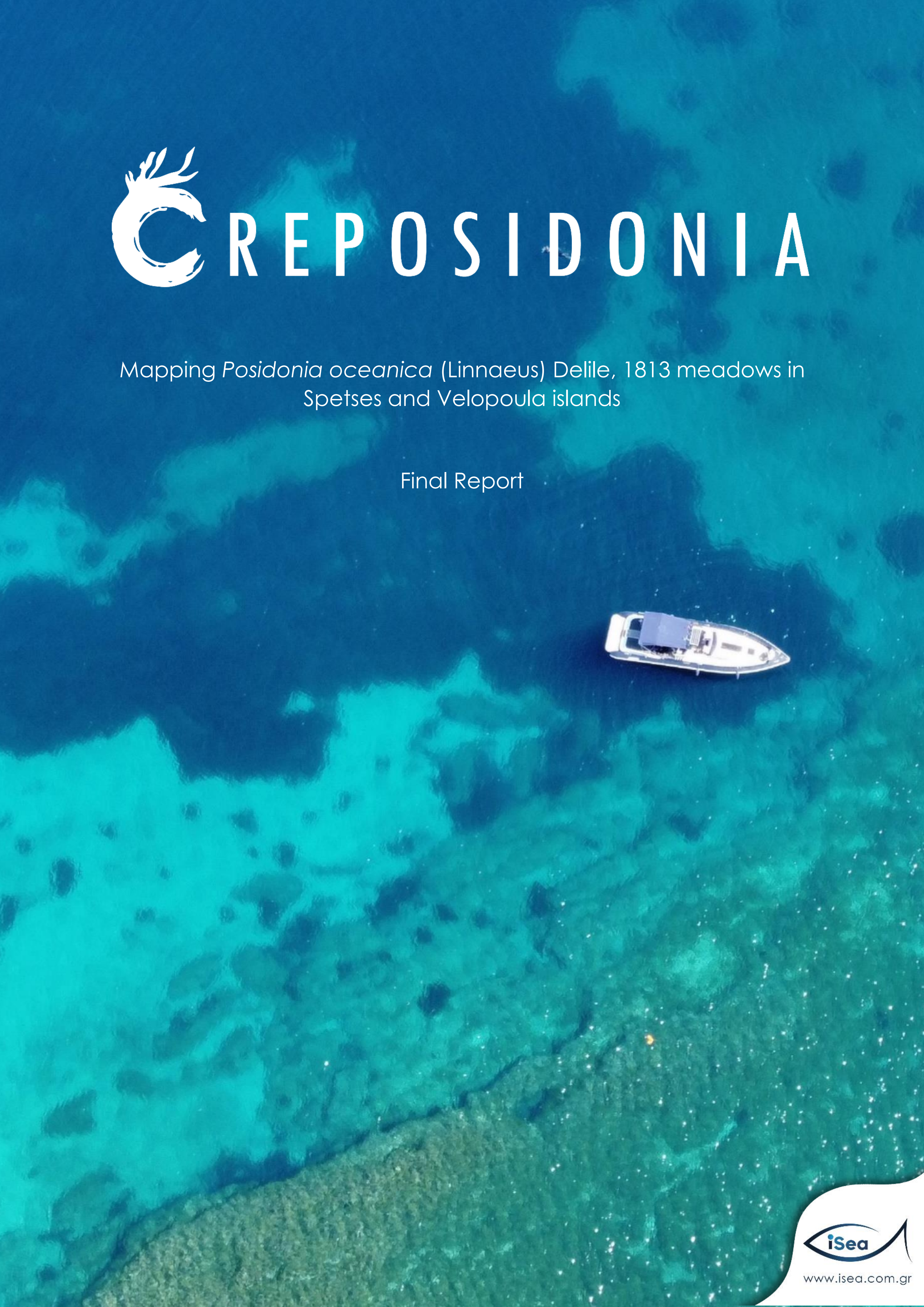

CREPOSIDONIA

Mapping *Posidonia oceanica* (Linnaeus) Delile, 1813 meadows in Spetses and Velopoula islands

Final Report

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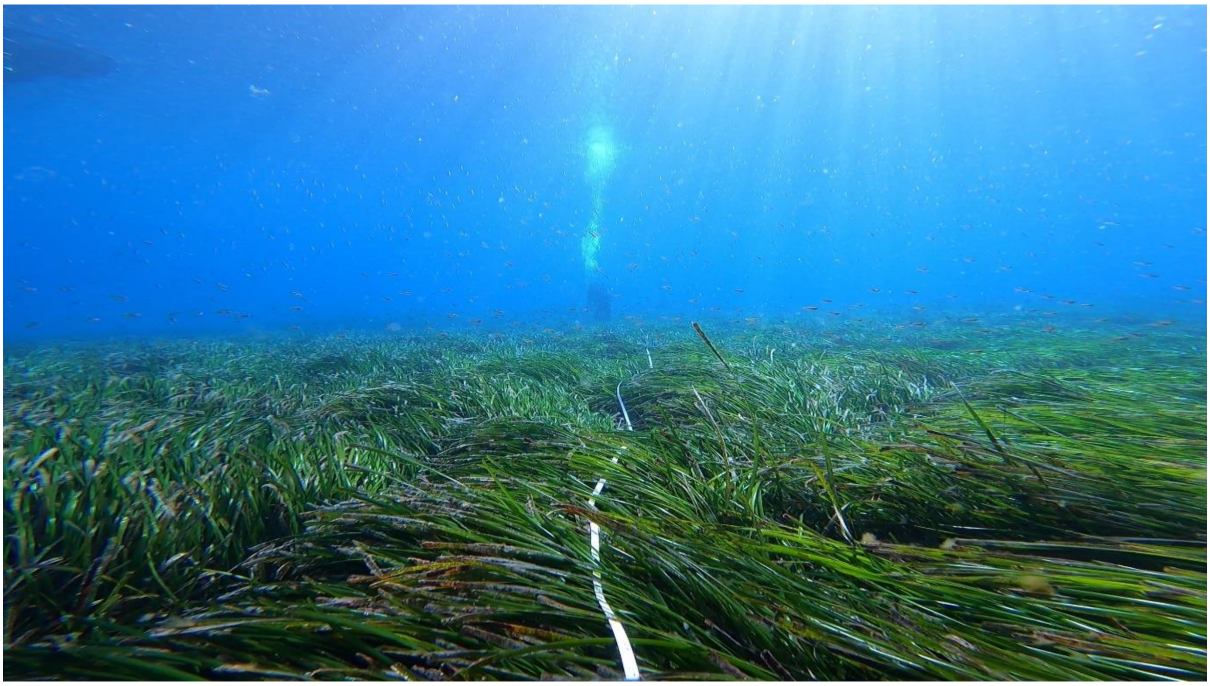

Declaration of conflict of interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this report.

