustainable fisheries. The variable protection scenario offers a more budget-friendly option while still offering significant protection levels and meeting the Aichi targets for 2020.

Since this project included many areas already recognised as important by the government, implementation should be easier. These areas, both ZPE's (Ria Formosa and Costa Sudoeste) and artificial reefs, are considered to have high ecological relevance being home to several important commercial species but do not possess any management plan that effectively protects them.

Nevertheless, to effectively apply this design, one must take into consideration a few constraints that can impair the local community and difficult the implementation process. No-take zones imply the cessation of harmful anthropogenic activities, with loss of fishing grounds, potential aquaculture areas, dredging and extraction activities, among others. Ceasing activities would be connected with an increase of enforcement to guarantee the fulfilment of the measures, being an additional cost to the project. However, this is a necessary measure to take to preserve the environment.

The majority of costs would come from fisheries. Being this project focused on an area down to 100m deep, small-scale fishermen would be the most affected due to the restriction of some of their most valuable fishing grounds. Despite only around 20% of the fishing yield being attributed to this community it still directly employs 17 thousand people nationwide, many of them living in precarious conditions and with fishing being their only source of income. Nonetheless, several options can support a healthy income for the community, with the valorisation of the marine reserves. This, however, requires a shift in the community structure and lifestyle, yet another necessary step to preserve the environment before it is too late.

Also, to prevent the temptation of weak MPA implementation in isolated and distant areas, this project assures connectivity between areas by relying on a minimum size threshold for each reserve. The minimum size considered is at least twice the size of several important commercial species home range areas, and it also respects literature recommendations for distance between MPA’s.

In conclusion, this framework can function as a very supportive tool not only for stakeholders but also to researchers that wish to pursue similar studies in other regions.

Abstract

Isolated marine protected areas, although an essential tool for the management and conservation of marine species and habitats, may not be enough to sustain viable populations. This is particularly true for small coastal MPAs, usually constrained by social, economic and political reasons. When properly established, MPA networks are more than the sum of MPAs due to the synergistic effects. Despite the efforts of the Strategic Plan for Biodiversity 2011-2020 and the World Parks Congress in preparing conservation strategies and proposing effective targets for biodiversity protection, it is highly unlikely that they will be met in time. With the aid of conservation planning software like Marxan and MinPatch, this project offers a framework, with various no-take areas proposals in a regional and local scale, taking into account fishing intensity, species and habitat distribution while considering the home range areas and dispersal distances of key marine species. The framework prepared is based on a ranking system that allows to set conservations targets based on the ecological relevance of habitats and the species conservation status. Two different sets of protection levels are suggested, an ambitious 30% protection scenario and a more budget-friendly variable protection scenario. Nevertheless, several constraints need to be addressed with care by both stakeholders and scientific community, to guarantee the success of the MPA's. With this approach, that can be applied anywhere, the first step towards discussion between stakeholders can be taken.

INTRODUCTION

Marine Conservation

Conservation is a topic that has been gaining strength in the last decades mostly due to the need to preserve and manage the earth natural resources and its wildlife. The degradation of ecosystems caused by anthropogenic activity has been intensifying in the past years. There is abundant literature referring to issues caused by overexploitation (Coleman & Williams, 2002; Pauly *et al.*, 2005), climate change (Doney *et al*., 2012), environmental pollution (Cole *et al.*, 2011; Islam & Tanaka, 2004), invasive species (Bax *et al.*, 2003; Molnar *et al.*, 2008) and others, leading to losses of natural resources, biodiversity and environmental functions (Lefebvre *et al*., 2017). To hinder the advances of harmful human activities in the marine environment, Marine Spatial Planning (MSP) was introduced. As a consequence, protected areas and reserves were created with the aim to represent biodiversity in each region and protect it (Margules & Pressey, 2000). This type of management is crucial in ecosystem and sea use management since it controls and organises anthropogenic activities by bringing together relevant stakeholders and ensuring operations are done sustainably and efficiently, using, for example, marine protected areas (MPAs) and other tools as means to its end (Douvere, 2008).

Marine Protected Areas

An MPA, as defined in 2008 by the IUCN is, "A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values", highlighting three very important aspects, conservation, management and cultural valuation.

There are various ways of protecting marine ecosystems that can range from protecting specific valuable habitats or species to forbidding any anthropogenic activity in the areas, depending on the goals that they intend to achieve. One of the most essential steps in designing MPAs is defining criteria to decide what should be protected, according to the goals and the opinions of the stakeholders (Roberts *et al*., 2003).

There are 11186 (of which 520 are still unimplemented) marine protected areas (MPAs) as of 2017 representing around 4% protection of the global ocean. The total number of fully protected marine reserves is approximately 2% (Atlas of Marine Protection, 2017). With the deadline of reaching 10% protection of coastal and marine areas (Aichi Target 11 of the United Nations Convention on Biological Diversity) by 2020 closing in, governments have been making efforts to increase MPAs. Large Scale Marine Protected areas (LSMPA) such as the Papahānaumokuākea Marine National Monument were established to reach this target. This reserve was expanded in 2016 and became the largest protected area in the world, being only recently surpassed by the Marae Moana sanctuary, implemented in 2017. Since 2009, at least 14 LSMPA were officially created or at least they were proposed (Lewis *et al.,* 2017).

Management efforts and failures

In the European Union, despite many efforts, the member states still fail to show good results regarding coverage and types of MPAs. According to a report by Oceana (2017), only one member state (Germany) in a total of 23 had a “good” MPA coverage with no major ecological gaps. Of those 23, 11 states (Belgium, Slovenia, France, United Kingdom, Poland, Lithuania, Denmark, the Netherlands, Estonia, Latvia, and Finland) presented a mediocre performance, with some notable gaps in their MPAs, especially in the coverage of specific habitats. The last 11 member states (Portugal, Ireland, Greece, Cyprus, Italy, Romania, Malta, Bulgaria, Sweden, Spain, Croatia) were far below the 10% target established on the Convention on Biological. Furthermore, according to the same report, there have been no attempts to go beyond the aims established by the Natura 2000 project, resulting in a restriction of protected areas to areas already defined in the project. The report concluded that it was highly unlikely for the EU countries to reach the 10% target by 2020. In a rough estimate, 6% of the European waters were declared as MPAs. However, due to lack of effective management and poor conservation status, most of the MPAs are not considered representative or ecologically relevant and so, are considered as “paper parks” (Oceana, 2017). Furthermore, high fishing pressure still hinders conservation purposes, complicating progress in protecting biodiversity, with reluctance within the member states to implement legislation to reduce and control fishing activities in Natura 2000 sites and MPAs (Oceana, 2017). Another report, by the European Environment Agency, shows that in a period between 2007 and 2013, none of the habitats assessed in the Atlantic, Mediterranean or Baltic sea showed habitats in a “good” condition, with the main reasons being the economic activities such as fishing and mining. They also suggest that there are serious issues with management, allowing most sites to be degraded.

In total, Portugal protects about 3% of its marine environment, with 71 marine protected areas. However, only 0.03% are fully protected and considered marine reserves (Horta e Costa, 2017). These numbers are still far from the 2020 Aichi Target 11. Most of the MPAs are “moderately” protected, which means activities such as fisheries and dredging are still allowed. Monitoring and enforcement are considered the biggest issues in Portugal hence most of the areas being considered “paper parks” (Horta e Costa, 2017). This is due to the lack of transparency from the government and unclear authorities competences which most of the time overlap and end up being belittled (Fazão *et al.*, 2015; Horta e Costa, 2017). Specifically, in the study area, the Algarve, there are two marine protected areas: Parque Natural da Ria Formosa and Parque Natural do Sudoeste Alentejano e Costa Vicentina (only a small percentage of the park is included in the administrative region of Algarve).

There are several sources of environmental pressure in coastal and marine habitats in the Algarve. One of them is tourism. The Algarve is considered the leading touristic attraction in Portugal, welcoming visitants from all around the globe that wish to enjoy the local attractions and the Mediterranean climate (INE, 2017). Naturally, a massive influx of people raises concerns over natural resource usage and environmental pressure, especially since the Algarve touristic attractions are sea-based (gastronomy, beaches, water sports, sailing, etc.). These attractions led to an uncontrolled and unplanned development of infrastructures along the coastline that tried to keep up with the constant influx of visitants, ignoring critical natural habitats (Pintassilgo & Silva, 2007). The Algarve possesses rich fish-based gastronomy due to its close relationship with the sea, providing a valuable business opportunity to the fishing industry, with particular importance to the bivalve industry that operates widely across the coast of the Algarve, including in protected areas like Ria Formosa. Anthropogenic pressure allied with environmental change have been depleting fishing stocks, hence the need for improvement in management and protection efforts (Vânia *et al*., 2014). Although the ecological pressures are recognised, marine protected areas in the Algarve still lack a management plan to adequately protect the area, being this situation very common in protected areas around Portugal (Horta e Costa, 2017). Additionally, until today there’s still a lack of protection of important habitats and species, such as the red corals (Boavida *et al*., 2016).

Threats and Opportunities

Nonetheless, global marine issues can be addressed by enforcing a systematic way of conservation planning dealing with the problem in a structured way which takes into account not only the location of the areas but also the importance of its design to guarantee effectiveness, while compiling relevant data, which can only be achieved with precise methods, transparent goals and constant evaluation of the work being performed (Margules & Pressey, 2000). Unfortunately, decisions to protect areas are usually heavily influenced by politics and economics and reserves tend to be degraded once economic interest is found (Aiken & State, 1994; Margules & Pressey, 2000; Singleton & Roberts, 2014). Therefore, there is a need to rehabilitate the system and create a transparent process of creating new areas that can meet environmental, political, economic and social aspects (Carwardine *et al.*, 2006; Watts *et al.*, 2017).

Marine reserves can provide higher benefits when compared to partially protected areas (Coleman *et al.*, 2013; Shears *et al., 2006*). Studies have shown that creating no-take zones increases density, biomass, organism size and species richness of the local community and even providing benefits for economic activities when compared to partially protected areas (Lester *et al*., 2009). One of the examples is evidence of fishing yield outside of the reserves being increased in the long-term due to the spillover effect and therefore giving solid arguments for the further implementation of reserves (Christie *et al*., 2010; Díaz *et al.*, 2005; Forcada *et al*., 2009; Kaunda-Arara & Rose, 2004). Spillover effect in marine protected areas is defined as the migration of fish from the protected area to the outside areas. It is important to refer that the creation of marine reserves will still decrease fishing yields in some well-managed fisheries in the short-term, due to the immediate reduction of area available for fishing (Hilborn *et al*., 2004). With careful management, ecotourism can be enhanced by protected areas, by providing an opportunity for wildlife watching and even providing alternative income for fisherman, thus promoting cultural valuation (Lopes *et al.* 2015). Many guidelines in how to encourage and manage ecotourism in protected areas have been published recently, with an overview of potential benefits in the economy, cultural heritage, natural ecosystems and quality of life (Mollet, 2016; Zwirn *et al.,* 2005). Nonetheless, there are risks to be considered as the touristic activity is associated with construction of new infrastructures, perturbation of wildlife and pollution (Eagles *et al.*, 2002).

Moreover, regarding marine protected areas, many issues are yet to be solved. MPAs face problems on two fronts, biological aspects, and management-related aspects. Small and isolated MPAs tend to be unsuccessful for a few reasons: they are unable to ensure genetic diversity, due to their small size they cannot adequately protect migratory species, and they also fail in safeguarding multiple critical habitats (nursery grounds, reproduction zones, etc.) (Agardy *et al*., 2003). Nevertheless, adequately designed networks of MPAs can be quite capable. By ensuring that multiple biological parameters like connectivity, adequacy, representation, replication, protection and viability, the MPAs can contribute to conservation efforts (Cicin-Sain & Belfiore, 2005; Delavenne *et al*., 2012; Gaines *et al.*, 2010). In contrast with small and isolated protected areas, networks work much better in protecting species with high dispersal ranges, not only being able to preserve different life cycles of different species at the same time but also a variety of critical habitats and ecological processes that are necessary to sustain healthy communities, promoting synergistic effect between different areas (Almany *et al*., 2009; Di Franco *et al*., 2012). Moreover, if larger populations are being protected, genetic diversity can also be enhanced, increasing population viability and decreasing the chances of species being unable to adapt to changes in the ecosystem (Frankham, 2005).

