Bachelor thesis

Mapping *Posidonia oceanica* around Samos island (Greece)

A case study towards developing a low-cost and time-efficient methodology

Host organisation: Archipelagos, Institute of Marine Conservation
Location: Mesokampos, Samos, Greece
Author: Jaco van den Berg
Student number: 881002101
Study program: Forestry and Nature management
Major: Nature and Landscape engineering
Institution: Van Hall – Larenstein University of Applied Sciences (VHL)

VHL Supervisor: Jack Schoenmakers (GIS lecturer)
External supervisor: Eleni Mihalopoulou (Team supervisor and assistant to scientific director)

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Keywords: Seagrass, Aegean, mapping, GIS

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Summary

Posidonia oceanica is a species of seagrass endemic to the Mediterranean Sea where it grows either in patchy patterns or forms extensive meadows, at up to 50m of depth. The species has great ecological and economical value. It provides a habitat and nursing ground for many marine fauna species and fixates both nutrients and sediment particles. Meadows have a dampening effect on wave action which reduces coastal erosion. *P. oceanica* is a slow growing species and a decline is measured in many regions. For these reasons protection is necessary, yet existing legislation is not effectively enforced. A major cause of this is the fact that seagrass habitat is uncharted in many regions, among which The Aegean Sea. This study presents a case study of mapping *P. oceanica* around Samos island in the eastern Aegean, aimed towards a the development of low-cost and time-efficient methods.

The studied methodology consisted of processing Google Earth satellite imagery and sidescan sonar data, combined with a new method pilot: kayak-based surveys. The satellite imagery was georeferenced to map the extent and coverage of *P. oceanica* around Samos. Sidescan sonar and kayak survey data were gathered in the Mesokampos bay, the main study area. A 250m base grid was created for the purpose of time-efficient mapping and compatibility of several types of data.

The satellite imagery-based map shows that seagrass is present along most of Samos' coastline. The total area covered is approximately 16,5km^2. Sidescan sonar provided clear images of seagrass up to depths of about 13m and was mapped into separate polygons showing coverage values. Furthermore, many trawling and anchoring marks were found in the sonar imagery. The kayak surveys resulted in a 49-point dataset that was used for validating the other data types and for mapping a seagrass coverage grid. The accuracy was determined by comparing the coverage values of the satellite data and the sonar data to the kayak point dataset, using the Spatial Join function of ArcGIS. The average deviation in coverage was found to be 12,5% for the satellite imagery map, mostly caused by slight georeferencing errors, and 17,6% for the sidescan sonar map, due to the data not being aligned to the 250m base grid. This was caused by the fact that the sidescan sonar surveys were carried out prior to the setup of the base grid method. The kayak survey points have a high level of accuracy, because at these points the exact seafloor situation was observed.

The processing of satellite imagery proved to be a cost-free and time efficient method resulting in the mapping of a large area. This mapping method has a depth limit of about 15m, in deeper areas the imagery is too dark to distinguish seagrass. The sidescan sonar data showed a high resolution image and *Posidonia* coverage polygon map. The data was however not properly aligned to the base grid and therefore less compatible with the ground truthing data. Next to that, for the shallower areas the satellite imagery method outperforms the sonar in time and cost efficiency. The kayak surveys were found to be a suitable method for gathering ground truthing data.

The current methodology does not cover the deeper areas where Posidonia oceanica can be found. The suggested approach is to is to use satellite imagery to map the shallow areas up to 15-20m and use the sidescan sonar for the areas up to 50m, combined with kayak surveys for ground truthing purposes. Satellite imagery consisting of a singular satellite photo would be ideal, to avoid the inaccuracies inherent to the georeferencing process. Sidescan sonar data should be aligned to the 250m grid, to make it compatible with the other sources of data. Kayak surveys with additional equipment, like an underwater camera, can improve the extent of the results found in the present study. In the future, the methodology can be used to map and monitor seagrass in similar areas. Mapping trawling and anchoring marks and investigating the effects on the seagrass meadows will also provide valuable information on the threats seagrass face. Lastly, it is recommended to include a plan for the enforcement of protective measures.