Funded by:

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Introduction

REPOSIDONIA, is one of the main projects, that falls under the scope of the Vulnerable Species pillar of iSea. It is an umbrella project that aims at the protection and the preservation of the priority habitat that P. oceanica constitutes to the point it fulfils its ecological role in a healthy marine ecosystem through various ecosystem functions and services. Through the REPOSIDONIA project, iSea aims to contribute to the management and protection of the P. oceanica seabeds in Greece, as it is one of the most important coastal habitats in the Mediterranean, providing nursery and hunting grounds for many species (Pergent et al. 2016), among other services. To achieve this, the project has four main thematic units of activities (i) increase the scientific knowledge about the distribution and coverage of P. oceanica meadows in the Greek Seas (ii) conduct biodiversity surveys and health assessments for the meadows (iii) estimate the mapped meadows' Blue Carbon potential to propose science-based management measures, and finally, (iv) educate and sensitise key stakeholders to propose target management actions for these habitats, highlight the important ecosystem services offered by the meadows. In this context, iSea uptook the mapping of Posidonia oceanica in Spetses and Velopoula island, with the support of the Argolic Environment Foundation and in collaboration with terraSolutions.

Importance of P. oceanica

Posidonia oceanica, is an endemic phanerogam plant of the Mediterranean Sea (Boudouresque et al. 2006). Also known as Neptune Grass, it is one of the most common species of seagrass in the Mediterranean, along with *Cymodocea nodosa*, and *Zostera marina*. *P. oceanica* has the largest size among Mediterranean phanerogams (Traganos et al. 2022). The plants consist of plagiotropic or erect stems, usually buried in the sediment, called rhizomes. Rhizomes also have roots that can grow to 70 cm beneath the surface of sediment. Its leaves form all year around and live between 5 and 8 months. The length of its leaves reaches up to 1.2 meters and their density can reach up to 1,000 per square meter (Díaz-Almela & Duarte, 2008). In Greece, Neptune's Grass is present along the majority of the mainland coasts and the islands, mostly to the protected sites from the dominant northwest winds. In the Northern Aegean Sea, its meadows can extend down to 25 meters, while in the South Aegean Sea to 35 meters (Gerakaris et al., 2014, Poursanidis et al., 2018), depending on many factors but primarily water clarity and local oceanographic conditions. In the Ionian Sea, a highly oligotrophic area, the meadow can reach depths up to 45 m depth (Gerakaris et al., 2014, Traganos et al. 2018).

Posidonia oceanica along with the Coralligenous/Biogenic habitats is the most important Mediterranean marine ecosystem (Giakoumi et al. 2013). The role of *Posidonia oceanica* meadows in marine coastal environments is often correctly compared to that of the forest ecosystems in terrestrial environments, as they constitute the basis of the richness of coastal waters in the Mediterranean Sea. By producing enormous quantities of vegetal biomass, the meadows form the basis of many food webs (McRoy & McMillan, 1977). This primary production is comparable to or greater than that of other high production environments, whether terrestrial or oceanic (Fergusson et al. 1980). In addition, *P. oceanica* meadows constitute a spawning ground, a nursery or a permanent habitat for a lot of species (over 400 different plant species and several thousand animal species populate the meadows of which many commercially important species; Pergent et al. 2016), making these underwater meadows a unique biodiversity hotspot (Boudouresque et al. 2012). Furthermore, *P. oceanica* is considered an "ecosystem engineer" as it stabilises the sediment with its roots and changes the hydrodynamic status of the sublittoral zone and protects from erosion (Pergent et al., 2012). Besides, it serves as a purifier as it improves the water quality by reducing particle loads (Hemminga & Duarte, 2000). Moreover, the plants produce large amounts of atmospheric oxygen, while also removing atmospheric CO_2. Through this process, the meadows can store large amounts of organic carbon, serving as long-term carbon storages (Pergent et al. 2012). Finally, their rhizomes concentrate radioactive substances, synthetic chemicals and heavy metals, reducing the levels of such persistent contaminants in the water column. Hence, *Posidonia oceanica* is also used as a 'biological quality element' in the long-term monitoring programmes of the Water Framework Directive (WFD 2000/60/EC) and also according to the Marine Strategy Framework Directive (MSFD, 2008/56/EC) as an indicator for assessing the "Good environmental status" of coastal water bodies.

Study area

Spetses is a relatively small island with a total area of 22 km^2 and a coastline of 40 km, that is located in the Argolic gulf. Spetses belongs to the group of islands of the Argolic and Saronic gulf, making it an ideal tourist destination as it is easily accessible from the port of Piraeus while also being less than 2 km away from the Peloponnese mainland, from Porto Heli port. The municipality of Spetses consists of four different islands: Spetses, Spetsopoula, Velopoula and Falkonera. The only mapping effort of the *P. oceanica* meadows that exists for Spetses was conducted for the needs of Fisheries Bureau of Greek Ministry of Rural Development and Food and financed by European

Maritime, Fisheries and Aquaculture Fund (EMFAF) and government funds on the implementation of the Common Fisheries Policy (CFP). The maps produced were published in 2015 (Figure 1).