Besides, when it comes to management, there is no lack of literature referring to "paper parks" and mismanaged protected areas (Advani *et al.*, 2015; Guidetti *et al*., 2008; Pieraccini *et al.*, 2017; Rife *et al.*, 2013). There is also a focus in LSMPA. The idea behind creating these vast reserves was to allow and improve population connectivity between areas by containing several ecosystems and habitats and allow their interaction (Wilhelm *et al*., 2014). Nevertheless, some authors criticised the rapid growth and appearance of such areas and questioned the capacity to manage and monitor such regions efficiently, since surveillance, for example, would be much more expensive (Dulvy, 2013; Jones & De Santo, 2016; Singleton & Roberts, 2014). In fact, even in smaller sized MPAs, controversy has always been intense. Authors also claim their protection is biased and misplaced, usually located in remote areas or places with no strong economic interest (Margules & Pressey, 2000; Mora *et al*., 2006), often fragmented resulting in low connectivity between ecosystems (Struhsaker, & Siex, 2005) and poorly managed, with lack of enforcement and monitoring (Advani *et al*., 2015; Guidetti *et al*., 2008; Liu *et al*., 2001). Only with the formal establishment of roles and responsibilities among the participants, it is possible to ensure that the work being performed will not be wasted (Gleason *et al*., 2010).

Furthermore, there's controversy between the scientific community in many technical aspects related to MPAs, with many attempts to reach a consensus about the ideal size and design of an MPA but also their location (Abecasis *et al.*, 2015; Gaines *et al*., 2010; Glazer & Delgado, 2006).

Conservation Planning Methods

However, it is possible to improve existing protected areas or create new protected areas from scratch with the aid of conservation planning software and consistent spatial data that were not available in the past (Abecasis *et al*., 2015). With high acceptance from the stakeholders, it is possible to create successful cases of biodiversity conservation since they are the ones actively engaged with the areas (Cicin-Sain & Belfiore, 2005; Dayton *et al.*, 2000; Gleason *et al*., 2010). Such feat can be achieved by presenting a variety of solutions to stakeholders, and these solutions can be obtained with the support of systematic conservation-planning tools, which are widely available.

This software generally can process high quantities of data and generate multiple optimised scenarios based on the parameters provided. Several options are available for use, with Marxan being one of the most popular. Another popular alternative software for conservation is Zonation. In contrast to Marxan, Zonation tries to maximise conservation benefits with a fixed cost. Marxan usually produces more efficient results while Zonation produces results with greater connectivity (Delavenne *et al*., 2012). Other tools such as C-Plan, the pioneer of conservation software, can be used in colligation with Marxan, to provide more robust results. ConsNet and ResNet are also useful software for this topic. ConsNet is more appropriate for larger datasets and offers a different approach by dynamically including multiple criteria such as many costs for the same planning area and additional spatial characteristics. However, a modified version of the Marxan software supports features which are not included in ConsNet, for example, providing multiple alternative conservation actions (Marxan with Zones) (Ciarleglio *et al.*, 2009). Nevertheless, this does not mean that the software will always produce the best result. Marxan assumes the users have a deep understanding of the problem being addressed. Otherwise, the true optimal solution won't be reached. Also, it is essential to understand that this tool only offers support in making decisions rather than replacing the process of decision-making. With the right use of this software, it's possible to create adequate proposals that are clear to stakeholders and policymakers thus leading to implementation (Smith *et al.*, 2009).

Marxan is the most used software for helping in systematic conservation planning due to its ability to recognize high-value areas to be included in a protected area or network, taking into account the social-economic costs, which means it can find a balance between conservation and economic development (Ball *et al.*, 2009; Smith *et al*., 2009). It aims to minimise costs associated mainly with implementation but also some management issues of the protected areas while meeting the conservation targets set by the user (Ball *et al*., 2009). Such conservation targets can represent both biological and geological features of interest to be protected, which are usually defined by a percentage. On the other hand, the costs represent the losses associated with the implementation, for example, acquisition, enforcement and other management costs but also costs associated with human economic activities such as fisheries and aquaculture.

Marxan relies on simulated annealing, a probabilistic function designed to find the optimal solution with the given parameters. More specifically, the algorithm tries to represent a minimum set of the features by the least possible cost although making sure it meets all the targets defined by the users, solving the reserve design problem known as "minimum set problem". Such algorithm is one of the main differences between Marxan and its alternatives (Ball *et al*., 2009; Smith *et al*., 2009). Marxan can also include an additional function, the boundary length multiplier (BLM), which helps to reduce fragmentation of reserve areas by forcing them to be clumped together. The BLM relates to the cost of the reserve, and usually, a higher BLM value results in more extensive portfolios, making them more attractive in a management point of view. The downfall is that it incorporates unnecessary areas making the final total cost higher requiring experimentation and additional software support (such as MinPatch) to reach a fine-tuned result, leading to very long processing times (Ball & Possingham, 2000; Smith *et al.*, 2010). Another important variant is the species penalty factor (SPF). This parameter forces the program to attribute area to specific conservation features depending on the value given.

MinPatch was initially developed to solve a common problem in conservation planning, which is fragmentation, by giving the users the ability to select a minimum size threshold to be used when selecting protected areas. This is a post-Marxan procedure since MinPatch uses the outputs provided by Marxan and manipulates them to achieve the minimum threshold set by the users. MinPatch does it by rearranging the planning units selected by Marxan, maintaining the original parameters but decreasing the levels of fragmentation by modifying areas that do not reach the minimum threshold defined by the user, therefore, creating outputs with less but slightly more extensive protected areas (Smith *et al.*, 2010).

One of the best examples of Marxan effectiveness was the rezoning of the Great Barrier reef (Australia) in 2004. Marxan was modified from its original software “SPEXAN” to support the Great Barrier Reef Marine Planning authority in their job of revamping the reef. Since then, the software has been extensively used around the globe, being successfully applied mainly in marine territories (Chan *et al.*, 2006; Delavenne *et al*., 2012; Klein *et al.*, 2010; Smith *et al*., 2009). However, Marxan is also suitable for terrestrial environments, especially with the updated Marxan with Zones, which has proven to be more versatile and efficient when dealing with more complex spatial planning issues that require zoning (Klein *et al*., 2010; Watts *et al*., 2009). It has also been used with different purposes due to its versatility of solving “minimum sets”, for example, to establish Aquaculture Management areas (Henriques *et al*., 2017), to select optimal fishing grounds (Schmiedel & Lamp, 2012), to find the best location for off-shore wind farms (Cordula & Jochen, 2012), among others.

One of the primary constraints with systematic conservation tools is usually the lack of baseline ecological information. MPA networks designs in an optimal condition require high-quality data (e.g., habitat types, connectivity, ecological processes, species richness) (Gaines *et al*., 2010; Magris, Pressey, Weeks, & Ban, 2014; Robert J. Smith *et al*., 2009a). For example, one of the assumptions of Marxan is the existence of consistent spatial distribution data. Of course, this is not always available, and despite the possibility of modelling species distribution based on biophysical data, it is often problematic to fulfil this assumption. At the European level, there is data available about habitats in coastal waters, which can be complemented with regional and national data that can provide additional information and a finer-grain scale (e.g. Di Franco *et al.*, 2012; Monteiro *et al*., 2013; Henriques *et al*., 2015; Assis *et al*., 2017; EMODnet, 2018). However, this can be quite difficult in other parts of the world. If no direct information can be found, it is always possible to make use of proxy data or information from similar environments in other locations, to establish a stable broad-scale baseline. Nevertheless, using proxy data might not always be suitable, especially when selecting priority habitats with multiple ecosystem services (Eigenbrod *et al*., 2010). Nonetheless, and despite the lack of data, management actions need to act in a preventive way and not after the tragedy, as it is very common. The precautionary principle in environmental conservation stands as one of the most important methods to prevent loss of poorly studied environments that are under pressure (Kriebel *et al*., 2001).

This project aims to establish a framework that can support stakeholder's decisions into creating and optimising the design of marine protected networks in the Algarve by offering possible solutions.

Materials and Methods

Data Sources

The majority of the data was collected from European Marine initiatives that provide a diverse range of data resources, mostly available to both public and private users. The European Marine Observation and Data Network (EMODnet) is one of those initiatives that aims to collect valuable marine data resources and preserve them in a freely accessible database. The EMODnet project offers data on bathymetry, geology, seabed habitats, chemistry, biology, physics, human activities and coastal mapping (The different portals can be accessed at: http://www.emodnet.eu/). Additional information regarding vulnerable marine ecosystems (VMEs) was collected from the OSPAR Commission (https://www.ospar.org/).

Habitat data was collected from various sources. EMODnet provided a reliable, broad-scale layer of seabed habitats (Available at: http://www.emodnet-seabedhabitats.eu). Medium scaled and fine-scaled data were also available in EMODnet and other sources of literature: Maerl beds (Peña *et al*., 2014), red corals (Boavida *et al*., 2016) and seagrass beds (Cunha *et al.*, 2014). The latter sources, were selected over the remaining available data, mainly due to their higher quality and also due to the algae ecological importance in their respective communities, being relevant as nursery grounds and as a structural habitat for a diverse range of species (Almany *et al*., 2009; Bertelli & Unsworth, 2014; Boavida *et al*., 2016; Espino *et al*., 2011; Fredriksen *et al*., 2010). There was also information provided from the project RENSUB, which aimed to map and make an inventory of the primary habitats and species of the Algarve Coast between 0 and 30 meters deep (Gonçalves et al., 2004, 2007, 2008, 2010).

Fishing activities data was obtained from two main sources. The first contained data from EU vessels above 15 meters length (Accessible at: https://bluehub.jrc.ec.europa.eu/webgis_fish/) using data collected by making use of

Automatic Identification Systems (AIS) (Natale *et al.,* 2015; Vespe *et al*., 2016). The second source was a project within the initiative PRESPO, which gathered knowledge about small-scale fishing intensity (boat size under 9 meters) in Portugal, through questionnaires in several fishing ports of every administrative region of the country. In the Algarve administrative region, this project performed a total of 458 face-to-face surveys collecting data of the fishing gear used by boats registered in Algarve ports (Gaspar *et al*., 2014).

Seabird data was obtained from Pereira *et al*., 2018, which conducted an 8-year census of 30 important seabirds species in Portugal and used Ensemble Ecological Niche Models (EENMs) to estimate their probability of occurrence and distributions. The models provided a substantial output to understand the conservation value of these species and identify key areas to nidification and development of the species.

Cetacean distribution ranges were obtained from the Portuguese Institute for Nature and Forests Conservation (ICNF: http://www.icnf.pt/portal). The data refers to studies made in 2013 and is available in a shapefile format.

Habitat Classification

Within the study area, 11 different types of habitats were identified. These habitats were classified under the EUNIS classification. This European project was developed with the aim of creating a hierarchic system that covered all types of habitats, through the use of criteria, facilitating habitat identification.

Further classification was done with the support of a National group of experts and finally with literature complementation. A new hierarchization of habitats in Portugal was done by the expert group, based on their ecological relevance. The description of all habitats and the EUNIS habitat codes associated to them can be seen in table 1.