Preface and acknowledgements

This research report was written in the context of the author's Bachelor thesis placement at Archipelagos, Institute of Marine Conservation on Samos island, Greece. The thesis serves as the final step in successfully completing the Forestry and Nature Management Bachelor of Van Hall University of Applied Sciences, located in Velp (Gelderland), The Netherlands. Carrying out this part of the study program abroad abroad was a very special experience and has had a great added value in terms of personal development, language skills and working together with people with different origins and cultural backgrounds.

I would like to thank the Archipelagos Institute for offering the oppurtunity to conduct this Bachelor thesis research. Furthermore, I want to express my gratefulness to Jack Schoenmakers for the University-side supervision and both Dimosthenis Traganos and Eleni Mihalopoulou for the supervision and guidance during the time spent working on the thesis project on Samos. Lastly, I want to thank the Archipelagos Marine and GIS research team members that provided assistance while carrying out the kayak surveys and provided useful input on the project.

Introduction

Posidonia oceanica: backgrounds

Posidonia oceanica is a species of seagrass endemic to the Mediterranean sea, where it grows submerged up to a depth of about 50m, covering a total area of approximately 50.000km^2 in the coastal zones (Pergent et al. 2010). It is found on several types of substrate, ranging from sand to solid rock. It can form large continuous meadows but also occurs in patchy patterns (Green & Short 2003; Larkum et al. 2006). *P. oceanica* spreads by means of horizontally growing rhizomes, which is a very slow process: the rhizomes only grow about 1 to 6 cm per year (Pergent et al. 2010). The seagrass species is of great significance to its environment. First of all, it has the ability to stabilize sediment and to dampen wave action, protecting coastal lines from erosion (Gacia & Duarte 2000). Secondly, seagrass provides oxygen to its surroundings and helps reduce eutrophication by fixating nutrients present in the water. Furthermore, *P. oceanica* meadows form a habitat for several dozens of marine fauna species, like turtles, sea horses and sirenians (Green & Short 2003) and play an important role as nursing grounds for many fish species (Vasallo et al. 2013). This includes many fish species that are important for commercial fisheries. The seagrass species also provides several other economic benefits. For example, it is used as animal fodder and the dried fibrous material is used as roof insulation and mattress fillings (Green & Short 2003). Next to that, the erosion protection it provides to the coastal regions is seen as an ecosystem service with an estimated monetary value of € 172,20 per m^2 of seagrass habitat per year (Vasallo et al. 2013). In short, *P. oceanica* is a species that is of great significance in both ecological and economical ways.

Problem analysis

A decline in *Posidonia* coverage has been measured in many regions of the Mediterranean, especially in areas with a greater level of human activities and urbanisation (Delgado et al. 1998; Boumaza et al. 2014). The expansion of harbours and construction of artificial beaches for recreational purposes influence the sedimentation of sand, causing either the burying or excessive exposure of seagrass (Green & Short 2003). Other phenomena greatly pressuring seagrass in the Mediterranean are the eutrophication of the water caused by urban effluents (Boumaza et al. 2014) and off-shore fish farming (Delgado et al. 1998). Illegal trawling and anchoring of heavy ships are also common threats, directly damaging the seagrass beds (Green & Short 2003; Leriche 2006). Once a meadow is damaged and degraded, the recovery takes a long time due of the low growth speed. Nonetheless, *Posidonia oceanica* has a “Least concern” status on the IUCN Red List of Threatened species, which is because the total decline according to IUCN is approximately only 10% over the last 100 years (Pergent et al. 2010). Other studies, however, have estimated its areal decline to be somewhere in between 13% and 50% in the last 50 years. Next to that, remaining meadows are reported to be more fragmented and to have a lower shoot density (Marbà et al. 2014). Because of its great environmental significance and slow recovery rate, it is important to protect this seagrass species against further harm. It is already legally protected by European legislation (the Habitat directive and the Bern and Barcelona conventions) (Pergent et al. 2010) and fishing regulations prohibiting trawling within 3 nautical miles from the coast, but currently these regulations are not effectively enforced and often ignored (Green & Short 2003; Leriche et al. 2006). To make effective enforcement of these laws and regulations possible, it is required to map the extent of *Posidonia* habitats. These habitats have not been mapped in the eastern Aegean region before, making this study an important step towards actually protecting the seagrass habitats from further damage. For large scale mapping in the future, it is desired to establish time-efficient and low-cost mapping methods.