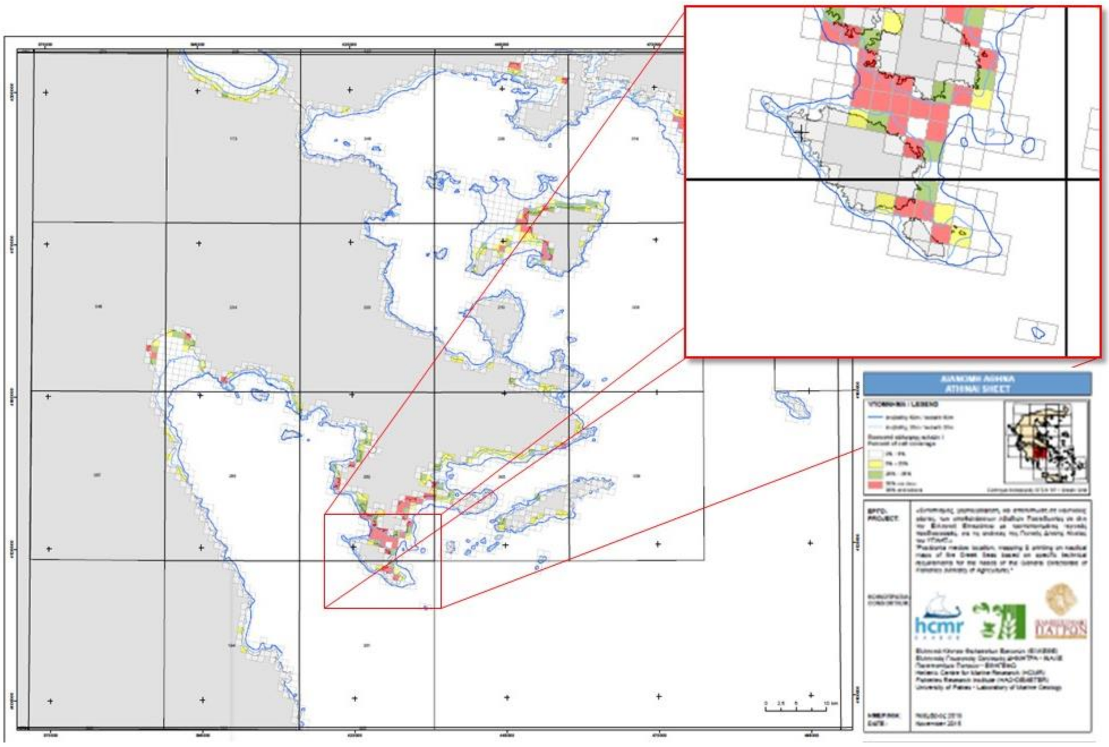

Figure 1: Adjusted by: Posidonia meadow location, mapping & printing on nautical maps of the Greek Seas based on specific technical requirements for the need s of the General Directorate of Fisheries (Ministry of Agriculture). November 2015.

However, the resolution of these maps is very low showing only a coverage percentage, which makes it impossible to be used as a management tool apart from the role it serves. The report's results showed that the highest coverage (>35%) of *P. oceanica* are located in the northern parts of the island, in the Kosta channel. Another area that is distinguished in the projects results as having high meadow coverage is located around Spetsopoula island, south-east of Spetses (5%-35% of coverage). This report was used to identify areas where trawling should be prohibited and concerns the entire Greece. It is worth mentioning that the Kosta Channel and the east coasts of Spetses have been protected from bottom trawlers since 1966 according to the article 8§10B of Β.Δ. 917/66 (ΦΕΚ 248Α) (Figure 2). The main pressures that are expected to affect the meadows in the area are deriving from touristic activities and coastal infrastructure.

In particular, the area expected to have the most extensive meadows exhibits the highest boat traffic around the island (Figure 3) with the most populated settlement and busiest ports of Spetses, located at its coasts, and the port of Porto Cheli situated across the channel.

Velopoula is an uninhabited island, located in the Myrtoan Sea, approximately 45km southeast of Spetses. Its total area is less than 2 km^2, the island was created by the area's intense volcanic activity and its coastline mostly consists of rocky cliffs, while the maximum elevation exceeds 200 m. In contrast to Spetses, Velopoula is undisturbed throughout the year with minimal boat traffic and few activities taking place in the surrounding waters such as fishing mostly by small scale fisheries. Velopoula and its surrounding waters are part of the NATURA2000 network since, belonging to the broader habitat's directive site: VRACHONISIA NOTIOU AIGAIOU: VELOPOULA, FALKONERA, ANANES, CHRISTIANA, PACHEIA, FTENO, MAKRA, ASTAKIDONISIA, SYRNA - GYRO NISIA KAI THALASSIA ZONI (Sitecode: GR4210011).

Figure 2: The area indicated in red stripes; trawling nets are prohibited. Source: Fisheries Control Directorate.

Although, it is suspected that the seabeds around Velopoula are covered with relatively undisturbed meadows due to the remoteness and low traffic of the region, the site's standard data form attributes only 0.032 km^2 to habitat 1120 (Posidonia beds) to the entire marine extent of the site. The maps provided by the Greek Ministry of Rural Development and Food also show that less than 5% of the areas around

Velopoula are covered with meadows. As mentioned above, these assessments are likely to underestimate the extent of the meadows around Velopoula, and the existing meadows are potentially in a pristine state due to the lack of anthropogenic activities in the area. However, to confirm the above statements, targeted actions are required for evaluate them and estimate their total area accurately.