Table 1. Summary of known habitats in the study area and their EUNIS codes

Habitat	EUNIS Codes	Source
Soft sediment (<50 m)	A5.13; A5.23; A5.24; A5.33; A5.34; A5.43;	(Monteiro *et al*., 2013) EMODNET/MeshAtlantic
Soft sediment (50 - 200 m)	A5.14; A5.15; A5.25; A5.26; A5.27; A5.35; A5.36; A5.37; A5.44	(Monteiro *et al*., 2013) EMODNET/MeshAtlantic
Soft sediment (>200 m)	A6.2; A6.3; A6.4; A6.5	(Monteiro *et al*., 2013) EMODNET/MeshAtlantic

Rocky reef (<50 m)	A.3.1; A3.2; A3.3	(Monteiro *et al*., 2013) EMODNET/MeshAtlantic
Rocky reef (50 - 200 m)	A.4.1; A.4.2; A.4.3	(Monteiro *et al*., 2013) EMODNET/MeshAtlantic
Rocky reef (>200 m)	A6.1	(Monteiro *et al*., 2013) EMODNET/MeshAtlantic
Biogenic reefs (<200 m)	A5.6; A4.24; A4.22; A4.27; A3.24; A3.712	(Monteiro *et al*., 2013) EMODNET/MeshAtlantic (Boavida *et al*., 2016)
Maerl Beds	A5.51	(Peña *et al*., 2014)(Tempera *et al*., 2013)
Seagrass beds	A5.53; A5.545	(Cunha *et al*., 2014)
Macroalgae forests	A3.11; A3.12; A3.15; A5.52	(Tempera *et al*., 2013) (Assis *et al*., 2017)
Estuaries and coastal lagoons	X01; X02; X03; A5.22	

Buffer Zones

Buffer zones are usually used as means to protect natural resources by establishing a safe range around the resource based on scientific knowledge. This range of influence can differ based on the type of resource being protected. For example, when creating buffer zones for known nursery grounds, it is necessary to understand the ranges of dispersal of species to safeguard their development hence establishing a zone free from potentially harmful anthropogenic activities. In this study, buffer zones were used as a mean to cover uncertainty in the location of particular habitats and species, but also to estimate the range of influence of some economic activities. The size of buffers was based on existing literature and technical reports and also informal expert advice, as can be seen in table 2.

Table 2. Buffer size utilised for threats/habitats

Threat / Habitat	**Range of Influence (m)**	**Source**
Kelp Forests	1000	(Abecasis *et al*., 2017);
Red Corals	1000	(Abecasis et al., 2017);
Dredge deposition	1000	(Ban *et al*., 2010)

Geographic Information System Software and Plugins

To compile the spatial data collected, QuantumGIS (Version: 2.18.18 Las Palmas) was used. QGIS is a free and open source software available at: https://www.qgis.org/en/site/. The projection used in the entire study was EPSG:32629 WGS 84 / UTM zone 29N, which displays the units in meters. This was chosen due to the small scale of the project and to facilitate the input and display of data. All the layers used in the project were converted correctly to this reference system.

A plugin called Conservation Land-Use Zoning software (CLUZ, Available at: https://anotherbobsmith.wordpress.com/software/cluz/) was used as a link between QGIS and Marxan. CLUZ is capable of designing protected area networks, acting as an on-screen planning tool that also functions as a link for Marxan.

Another software package used in this project was MinPatch, which is also included in the CLUZ plugin (Smith *et al*., 2010).

Scenarios

Four scenarios were constructed for the scope of this project. The first two scenarios (A) were comprised of the marine area existing between the coastline and the 100 meters depth contour as can be seen in figure 1. The remaining two scenarios (B), were based on a previously studied area which ranged from Ponta da Piedade (Lagos) to Ancão (Faro) (figure 1), that contained fine data derived from the RENSUB project, up to a 30m depth and presented a smaller, more detailed perspective with the aim of supporting future smaller projects.

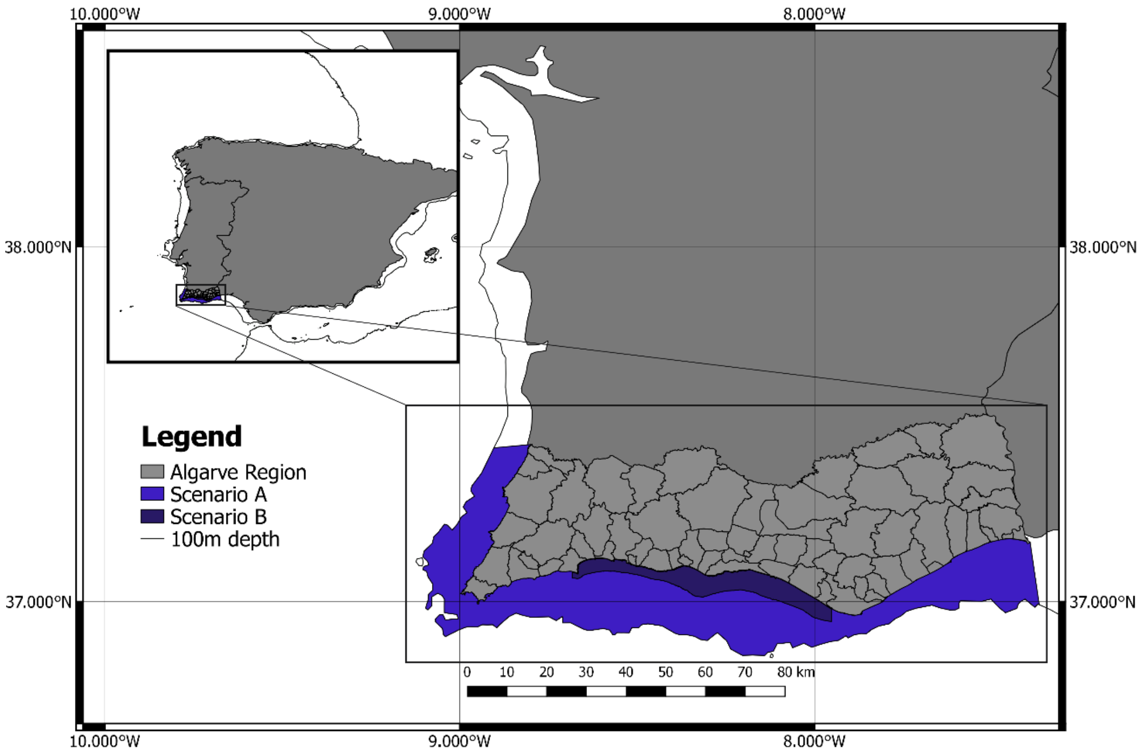

Figure 1 - Map of the study area showing the location of the two scenarios and the 100m depth contour.

The aim in scenario A was to test two different protection levels at a regional scale:

1) Protect 30% of all habitats and species.

2) Test a variable protection scale, in which habitats and species would be protected according to their ecological value and ranking, ranging from a minimum 10% protection to a maximum of 30% (further explanation in Cost Layers and Conservation Features).

The reasoning behind these targets was to have the Aichi 2020 Biodiversity targets as a minimum reference point and the World Parks Congress recommended targets as a maximum threshold since these two were already discussed by the scientific community and governments. Furthermore, these targets can be useful in protecting overfished stocks and restore them in the long term, while being compatible with sustainable fishing (Krueck *et al*., 2017).

Both tests were also applied to a local scale (scenario B), with finer-grain data. All scenarios contained fishing costs and all the conservation parameters.

Table 3. Summary of the scenarios established for this project

Scenarios			
A (Regional Scale)		B (Local Scale)	
Fixed Protection (A.1)	Variable Protection (A.2)	Fixed Protection (B.1)	Variable Protection (B.2)

Planning Units

Planning units (PUs), serve in spatial conservation exercises, as a basis on which data is compiled with the various conservation features. As so, by modifying its size and shape, the selection of patterns of spatial biodiversity can be consequently altered, thus providing different results when choosing priority sites (Hess *et al*., 2006; Larsen & Rahbek, 2003; Nhancale & Smith, 2011). Therefore, it is necessary to carefully choose the type of planning units to use to minimise potential technical mistakes. In respect to size, studies in the literature have shown that small-sized PUs are generally more efficient than larger units since they possess higher resolution and also decrease the number of redundant areas, which are not necessary to achieve the conservations targets established (Larsen & Rahbek, 2003; Nhancale & Smith, 2011).

There are several types of designs used in conservation planning that can be considered when choosing planning units:

1) Regular shapes such as hexagons and squares, the most common type of PUs used (e.g., Abecasis *et al*., 2017; Henriques *et al*., 2017),

2) Irregular shapes like drainage basins and private properties (used more commonly in terrestrial cases) (e.g., Lombard *et al*., 2003; Roux *et al*., 2008),

3) a combination of the two methods (e.g., Huber *et al*., 2010).

Generally, when dealing with a marine environment, regular shaped units are selected, since there is rarely a need to deal with complex administrative boundaries due to the area being communally managed (Smith *et al*., 2008).

Small hexagonal shapes have been suggested to be slightly more efficient when compared to squared shapes since they are easier to arrange spatially in a compact way, being able to contain important conservation features with less unit usage (Nhancale & Smith, 2011).

In this study, two different grids were used. The grid used for the entire Algarve study area contained 12393 hexagonal units with a 0.25km² area. The second grid included 4824 hexagonal units with a 0.075km² area and was used for the smaller scale scenario. The boundaries of the planning units were defined by using the most up to date coastline and bathymetry data available in the Portuguese Hydrographic Institute.

Cost Layers and Conservation Features

To estimate the cost of each planning unit, it is necessary to create a unique cost layer. The costs estimated in this project were derived from fishing activities, both artisanal boats (<9m) and coastal ships (>15m). Coastal boat fishing represented around 80% of yield produced in the region, while the remaining 20% were attributed to the various methods of artisanal fishing (Viegas, 2010).

Fishing intensity from vessels above 15m was originally divided into five categories, being 1 the rank with lowest fishing intensity and 5 the highest. In order to make a comparison possible between the two types of fishing, artisanal fishing was also divided into 5 categories, however, as AIS is not available in this case, fishing intensity was estimated by using the number of licenses for each fishing gear as available in the PRESPO report (Gaspar *et al*., 2014). It is essential to be aware that licenses number is not necessarily the same as fishing intensity since it is possible for a fishing boat to have multiple licenses while only using one type of fishing gear. The process behind the categorisation of artisanal fishing can be seen in table 4.

Table 4. Fishing gear utilised by artisanal fishers and the number of licenses for each gear.

Fishing Gear	Number of Licenses	Ranking
Longline fishing	1230	5
Gill Nets	1136	5
Jig (Cephalopods)	860	4
Trammel net	844	4
Traps/Pots	436	2
Rod and reel	305	2
Jig (Octopus)	305	2
Octopus pots	297	2
Trolling	66	1
Purse seine	33	1
Clam dredge	29	1

Afterwards, the costs were calculated by multiplying the corresponding percentage of each fishing group, as mentioned above, with their respective ranking and summing overlapping outputs, as can be seen in table 5. Since some planning units were fragmented and displayed various costs, the maximum cost value represented in each unit was used. The final cost layer can be found in the annexes (Fig. A1) for a more detailed inspection.

Table 5. Cost attributed to each type of fishery based on their ranking.

Ranking	Cost Artisanal Fishing (20%)	Cost Coastal Fishing (80%)
5	1	4
4	0.8	3.2
3	0.6	2.4
2	0.4	1.6
1	0.1	0.8

Additional costs such as diving and off-shore aquaculture were not used since their exact location, and economic yield was unknown.

The habitats available were then classified, grouped according to the EUNIS habitat type classification and ranked by a team of national experts. The ranking system attributed an ecological value for each habitat, and that environmental value was then used as a conservation parameter, with the higher ranked habitats being prioritised over the lower ranked.

A similar method was used for seabird's and cetacean's data. Data was categorised and converted to a ranking. In the case of seabirds, 5 categories were established, being 5 the highest and 1 the lowest as can be seen in table 6.

Table 6. Ranking attributed to seabird species based on probability of occurrence.

Probability of Occurrence (%)	Ranking
81-100	5
61-80	4
41-60	3
21-40	2
0-20	1

Cetacean's data, was based on presence/absence data and a rank 2 was attributed to each species range.

Afterwards, rankings were converted in conservation targets depending on the scenario. In the fixed protection scenarios, all the species and habitats available were set for a 30% protection target.

As for the variable protection scenarios, the targets varied between a minimum of 10% and a maximum of 30% depending on the ecological value and conservation status (table 7).

An exception was made for species which were considered vulnerable, endangered or critically endangered by the IUCN Red List of Threatened Species.