Research objective and research questions

The objective of this research is to map the extent and coverage of *Posidonia oceanica* around Samos island and the Mesokampos bay on the southeast side of the island. Furthermore, the aim is to evaluate the effectivity of a combination of kayak-based surveys, the processing of satellite imagery and acoustic methods for this purpose. for evaluating effectiveness. The Mesokampos bay area will serve as a case study subject for assessing the effectivity of this combination of methods, using accuracy, cost-efficiency, time-efficiency as the main criteria. This objective leads to the following main research question for this project:

What is the extent of* Posidonia *habitat around Samos and how effective is the use of satellite imagery and sidescan sonar data combined with kayak-based surveys for mapping this habitat type?

To answer the main question it will be split up into five sub-questions:

1. *What is the extent of* Posidonia *habitat around Samos?*
2. *How effective is the use of satellite imagery for mapping* Posidonia *habitat?*
3. *How effective is the sidescan sonar for mapping* Posidonia *habitat?*
4. *How effective are kayak-based surveys for mapping* Posidonia *habitat?*
5. *How can the mapped data be reviewed for accuracy?*

Process overview

The study was conducted in three phases: data collecting, data processing and data analysis. In the first phase, hydrographic data was collected during kayak- and boat-based surveys in the Mesokampos bay. Archipelagos has a kayak with research equipment available, which was used for collecting data on *Posidonia* coverage and for gathering ground truthing data. Sidescan sonar data was gathered during boat-based surveys in cooperation with Cardiff University. The data processing phase started with creating a 250m study area grid. The next step was the processing of Google Earth satellite imagery to map the general extent of seagrass around Samos. Next to that, the various types of survey results were processed and mapped. The analysis phase consisted of assessing accuracy of the mapped data by comparing it to the collected ground truthing data. This shows to what extent the mapped data corresponds to the actual seafloor habitat. Figure 1 displays a schematic representation of the methodology.