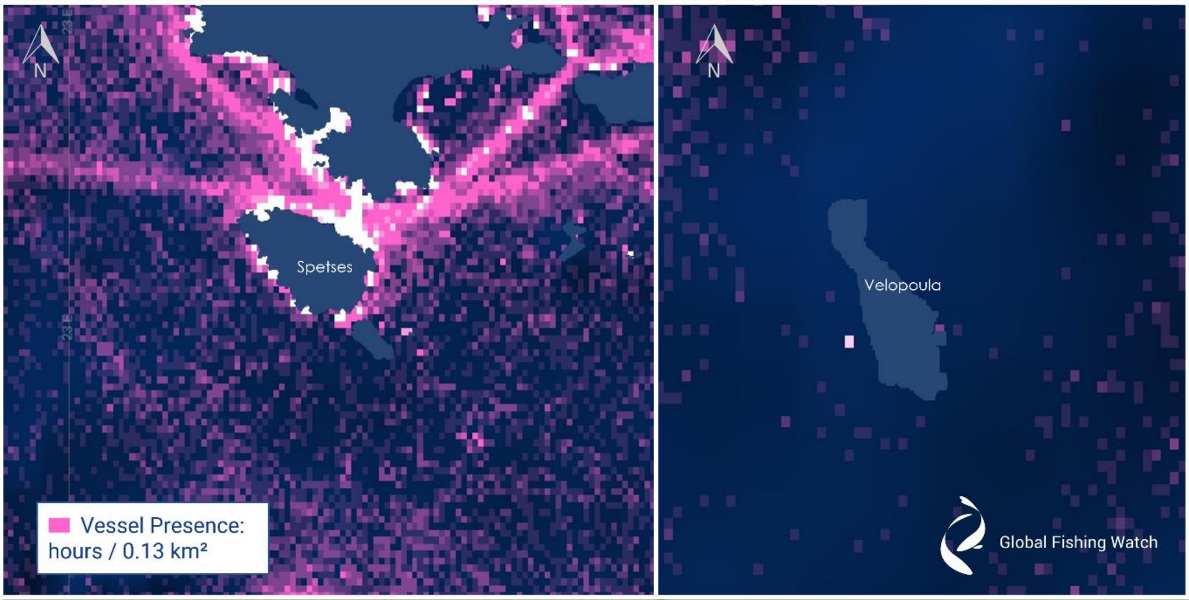

Figure 3. Boat traffic in 2021, demonstrated by hours per 0.13 km2. Source: Global Fishing Watch

Methodology & Results

1. Field activities

Figure 4. Recording in the camera the dead Posidonia mattes (matte morte) that is currently colonized by Cystoseira sp., in Velopooula island, April 2022

An important aspect of the mapping process was to obtain accurate ground truthing points, representing the different seabed habitats, which will be used as training data for the classification of the pixels in habitat types as well as for validation. On the 10th of April, iSea visited Spetses island to conduct the fieldwork activities. To obtain the ground truthing points iSea developed a plan for the samplings using free source satellite images from Google Earth, and consulting with the external collaborator, as the satellite image was not purchased at that point. The team tried to cover as much area as possible from the two islands giving an emphasis to the areas that Posidonia oceanica was suspected to be more extended. The areas visited are apparent from the ground truthing points collected (Figure 7). As the team could not dive in all areas of Spetses island due to port police restrictions, 4 sampling methods were developed: i) using an ROV, ii) circumnavigation with a boat (waters less than 10m deep.), iii) scuba diving and iv) snorkelling and apnoea. (Figure 5). To decide on which location the team was going to deploy the ROV, snorkel, or dive, a drone, provided by Spetses

Cruising (the boat rental company) was used to find meadows with large sand patches and mixed habitats.

Figure 5. The four methodologies deployed for attributing the different habitats to the ground truthing points; i) using an ROV, ii) circumnavigating with a boat, iii) scuba diving and iv) snorkelling and apnoea.

The coordinates for each specific point were listed along with the habitat type observed for each point. A GPS device (Garmin 22x) was used with a minimum accuracy of 3m. The team was careful to record each point, of habitats covering approximately 10 m2 to avoid the reduction of the accuracy of the habitat classification due to the GPS's accuracy. All the points were then transferred in a text file, along with the date taken, the coordinates and the affiliated habitat. The text file then was transformed into a shapefile using ArcGIS (Version 10.4) (attached with the report).

1.2. Defining the deep limit of the meadows

To define the deep limit of the meadows two field methods were used: i) scuba diving and ii) the ROV (PowerRay). Specifically, two dives were conducted one in Spetses' west side and one in Velopoula's east side. In Velopoula the deep limit was defined at ~25 m depth, while in west of Spetses at ~18m. However, the team had to check the deep limit in different regions and for those, two more efforts were made, in both islands using the ROV. Following, the characteristic coloration of the meadow, iSea navigated the boat vertically from the shore and when the boat reached a depth of 25m the ROV was deployed to the seabed and navigated to the deep limit, where the deep limit depth was recorded by the team.

Specifically, the field activities for Velopoula were conducted on the 12th of April 2022, while for Spetses were conducted in a three-day period (during the 11th, the 13th and 14th of April 2022), in order to visit different parts around the island and obtain information on the different habitat types.

2. Analysis workflow

The analysis consisted of 6 main steps. The steps are briefly described in the workflow below (Figure 5), and then are briefly explained in the following paragraphs accompanied with the produced results.