In this case, the most critical areas for each habitat/species (rank 4 and 5) were subject to special protection levels as can be seen in table 7. The remaining rankings would be under the standard conservation targets applied to the remaining species. If the species does not have a defined ranking, but it is under a special conservation status, the minimum conservation target for each status was applied (table 8).

Table 7. Conservation targets attributed to Habitats based on their ecological value.

Habitats	Ecological Value	Conservation Target (%)
Rocky reef (<50 m)	9.9	30
Macroalgae forests	7.4	23.53
Seagrass beds	6.7	21.71
Rocky reef (50 - 200 m)	6.1	20.15
Rocky reef >200m	4.7	16.51
Biogenic reefs <200	4.7	16.51
Maerl Beds	3.9	14.43
Soft sediment (>200 m)	3.5	13.39
Soft sediment (<50 m)	3	12.09
Soft sediment (50 - 200 m)	2.8	11.57

Table 8. Conservation targets attributed to species based on their ranking and conservation status.

Species	Ranking	Conservation Target (%)
Seabirds	1	10
	2	10
	3	15
	4	20
	5	25
Cetaceans	2	10
Critically Endangered	4	30
	5	30
Endangered	4	27.5
	5	30
Vulnerable	4	25
	5	27.5

For the Local scenario, as mentioned before, an additional layer containing data from the RENSUB project was added. This layer included a Margalef index, which values ranged from 1 to 10 and was converted into a 5-category ranking system as used for the rest of the data (Table 9).

Table 9. Conservation target attributed to each ranking of the Margalef layer included in the Local scenario (B).

Margalef Index Value	Ranking	Conservation Target (%)
1	1	10
2		
3	2	10
4		
5	3	15
6		
7	4	20
8		
9	5	25
10		

Conservation Parameters

CLUZ offers the option to pre-select units based on four different status: “Available”, “Conserved”, “Earmarked” and “Excluded”. “Available” units are those in which there’s no special classification and will be used by the software with no restriction. “Conserved” units represent units which are under protection, such as already existing marine protected areas (Parque Natural da Ria Formosa, in the Southeast, and Parque Natural do Sudoeste Alentejano e Costa Vicentina, in the Southwest). “Earmarked” are units that are already proposed as future protected areas or are already under some protection or recognition. In this project, artificial reefs and ZPE's (Special Protection Zones) were considered as “Earmarked” as they already possess recognition from the government as special management/protection zones, such as artificial reefs areas, where non-recreational fishing is limited or ZPE's, which are areas with important conservation value. Whenever they display the same conservation value "Earmarked" units are prioritised over "Available" units in the final output, “Excluded” units are usually locations that can’t be selected for protected areas due to political, economic or ecologic reasons, and thus are excluded from usage. In this project, areas destined for dredging and dumping of materials were considered as excluded.

Figures 2 and 3 provide an overview of the status of the planning units for the Regional scenario and the Local scenario, respectively.

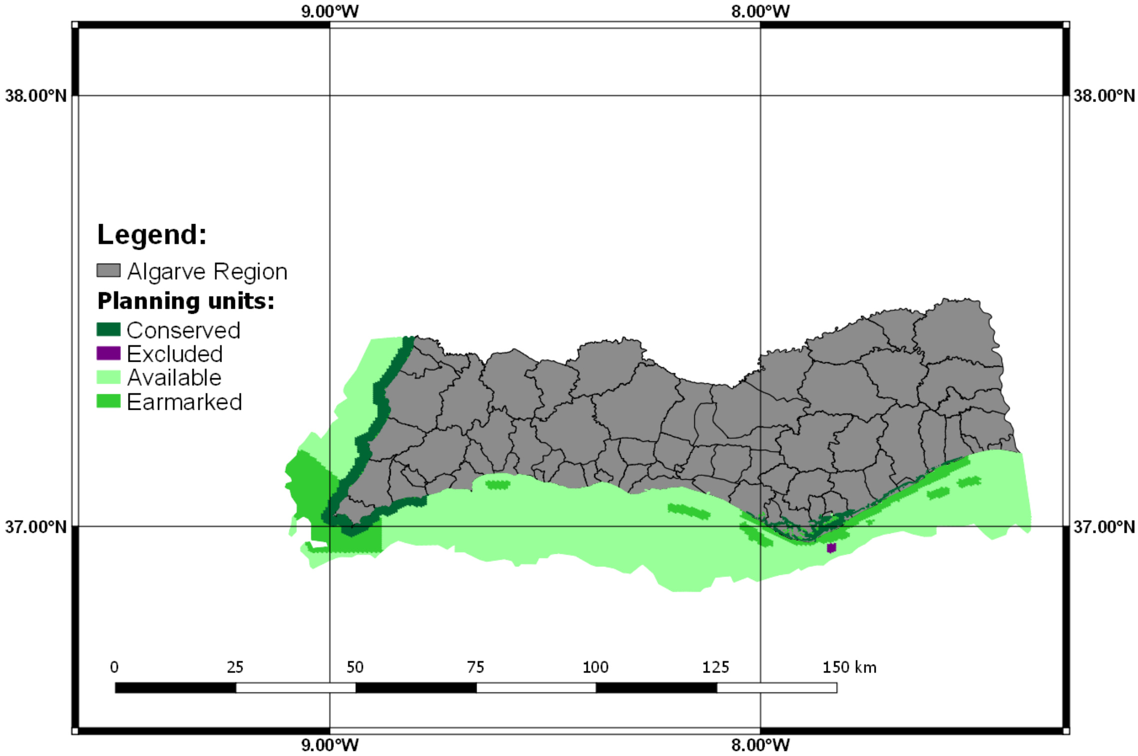

Figure 2 - Planning unit status for Regional scenario (A). Conserved areas as already existing MPA's, earmarked areas are ZPE’s and artificial reefs, and excluded as dredging/dumping points.

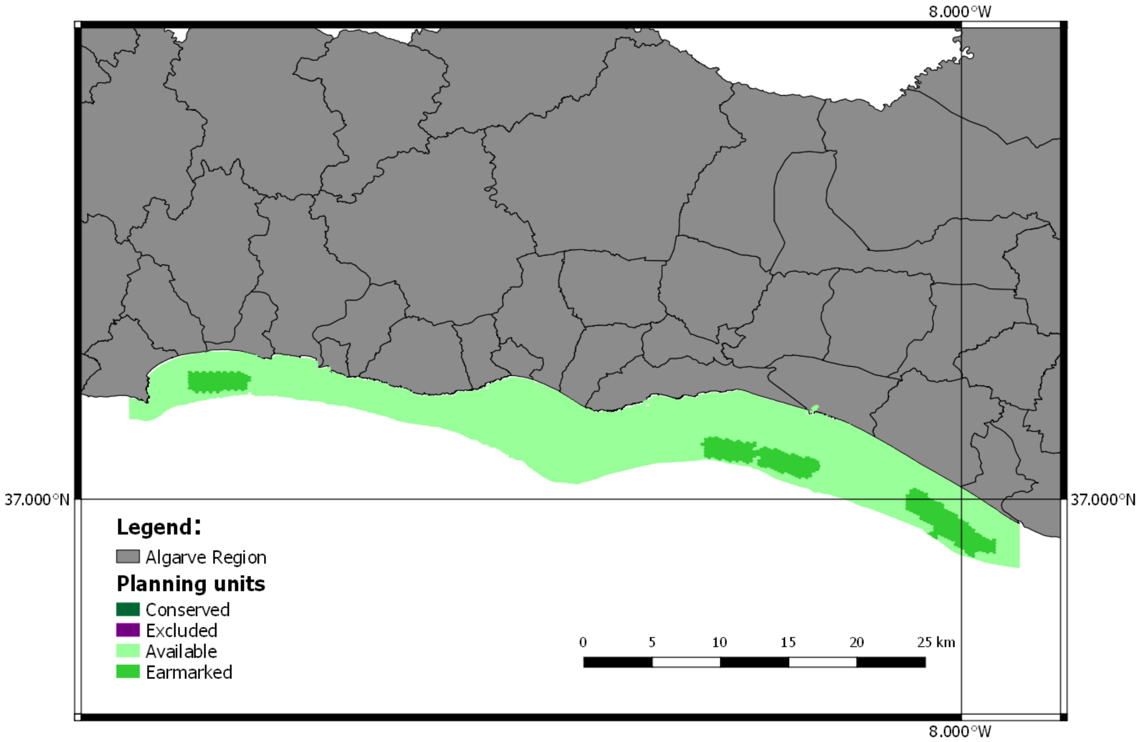

Figure 3 - Planning unit status for Local scenario (B). Earmarked areas are artificial reefs.

Marxan Models and Minpatch

After all the input data was processed, 100 models with $1x10^9$ iterations were performed for each scenario. To find out the adequate BLM, SPF values, a calibration tool from the CLUZ plugin was used. This tool completed over 1500 runs with $1x10^7$ iterations, with BLM values between 0 and 8, and SPF values between 0 and 50, testing different combinations to identify the optimum value. The output provided a range of information, including total portfolio costs, the number of units used and average portfolio minimum target proportion met, which were analysed to understand what would be the optimal parameters based on recommendations in the literature (Ball *et al.*, 2009; Watts *et al.*, 2017).

After this preliminary analysis, it was decided to set the BLM value to 0 in both scenarios and the SPF value to 1 in the Regional scenario and 2 in the Local scenario. Higher BLM and SPF values were discarded since they increased the costs and unit usage while not offering any significant added protection.

Following this step, MinPatch was used to modify the outputs and reduce the excessive fragmentation that was present in the models but also to ensure that all suggested reserves were above the minimum threshold. The minimum size established for an MPA was 5 km^2, based on previous literature, which used results of acoustic telemetry studies of some Portuguese commercial and ecological key species to estimate their home range (Abecasis *et al*., 2017 and references within). This is an important step to make in every similar project, to effectively promote the dispersion of species and protect offspring, while also protecting their home range, fostering a long-term improvement in the species stocks, (Di Franco *et al*., 2012; Shanks *et al.,* 2003).

Results

Regional Scenario Models (A)

The outputs provided from Marxan in the Regional scenario had far more MPA's than the outputs optimised by MinPatch, despite the targets being met equally in both situations. There were only a few targets missing. However, at least 99% and 90% of those missing targets were achieved in A.1 and A.2 respectively. The summary of the regional scenario can be found in table 10. As expected, MinPatch removed excess features selected by Marxan and rearranged the remaining ones, thus reducing the number of protected areas while increasing their size and maintaining the minimum size threshold established. Nevertheless, the total amount of features used by each software was very similar. Additionally, the median MPA size in both scenarios was equal to the planning unit size in Marxan while in MinPatch, it was larger than the minimum size established (5km^2).

Table 10. Summary of Marxan and MinPatch runs for the Regional scenarios (A.1 and A.2).

	Regional (A)	
	Fixed Protection (A.1)	Variable Protection (A.2)
Total Area Cost	39402	39402
Portfolio Cost (MinPatch)	12723	11032
Portfolio Cost % (MinPatch)	32.29%	28.00%
MPA number (Marxan)	256	115
MPA number (MinPatch)	19	23
All Targets met	-1(>99%)*	-3(>90%)*
Total Planning Units	12393	12393
Planning Units Count (Marxan)	3694	3167
Planning Units Count (MinPatch)	3576	3205
Planning Units used (MinPatch)	29.81%	25.55%
Median MPA size (Km^2) (Marxan)	0.25	0.25
Median MPA size (Km^2) (MinPatch)	6.5	7.2

Total MPA area (Km^2) (Marxan)	1061	966.9
Total MPA area (Km^2) (MinPatch)	1102	974.5
Median Distance Between MPA's (Km^2)	8.2	5.4
Minimum Distance Between MPA's (Km^2) (MinPatch)	1.4	1.4
Maximum Distance Between MPA's (Km^2) (MinPatch)	64.7	110.1

*All targets were met except -n, however at least x percentage of the missing targets were met.

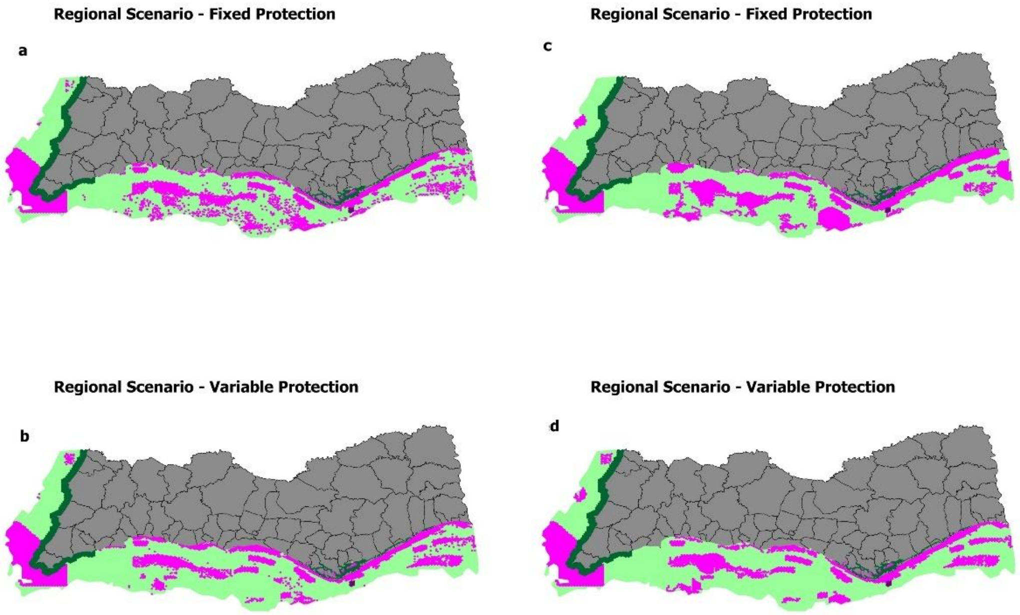

Figure 4 - Regional Scenario Outputs. Models a) and b) are Marxan outputs. c) and d) are models optimised by MinPatch.

Local Scenario Models (B)

The same observations could be done for the Local scenarios, with MinPatch reducing the number of MPA’s by establishing the minimum size threshold. The summary of the Local scenario can be found in table 11. Nevertheless, in both Local scenarios, the Median MPA size almost doubled the extent observed in the Regional scenarios, and the estimated portfolio cost was slightly lower. All the targets were met except three targets in B.1 and 2 targets in B.2. However, at least 98% and 95% of those missing targets were met, respectively.

Table 11. Summary of Marxan and MinPatch runs for the Local scenario (B.1 and B.2)

	Local (B)	
	Fixed Protection (B.1)	Variable Protection (B.2)
Total Area Cost	15599	15599
Portfolio Cost (MinPatch)	4680.5	4085
Portfolio Cost %	30.01%	26.19%
MPA number (Marxan)	93	60
MPA number (MinPatch)	8	7
All Targets met	-3 (>98%)*	-2 (>95%)*
Total Planning Units	4824	4824
Planning Units Count (Marxan)	1569	1392
Planning Units Count (MinPatch)	1586	1463
Planning Units used (MinPatch)	32.52%	28.86%
Median MPA size (Km^2) (Marxan)	0.075	0.075
Median MPA size (Km^2) (MinPatch)	13.3	13.2
Total MPA area (Km^2) (Marxan)	110.1	100.5
Total MPA area (Km^2) (MinPatch)	116.2	104.1
Median Distance Between MPA's (Km^2)	5.6	5.4
Minimum Distance Between MPA's (Km^2) (MinPatch)	2.9	2.9
Maximum Distance Between MPA's (Km^2) (MinPatch)	49.8	49.9

*All targets were met except -n, however at least x percentage of the missing targets were met.

Figure 5 - Local Scenario Outputs. Models a) and b) are Marxan outputs. c) and d) are models optimised by MinPatch.

All the individual maps for each scenario can be found in the annexes for further analysis (Fig. A1 to A13).

Discussion

Conservation planning software presents itself as a very supportive tool for achieving optimal designs for marine protected areas (Smith *et al*., 2010) and the software used in this project, Marxan, is one of the most widely used (Ball *et al*., 2009). Through optimisation with MinPatch, the outputs generated can offers various optimised solutions, in both regional and local scale, presenting a useful tool to promote debate among stakeholders.

Considering that there is an urgent need to raise the protection levels practised, not only in Portugal but also around the world, the importance of this work becomes clear since it offers realistic, balanced and practical designs, which make it possible to move forward and set new milestones. However, it is always important to keep in mind, that outputs produced by this kind of software, should be interpreted as the starting line, rather than the final result (Smith *et al*., 2009).

To that end, with this framework it is possible to improve the solutions over time, with both updated and new data, thus allowing for constant evolution to reach an optimal point. Additionally, this project also intends to innovate by introducing fishing data into the equation, along with a ranking method to establish priority habitats, which can serve as proxies for biodiversity (Smith *et al*., 2009) and species, whether they are under special conservation status or not. Furthermore, it offers two possibilities, an ambitious 30% fixed protection scenario meant to achieve the latest agreements in biodiversity conferences. This level of protection is compatible to some point with sustainable fisheries (Krueck *et al*., 2017) and while still effective in protecting biodiversity (Sale *et al*., 2005). On the other hand, a variable protection scenario, with lower costs and area usage aimed for governments that are reluctant to invest heavily in conservation. Nevertheless, it still offers considerable protection levels with regard for species and habitats with special conservation status and within the targets set by biodiversity conferences, being already an essential first step for more ambitious and conservative plans.

Also, the output of this project contains several areas which are already under special conditions, such as ZPE's and the artificial reefs, due to their ecological relevance. Both Marxan and MinPatch outputs considered that these had excellent conservation value despite their costs. Including such areas in this new protection plan facilitates implementation since stakeholders already recognise their importance, pushing the process to the next step, which is efficiently protecting the areas instead of only considering them as important.

The ZPE's included in the Regional scenario, "Costa Sudoeste" and "Ria Formosa" are an extension of the existing marine protected areas which have not been classified as protected yet.

"Costa Sudoeste", has been attributed great significance mainly due to its value as a migratory corridor for many bird species, including the Bonneli's Eagle (*Hieraaetus fasciatus*), the Short-Toed Snake-Eagle (*Circaetus gallicus*) and the Peregrine Falcon (*Falcus pereginus*). It is also relevant to refer that this location constitutes the last known habitat in Portugal for nidification of Osprey's (*Pandion haliaetus*) and the only known worldwide area of marine cliffs where nidification of White Stork (*Ciconia ciconia*) occurs (ICNF, 2016).

"Ria Formosa" is considered to be one of the most important and unique places in Portugal to migratory and whole year resident bird species (Farinha *et al*., 2001) with at least 20000 aquatic birds being regularly present (ICNF, 2016). Furthermore, it is home to many of the most important bivalve species in the region, much appreciated in the local gastronomy, such as the Sword Razorshell (*Ensis siliqua*), the Edible Cockle (*Cerastoderma edule*) and the Grooved carpet shell (*Ruditapes decussatus*) (ICNF, 2016). Concerning fish species, it is recognised as an important nursery area to several economically important species such as the Gilthead Seabream (*Sparus aurata*), the European bass (*Dicentrarchus labrax*), the sole (*Solea senegalensis*) and the European eel (*Anguilla anguilla*) (Erzini *et al*., 2002; ICNF, 2016; Veiga *et al*., 2010).

Regarding the artificial reefs, studies have demonstrated the increase in fishing yield in the structures placed in Algarve (Santos & Monteiro, 1997, 1998; Whitmarsh *et al.*, 2008). Although the full impact of the placement of the artificial structures is not yet determined, there are studies suggesting their economic benefits will improve in the long-term (Whitmarsh *et al*., 2008).

Finally, the already existing marine protected areas (Parque Natural da Ria Formosa and Parque Natural do Sudoeste Alentejano e Costa Vicentina) are complemented with new areas, highlighting the areas around Ria Formosa, whose protection was greatly expanded to the surrounding channels and coast, proving better connection between the existing patches and increased area for the local species. However, it is important to be aware that the existing MPAs do not possess a management plan, being considered at the moment as “paper parks” (Horta e Costa, 2017).

Knowing this leads to common constraints when dealing with MPAs, starting with the immediate costs of implementation and the long-term expenses related to management of marine protected areas. Since no-take zones would be created, all activities in the protected areas would have to cease. In this project, the immediate costs estimated would range between 25-30% of the total area cost. To have a better understanding of the meaning of this value, there was an attempt of making a rough estimation of the regional cost by collecting data from reports of the National Statistics Institute. This estimation provided value between 14-15 million euros per year for the Variable scenario and 17-18 million euros per year for the fixed scenario. This amounted only to the total value of commercial landings in the Algarve fishing ports. However, it important to be aware that this value includes fishing done outside of the 100m depth area which was not within the scope of this project, meaning that the true amount for this area should be smaller. Nevertheless, successful examples of sustainable income creation in marine reserves exist and can be taken into consideration to create a successful case. (Asafu-Adjaye & Tapsuwan, 2008; Uyarra *et al.* , 2010; Videira *et al*., 2006; White *et al.*, 2002). Regarding management, the current state of Portugal management plans would not be enough to create multiple no-take areas effectively (Horta e Costa, 2017). To do so, enforcement would have to be considerably increased, further increasing the costs. However, this is a necessary measure to take if the plan of conserving the environment is to go forward.

The majority of costs when implementing MPAs comes from fisheries. Fishing pressure is, for starters, one of the main reasons why MPAs had to be created (Brady & Waldo, 2009; Sumaila *et al*, 2000). This project is focused in the area down to 100 meters, which is the most common area for small-scale fishermen, with particular attention to the Ria Formosa, one of the most important fishing grounds for bivalves and crustaceans which fuel the local commerce (Veiga *et al*., 2010). Moreover, other significant fishing sites are also within the protection proposals made by this study. The area covered by the ZPE "Costa Sudoeste" fully englobes one important fishing site in the Southeast of Sagres and partially covers another valuable fishing area between Sagres and Ponta da Piedade. Baia de Pêra, one of the most important biodiversity hotspots (Gonçalves *et al.*, 2007, 2008, 2015) and therefore, a very sought-after area for fishermen, is also targeted for protection in both Local and Regional scenarios. This could create some difficulties in negotiations since many traditional fishing sites would be restricted. Despite only around 20% of the fishing yield being attributed to artisanal fishing it still directly employs approximately 17 thousand people nationwide, with many of them still living in precarious conditions due to low income, requiring considerable attention when dealing with this topic (Viegas, 2010). Nevertheless, the fishing community can be involved in the sustainable touristic exploration of the marine protected areas due to their vast knowledge of the areas but also to conserve and promote their tradition and lifestyle (Helvey, 2004). There are also other sectors and activities to be taken into consideration, such as aquaculture, marine traffic, which can be quite impactful to biodiversity (Abdulla & Linden, 2008; Read & Fernandes, 2003) hence requiring detailed discussion with the respective stakeholders. Other recreational activities such as diving can also be an added element for the valorisation of the marine reserves and function as a support for maintaining a healthy income to manage the MPAs (Asafu-Adjaye & Tapsuwan, 2008). Of course, all of this would require a significant change in the community structure and lifestyle. However, it is another necessary step to preserve the environment before it is too late.

To avoid complications with the fishing community and other anthropogenic activities, marine protected areas are sometimes established in remote locations with low ecological relevance and usually quite fragmented, thus failing to achieve proper connectivity between areas (Margules & Pressey, 2000; Mora *et al*., 2006; Struhsaker *et al.*, 2005). Lack of connectivity may be a significant limitation to success in marine reserves, impairing different life cycles of species by hindering their natural movements and dispersal (Almany *et al*., 2009; Botsford *et al*., 2009; Magris *et al*., 2014). In this project, due to its relatively small-scale connectivity should not present an issue, as the maximum recommended distances between MPA's tend to vary between 10 and 150km (Di Franco *et al*., 2015; Shanks *et al*., 2003), being compatible with what is proposed in this project, with the maximum distance being 110 km in the A.2 scenario. The minimum threshold used for marine protected areas (5 Km^2) was meant to protect key species, by being at least twice the size of their home range and to reduce fragmentation of protected areas, which is a common Marxan issue (Abecasis *et al*., 2017; Green *et al*., 2015). If data about such dispersal rates is not available, proxies can be used to try to cover up what is lacking (Abecasis *et al*., 2017).