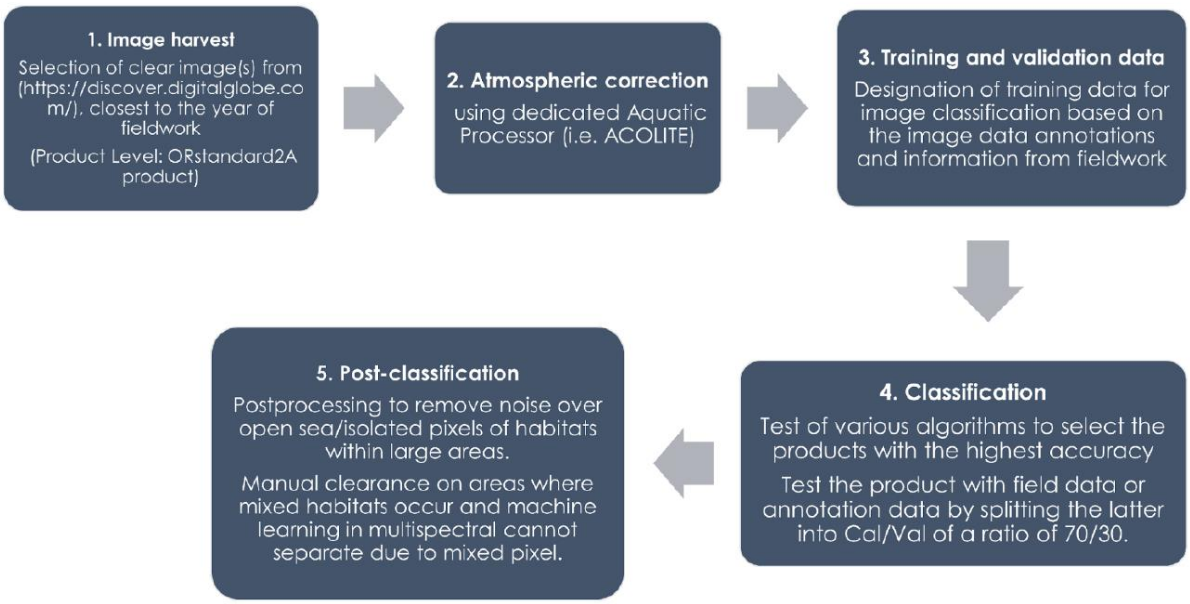

Figure 6. Workflow of the analysis followed for producing the final maps of P. oceanica meadows.

2.1 Image harvest

In order to produce high resolution maps of the meadows' full extent around both islands, high resolution satellite imagery of both locations was utilised. Specifically, the team used two different images collected by Maxar's WorldView 3 satellite, that offers 8 multispectral band imagery with a mean resolution of 1.31 m per pixel (Table 1).

Table1. The 8 spectral bands of the images used for the mapping of Posidonia meadows.

Band name	Spectral range
Coastal Blue	400 - 450 nm
Blue	450 - 510 nm
Green	510 - 580 nm
Yellow	585 - 625 nm
Red	630 - 690 nm
Red edge[1]	705 - 745 nm
Near-IR1	770 - 895 nm
Near-IR2	860 - 1040 nm

The image for Spetses island covered an area of 61 km^2 while for Velopoula it covered an area of 25 km^2. The product "ORStandard2A" was purchased for the project. The image for Spetses was sensed on 20/01/2021 and for Velopoula on 26/06/2021. The criteria for choosing the images from the archive were i) the atmospheric noise, ii) angle of capture, iii) vessel presence and iv) visual inspection for minimal presence of sun and wave glint; the later cannot be compensated through image correction algorithms while the former can be corrected using specific algorithms.

2.2 Atmospheric correction

For both images atmospheric correction was performed using the ACOLITE application (version 20220222.0). The default parameters for the retrieval of bottom reflectance have been used (Vanhellemont & Ruddick, 2018). A mask was applied to remove the terrestrial part of the imagery using the Near-IR1 band. The study area was further reduced by applying a manual mask, via manual delineation, close to the deep limits of the meadows, as these were clearly visible from the imagery and the fieldwork data. Further the data used for algorithm calibration follow the approach by Poursanidis et al., 2018, as there apart from the reduction of deep areas, a class named "deep water" was included in the analysis to allow the algorithm to distinguish which pixels belong to the deep sea rather than seagrass meadows class.

Image annotated data were created to be used in the supervised image classification following approaches by Poursanidis et al., 2018 and Traganos et al., 2018. In that, areas with seagrass and other bottom types are clearly identified in the bottom reflectance images after the use of ACOLITE module. Experienced scientists

[1] Red edge: This refers to the wavelengths of the electromagnetic spectrum, which belong to the near-infrared and at which the reflectance of vegetation changes dramatically.

carefully draw polygons for each target habitat so that the algorithms have a sufficient number of pixels to separate the designed classes; In the case of the present study a binary classification scheme was used ("seagrass / non-seagrass").

2.3 Training of classification algorithm and validation data

As mentioned above, during the field work training and validation points were collected and a habitat was assigned for each one. The habitats were divided in five categories; i) *Posidonia oceanica meadows*, ii) Sandy bottom, iii) Rocky substrate, iv) Brown algae and v) matte morte (which represents coverage from dead *P. oceanica* plants) (Table 2). In total, 56 ground truthing points were collected from the island of Velopoula and 198 points were collected from four distinct sampling areas around Spetses (Figure 7).

Table 2. Number of Training and Validation points in the two sites.

Substrate type	Spetses island	Velopoula island	Total (N;%)
Posidonia meadows	77	24	101; 40%
Sandy bottom	66	24	90; 35%
Rocky bottom	20	3	23; 9%
Brown Algae	31	5	36; 14%
Matte morte	4	-	4; 2%
Total	198	56	254; 100%