It is not a long walk to achieve good representativity in a marine network since there are good base references to convince stakeholders (Jones & Carpenter, 2009). Allied with potential for spillover effect and sustainable touristic income the first step towards a realistic and effective conservation plan can be taken.

Limitations

Both Systematic Conservation Planning and software design to that end requires detailed baseline information and further data to produce reliable outputs (Margules & Pressey, 2000; Smith *et al*., 2009). However, it is not always easy to find or have access to such information. In this project, some limitations did not allow the outcome to be further polished. Such restrictions were:

- Access denied to data. A few institutes and authorities refused to provide data that would be relevant to the project.
- Unreliable data. Often, data would be complicated to interpret, due to the lack of metadata or due to the use of unreliable methods to achieve its purpose.
- Lack of any data. Despite efforts of projects like EMODnet and RENSUB that try to compile and provide the public with relevant information, there are still many locations that lack proper research. Nevertheless, since this project adopted a precautionary strategy, the impact of this limitation was reduced.
- Data never arrived or arrived too late. There were also a few cases where data would be available, but the owners never sent it, or if they did, it was already at very late stages of the project when they could not be analysed correctly and in time.

It is also important to refer that no data of fishing boats between 9 and 15 meters could be included in this study since it was not available.

Furthermore, other issues that hindered the process are related to the software itself, since it requires substantial processing power when dealing with a significant amount of: Conservation features, Planning units, and study area. Additionally, open source software developed and maintained by the community can present errors and bugs sometimes quite challenging to overcome.

Nevertheless, these limitations were solved adequately and the results were obtained with confidence.

Conclusion

This project offers multiple solutions for a much-needed increase in protection to habitats and species, with a higher cost high protection scenario (30%) that meets conservations target established by the World Parks Congress and a lower cost, with variable protection that still meets the minimum targets to be achieved by 2020. Nevertheless, more detailed information about fishing, vulnerable habitats and species distribution is needed to create more efficient designs. A long-term monitoring plan is also required to understand the effects of the creation of the MPA's, which should always be followed by a flexible management plan that can adapt to unexpected situations.

In sum, this framework can function as a support tool not only for stakeholders but also to researchers that desire to pursue similar studies in other regions. Additionally, the data collected can also be used as a baseline for future projects both in Algarve and Portugal.

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Annexes

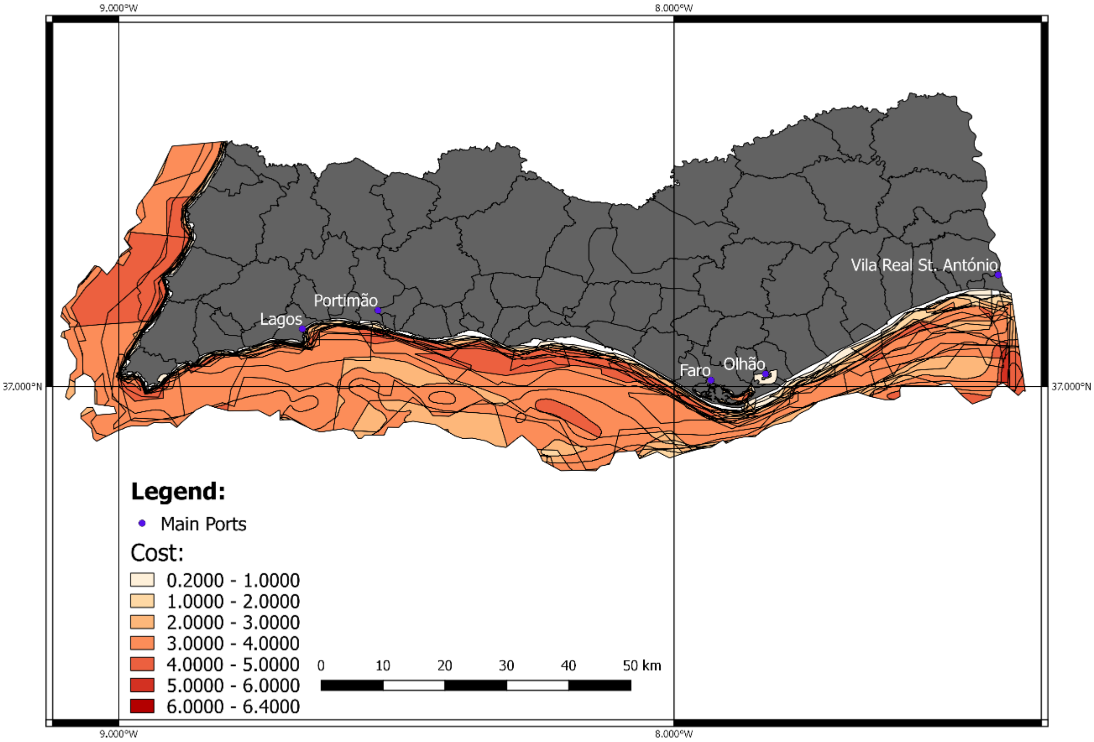

Figure A1 – Final output of the cost layer after summing all the costs from artisanal boats (<9m) and coastal boats (>15m).

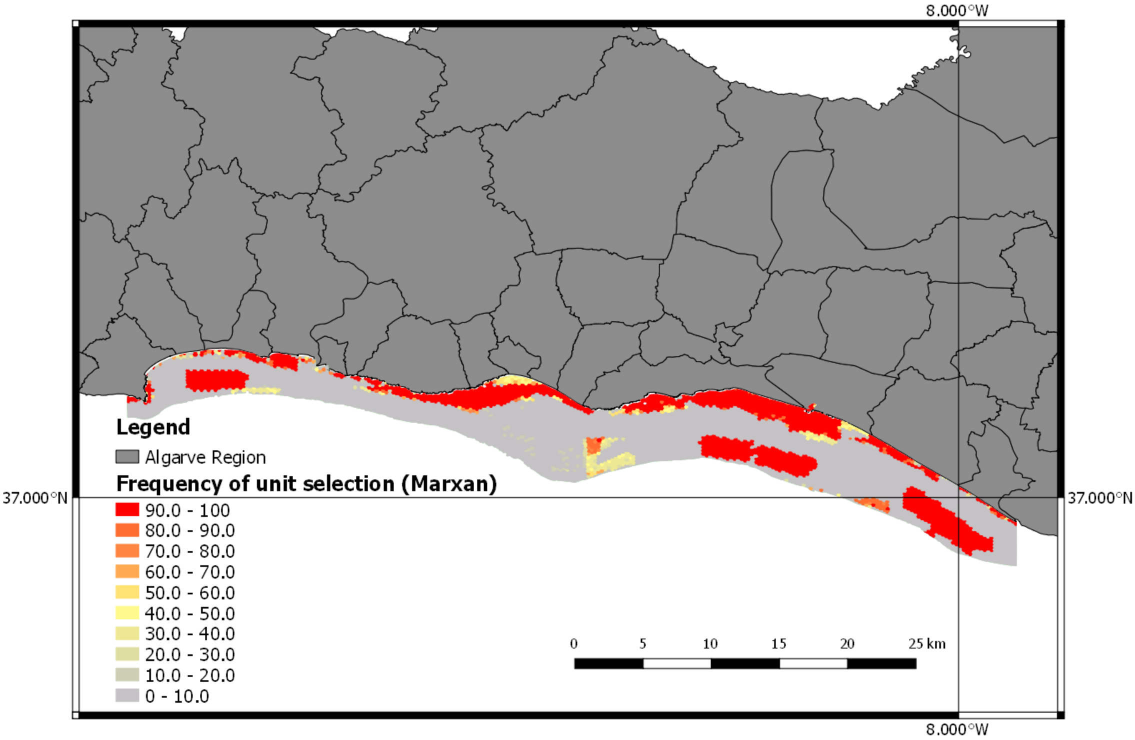

Figure A2 – Frequency of unit selection by Marxan for the Local scenario with variable protection.

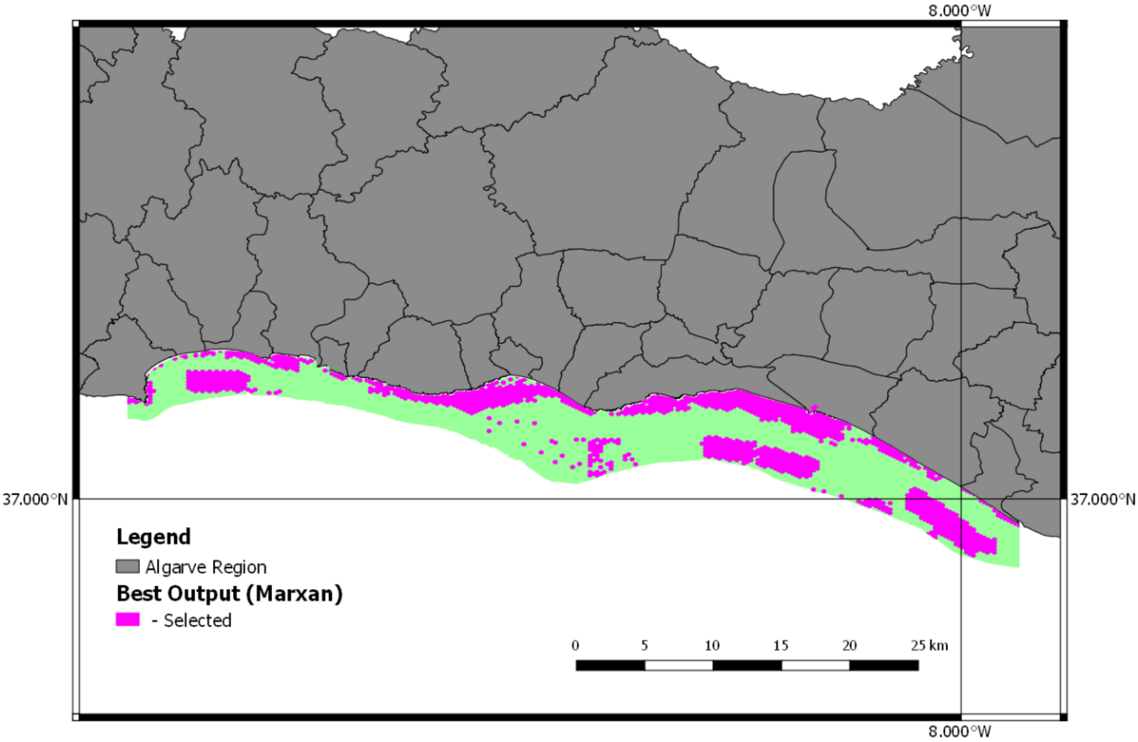

Figure A3 – Best Marxan output for the Local scenario with variable protection.

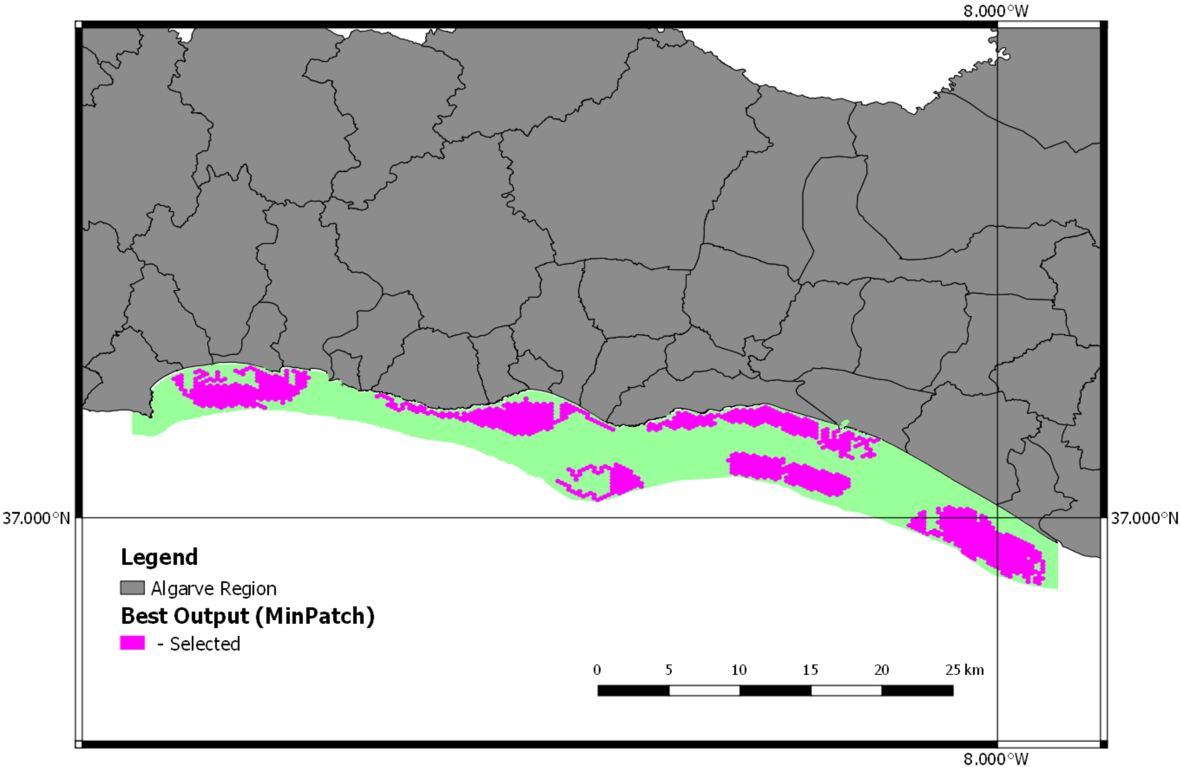

Figure A4 - Best MinPatch output for the Local scenario with variable protection.

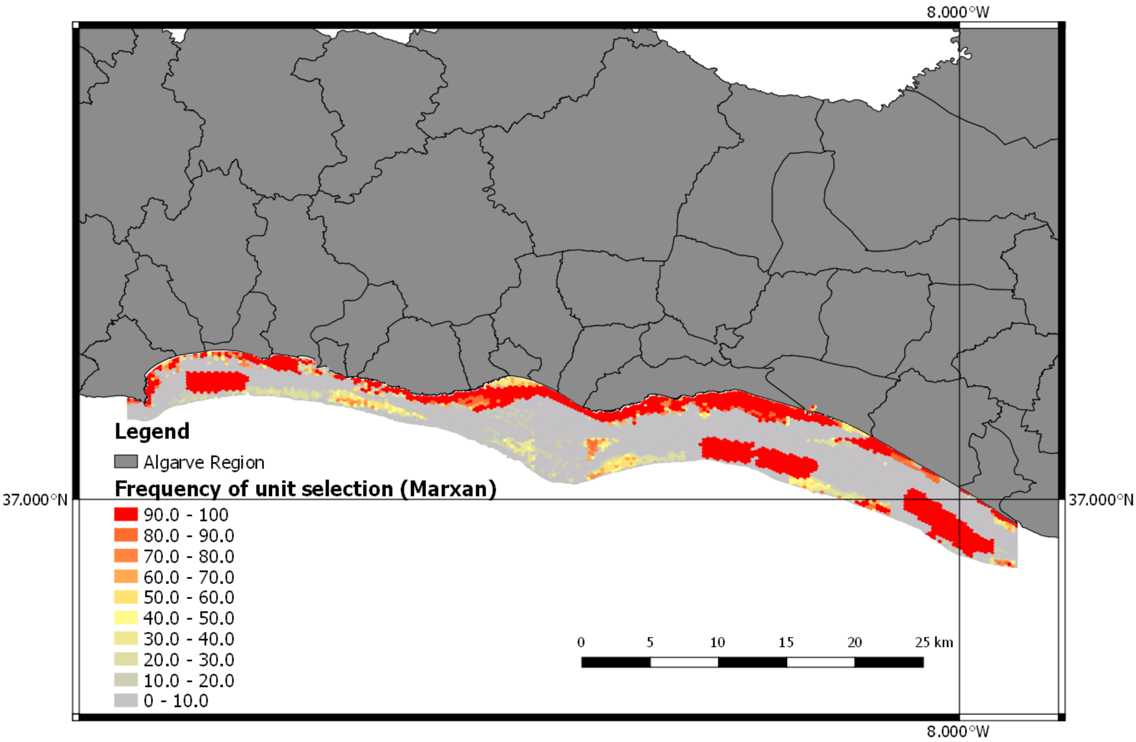

Figure A5 - Frequency of unit selection for the local scenario with fixed protection.

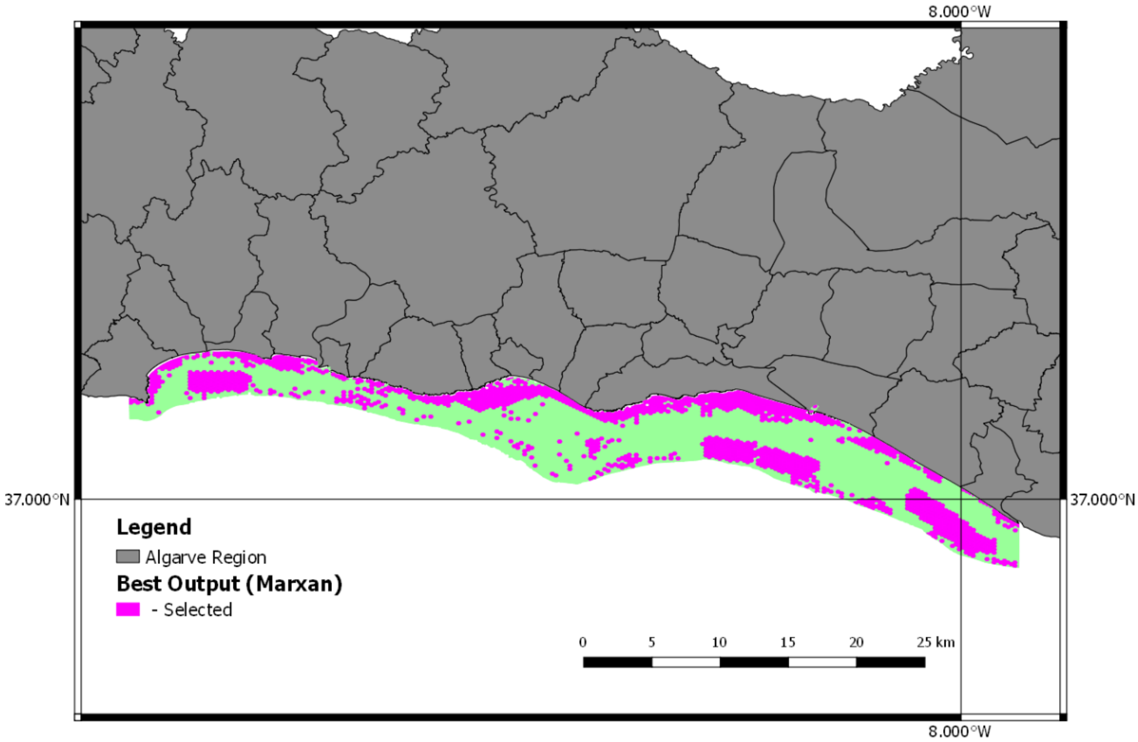

Figure A6 – Best Marxan output for the Local scenario with fixed protection.

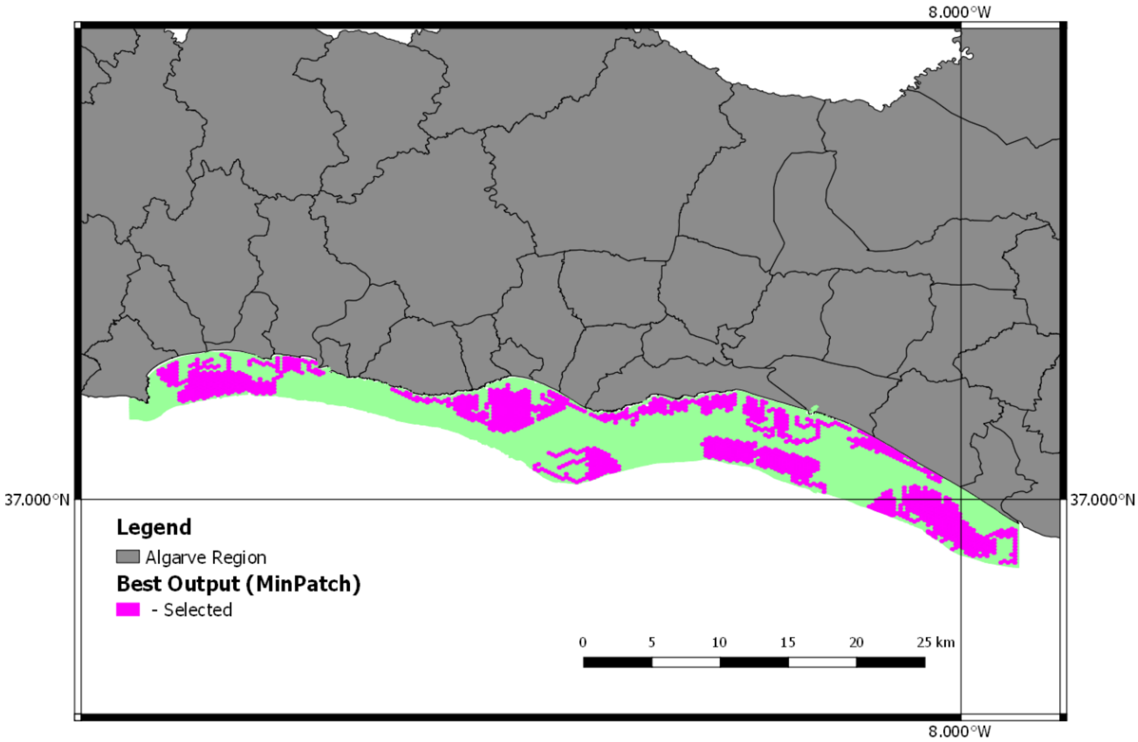

Figure A7 - Best MinPatch output for the Local scenario with fixed protection.

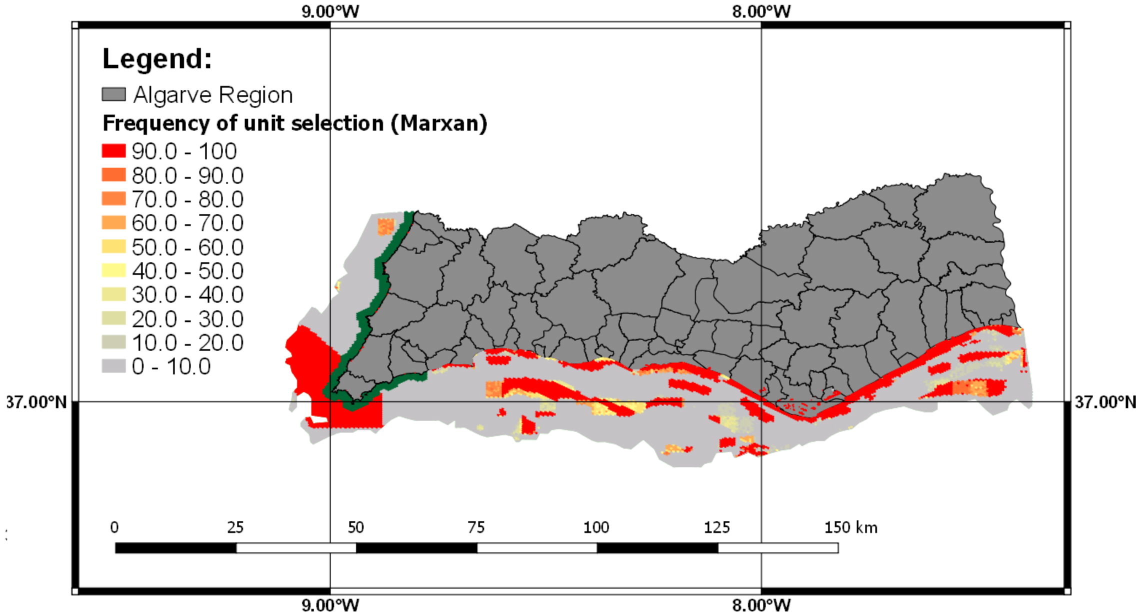

Figure A8 - Frequency of unit selection for the Regional scenario with variable protection.