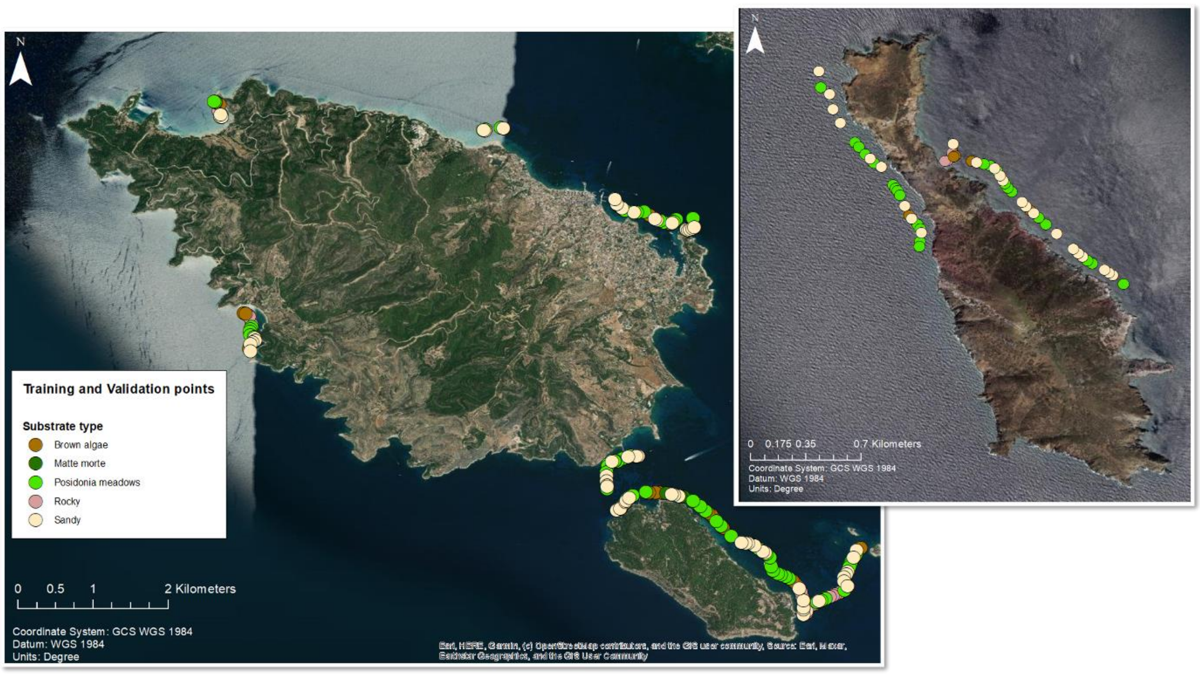

Figure 7. Training and Validation points obtained in April 2022.

2.4 Classification

For Spetses island, the supervised classification was performed with the Maximum Likelihood algorithm (Haynes 2013) in ENVI software (Version 5.6.2). For Velopoula island, Random Forests (RF) (Breiman, 2001), was used in QGIS, the EnMAP toolbox, (stable version 3.10.0.20220609T095816).

The algorithms Support Vector Machines (Vapnik, 1995) and Minimum Distance (Richards, 1999) were also used to explore if they could result in a classification with higher accuracy, in both islands in comparison to the others. However, the highest accuracies were achieved by Maximum Likelihood and Random Forests for Spetses and Velopoula, accordingly (Table 3).

Table 3. Overall accuracies achieved by the different algorithms for the two study areas.

Classification Algorithms	Spetses	Velopoula
Random Forests	> 86%,	**> 93%**
Maximum Likelihood	**93%**	> 88%
Support Vector Machines	> 89%	> 90%
Minimum Distance	> 75%	> 78%

2.5 Post-Classification

The post-classification part consists of two components: 1) a low pass filter to remove the "salt n' pepper" effect over the homogeneous areas of the seascape, using a small kernel window[2] of 3x3 pixels, 2) the editing of seagrass polygons due to misclassified pixels as seagrass in deep water (remove pixels over the open sea that behave spectrally similar with the seagrass class due to sun angle and phytoplankton pigments). The accuracy assessment employs the use of the ground truthing points collected during the field activities as seagrass-non seagrass (binary approach) since the aim of the current project is the mapping of the seagrass meadows.

[2] Small kernel window: A kernel is a matrix, which is slid across the image and multiplied with the input such that the output is enhanced in a certain desirable manner. (Source)

Conclusions

Spetses island

The mapping results for Spetses island are presented in Annex 1; Map 1. The meadows cover a total of 3.73 km^2 of the seabed surrounding the island. The produced map has an accuracy of ~93% from the Maximum Likelihood algorithm in synergy with the manual corrections. The manual corrections where mostly concentrated in the northwest part and southeast, where the banding effect of the image is very hard and the Maxar technologies do not distribute it.

The deep boundary of the meadows was delineated from the satellite image after atmospheric correction and reached a maximum depth of 32 meters which aligns with the field data. It is worth mentioning that the confidence of the deep limit, as it has been delineated by the current work, is very high since the image does not have any water column sedimentation that can hinder the visibility of the sea bottom.

The highest bottom coverage of meadows is located off the island's north coast and between Spetses, Spetsopoula and the surrounding islands in the south-east part of the study area. As expected, these results agree with the map of the Greek Ministry of Rural Development and Food (Figure 1), although the *Posidonia oceanica* meadows appear to be very fragmented.

The rest of the island is also surrounded by meadows, yet their extend is relatively limited, especially on the island's south-west, presumably due to the wave action and the harsh winter oceanographic conditions, and not by anthropogenic pressure. However, in the Eastern part of the island the impact of anthropogenic pressure is evident even from the satellite images and the mapping (anchor tracks >1.2m in length and width).

Specifically, in the areas with the most extended meadows, in the Kosta channel, the meadows are fragmented with circular patches of sand most probably caused by anchoring (Figure 8; A.). While between Spetsopoula island and Spetses where the maximum depth is of 15m, anchor trails can be observed in front of the port (Figure 8; B.) and in front of villas that can only be reached from the sea (Figure 8; C.).