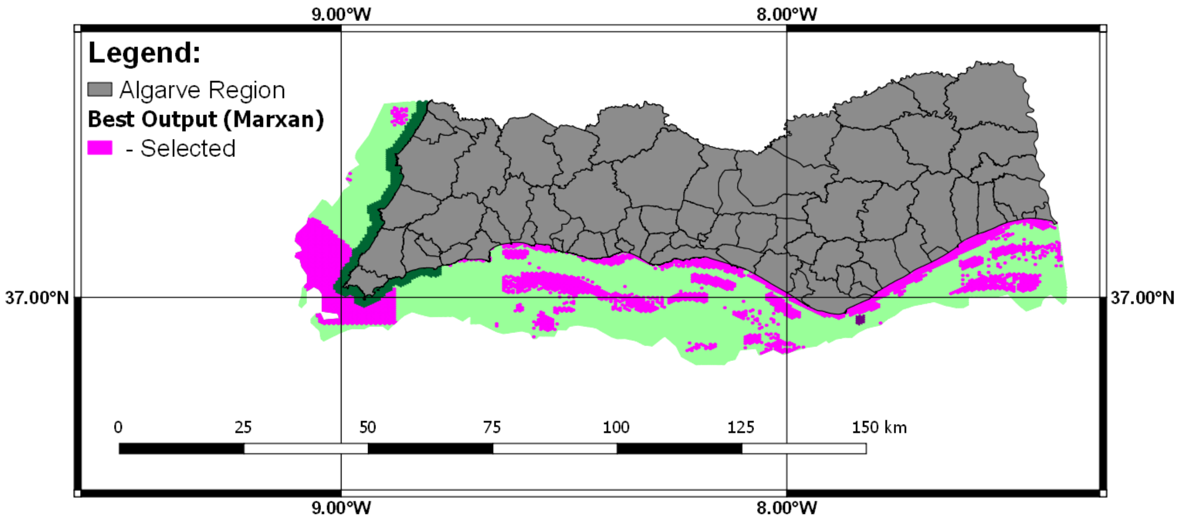

Figure A9 – Best Marxan output for the Regional scenario with Variable protection.

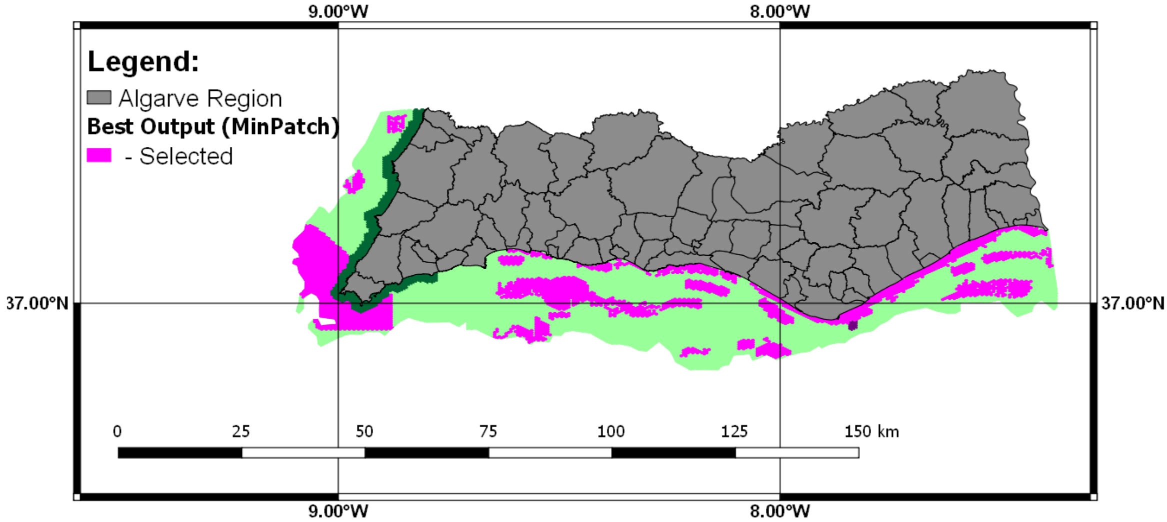

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Figure A10 - Best MinPatch output for the Regional scenario with Variable Protection.

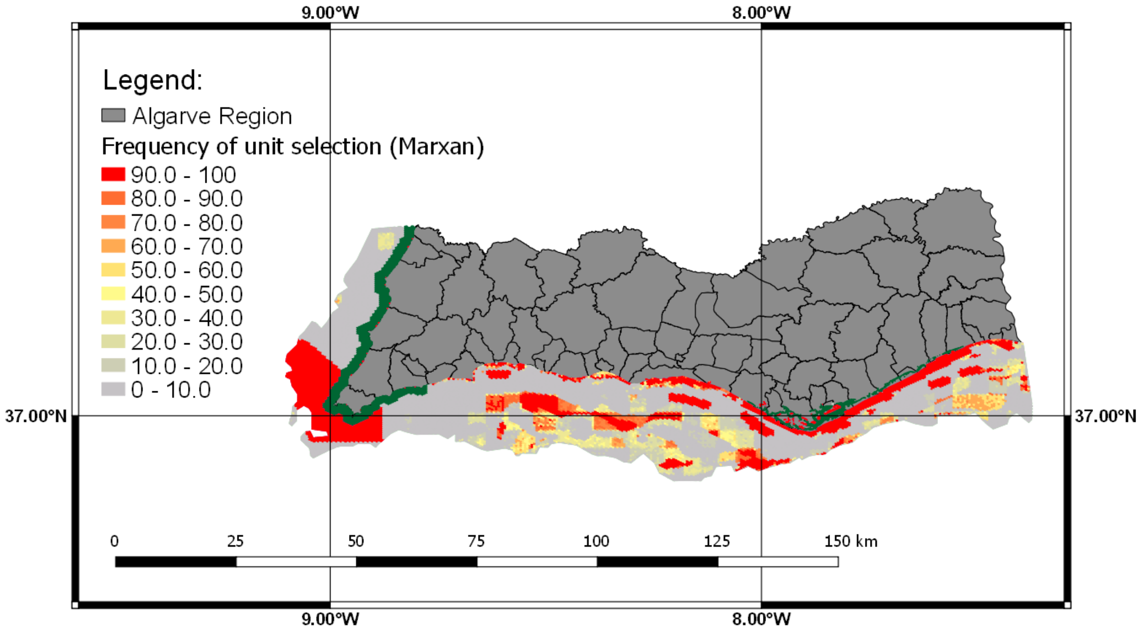

Figure A11 - Frequency of unit selection for the Regional scenario with fixed protection.

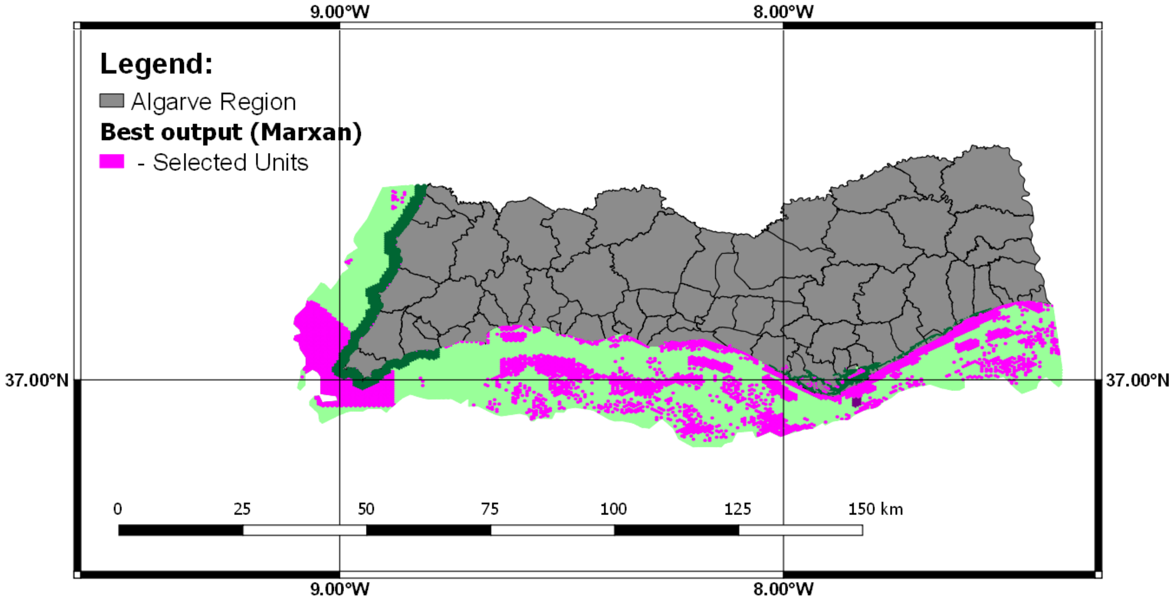

Figure A12 - Best Marxan output for the Regional scenario with Fixed protection.

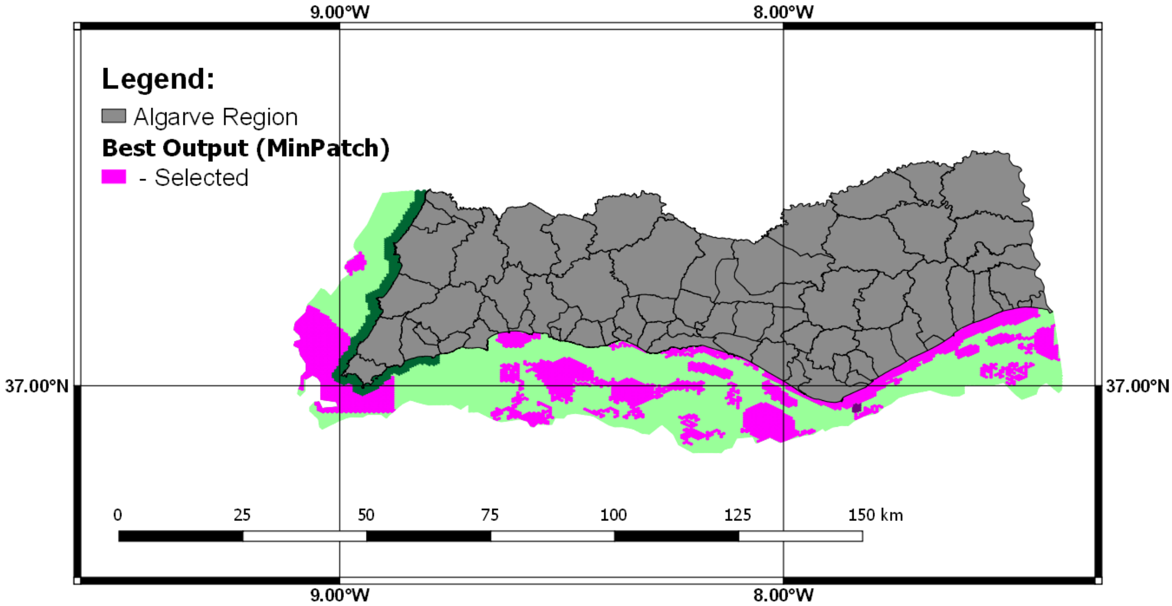

Figure 613 - Best MinPatch output for the Regional scenario with Fixed protection.