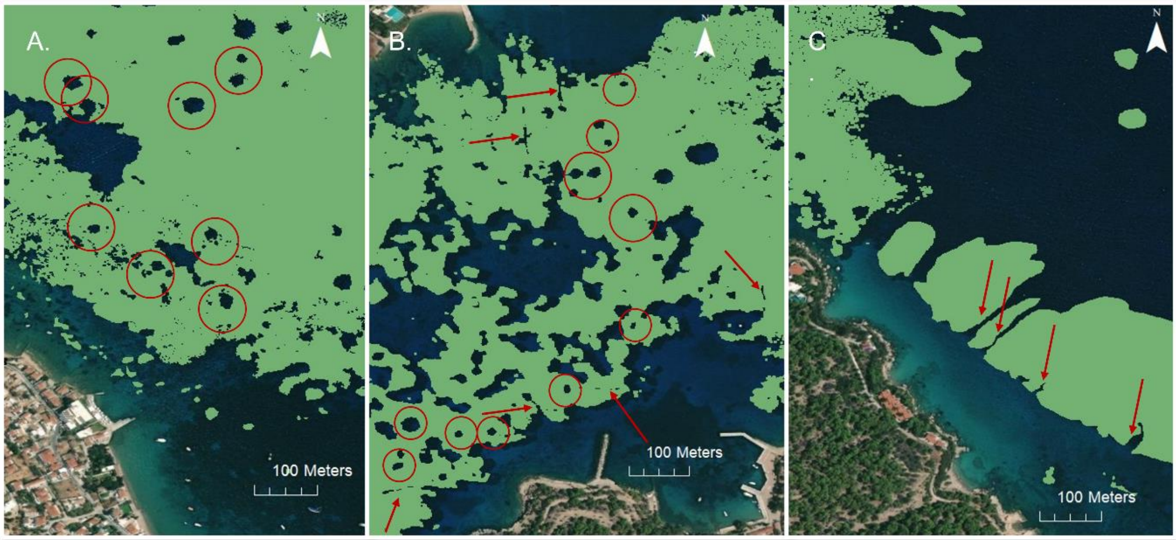

Figure 8. Three distinct locations are shown with the mapped P. oceanica meadows overlayed, with the red circles indicating the patches of sand caused by anchors and the arrows indicating the anchor trails: A. The P. oceanica meadows in front of Spetses beach; B. The P. oceanica meadows in front of the port of Spetsopoula; C. the P. oceanica meadows between Spetsopoula and St. Ioannis islet.

It is worth mentioning that the meadows in Spetses were also degraded in certain areas due to pollution. Specifically, the meadows around that extend to the south of the old port had various litter items on them and in their surroundings, including chairs, tires, and plastic bottles.

Velopoula island

The results of the mapping process for Velopoula are presented in Annex 1; Map 2. Specifically, the mapping process resulted in 0.356 km^2 of healthy and undisturbed meadows that spread around the island. The result has an accuracy of 93%.

The deep boundary of *P. oceanica* meadows could be derived from the satellite image after atmospheric correction, and reached a maximum depth of 34 m. The meadows do not extend far from the shoreline as the plateau sharply deepens. From the 2 km^2 that comprise the surveyed area, around 18% were covered with *P. oceanica*. The meadows are more extensive and coherent on the eastern side of the island, corresponding to the morphology of the seabed, as the slope of the seabed is more gradual. In Velopoula, dead meadows were observed that were covered with *Cystoseira sp*. and seasonal algae (Figure 4), but no anthropogenic impacts were recorded (i.e., anchor tracks, litter, etc.).

Discussion and future steps

The mapping around Velopoula island resulted in 0.356 km^2 of undisturbed Posidonia meadows which is 11 times more than the estimated coverage in the NATURA2000 standard data form (SDF) for the entire site "VRACHONISIA NOTIOU AIGAIOU: VELOPOULA, FALKONERA, ANANES, CHRISTIANA, PACHEIA, FTENO, MAKRA, ASTAKIDONISIA, SYRNA - GYRO NISIA KAI THALASSIA ZONI", which contains three marine areas that surround the islands. Mapping the rest of these areas will likely result in a far greater difference between the reported and actual coverage of the meadows in this area.

Although the spatial extent of the meadows in Spetses island is fairly big, covering 3.73, the meadows suffer from fragmentation and are degraded due to anthropogenic pressures. It is likely that the area in Kosta channel and the gulf of Zogeria used to be covered with meadows, as for both areas, the depth and the oceanographic conditions permit the growth of P. oceanica. According to Local Ecological Knowledge this is highly possible, considering the heavy boat traffic and the anchor tracks in the resulted map (Figure 8). To confirm this, a study could be conducted through the use of questionnaires of local sea users and if possible, by comparing old aerial photos with the current extend of the meadows. On the contrary, the meadows located at the western parts of the island seem to be limited by the steep decline of the seafloor's elevation. The 50 m bathymetric contour on these areas is located a few hundred meters off the coast.

When comparing the results for both islands, it can be concluded that although Velopoula's meadows have areas that are patchy, the patchiness in Spetses' meadows is far more extended. According to Montefalcone et al. (2010), fragmentation in P. oceanica meadows is strongly influenced by the human component, while being lower in natural meadows than in anthropized ones and patchiness is little influenced by the morphodynamic state of the coast.

Furthermore, a detailed comparison of the meadows in the two islands would help to showcase the damage uncontrolled anchorage and urbanization causes, by accessing the meadows health and age in both areas while compiling also historical data about the previous extend.

This map could be used for decision making for the management authorities and could help in the efforts of the municipality of Spetses in positioning eco-friendly anchorages that, apart from protecting this important habitat, could regulate the boat traffic in the area. Finally, it could be used by the local boat rental companies to avoid anchoring over the meadows.

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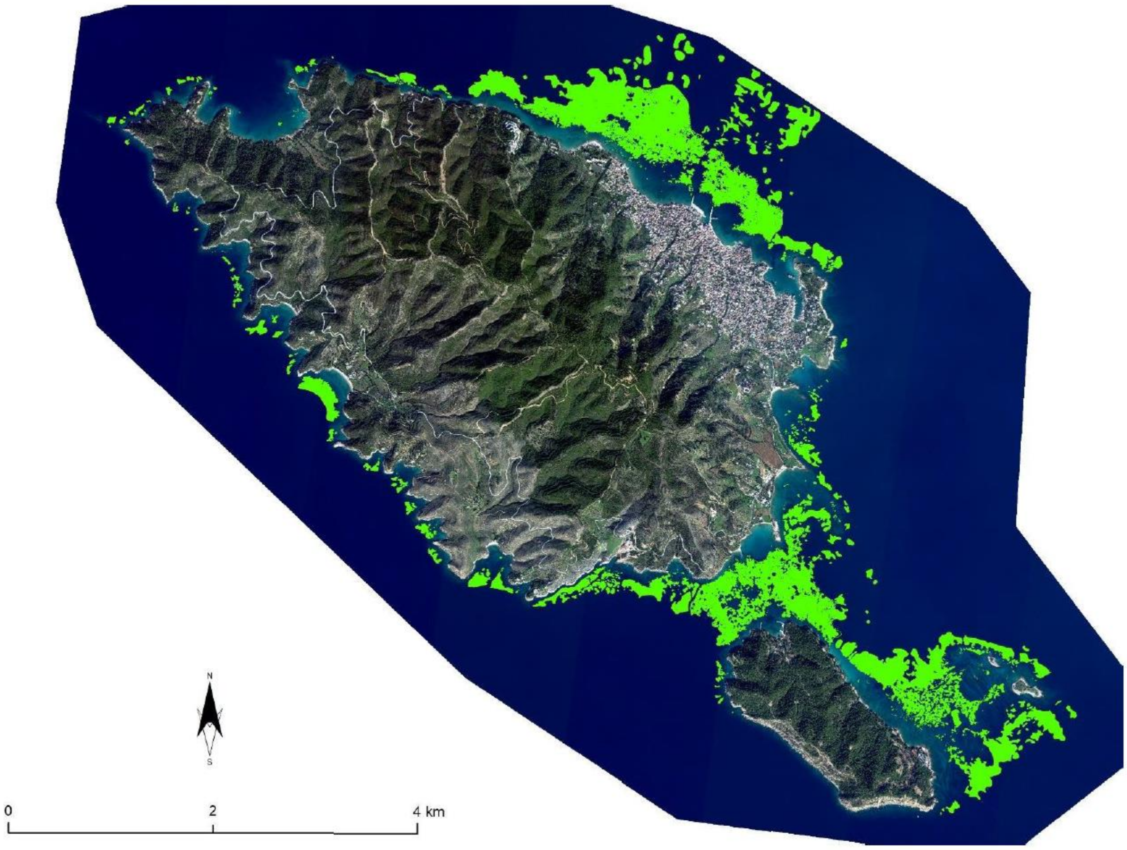
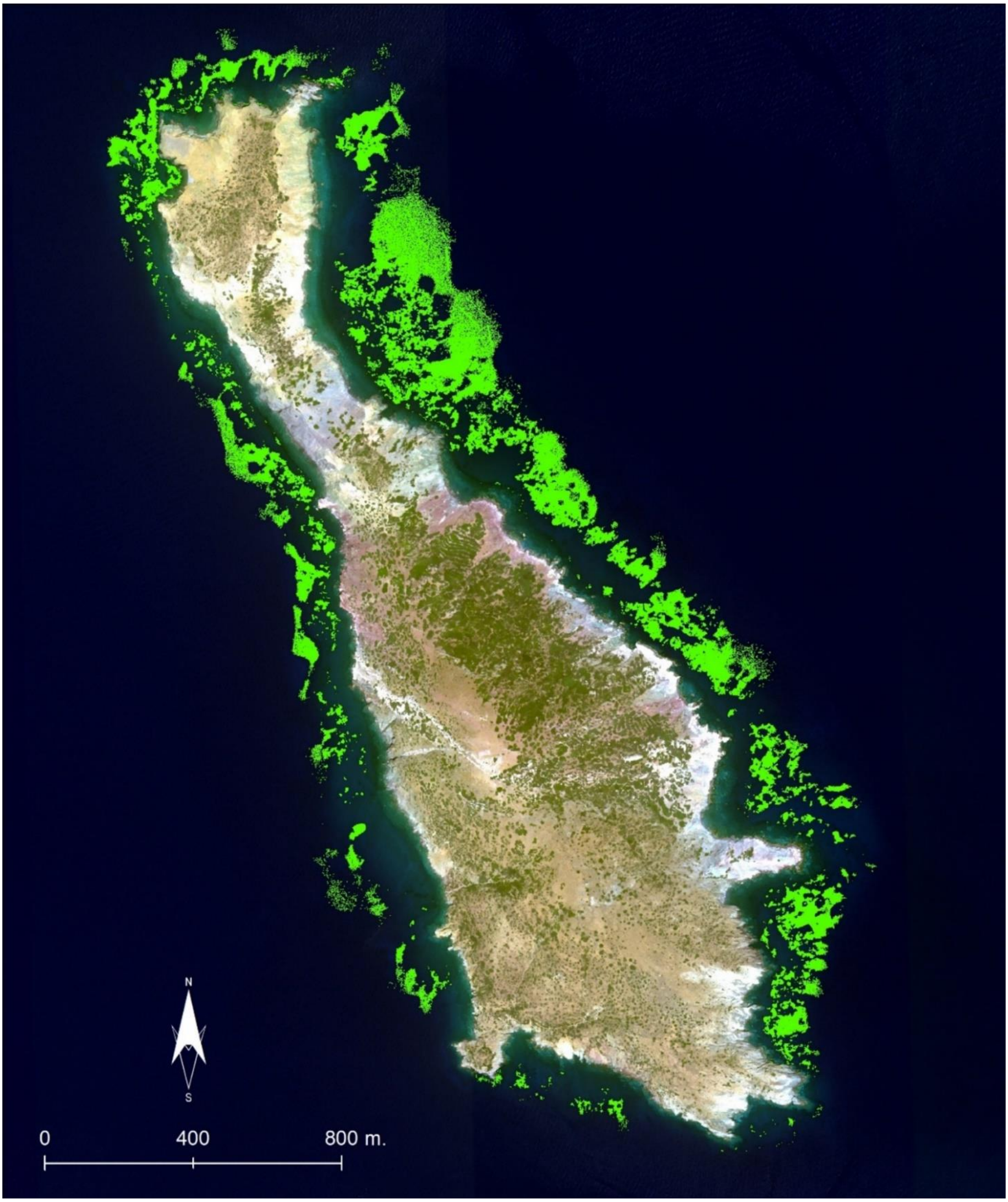
Annex 1



Map 1. The meadows of P. oceanica around the island of Spetses, derived from the mapping produced in the context of this project.



Map 2. The meadows of P. oceanica around the island of Velopoula, derived from the mapping produced in the context of this project.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