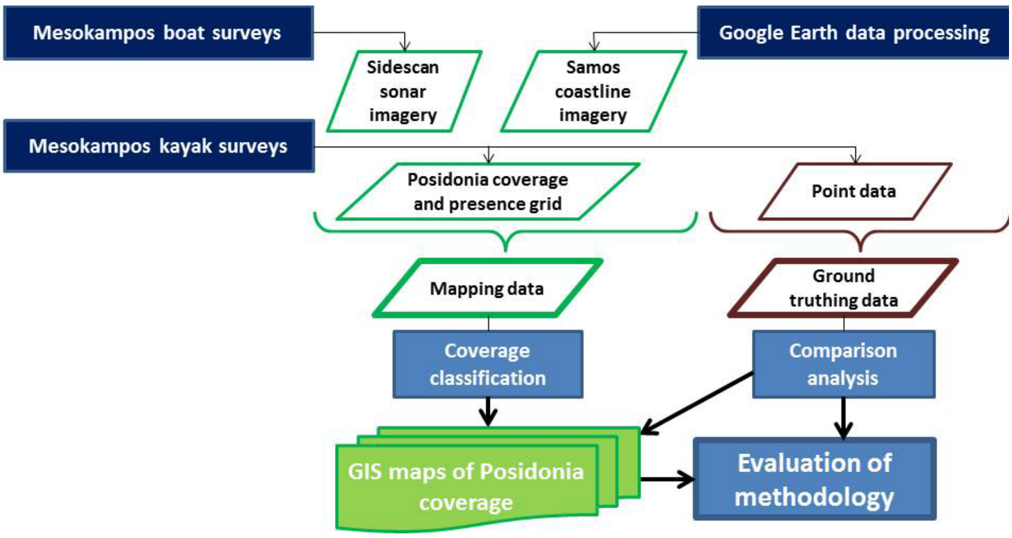


Figure 1: a schematic overview of the work process

Preconditions

A number of preconditions was taken into account while conducting this study. First of all, Archipelagos is a non-profit organisation so the research had to be completed as cost-efficient as possible and using the equipment and resources readily available. Cost-efficiency is important in developing a sustainable seagrass mapping method that is widely usable and accessible for different kinds of organisations even when funding is difficult. Similarly, time-efficiency was a precondition, to ensure feasibility of future studies. Next to that safety was a precondition, requiring certain weather conditions. The surveys could only take place in calm weather conditions for the safety of the research team and equipment during kayak and boat surveys. Furthermore, calm conditions increase accuracy of the recorded data, since rough water can distort the acoustic signals and the visibility of the seafloor.

Study area and scope

The satellite imagery-based mapping was done for the entire coastline of Samos island. The Mesokampos bay, located on the south-eastern side of Samos, served as a case study subject for the other methods. In this study area, the required data was gathered during a series of surveys. Figure 2 shows the location of the study area in the eastern Aegean Sea.

The focus of this study lies on the mapping of seagrass habitat and the methodology involved. Legislation and policy aspects as mentioned in the introduction are not elaborated on.

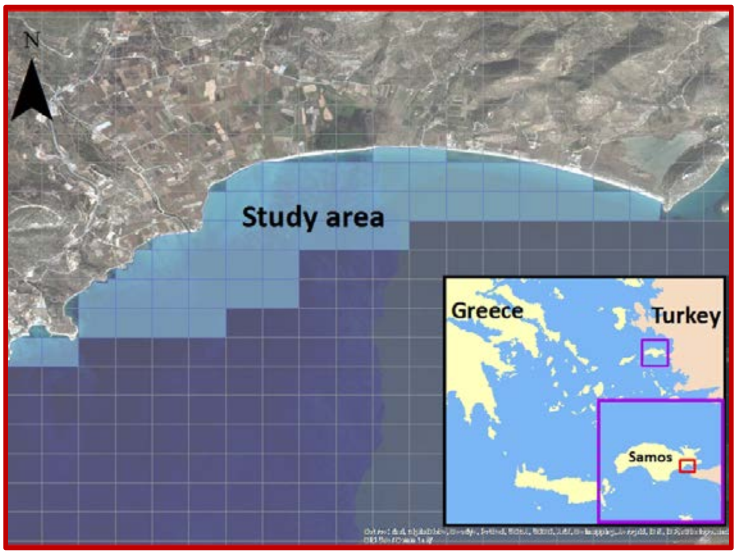


Figure 2: the location of the study area

Involved partners

There are several partner groups involved in this project. First of all, the Archipelagos Institute of Marine Conservation is the host organisation and initiator of the project. They greatly value the marine ecosystems and prioritize their conservation as a main mission. Archipelagos is aware of the significance of seagrass beds in the Mediterranean and contributes to protecting these productive marine habitats by conducting boat-based surveys to collect data for producing GIS maps and developing methods. Archipelagos provides an external supervisor during the entire thesis process. Secondly, Van Hall - Larenstein (VHL) University of Applied Sciences is involved. This is the sending institution of the author and a supervisor representing VHL will be involved in reviewing the provided thesis report and final presentation, together with the Archipelagos supervisor. Next to that, both supervisors will assess the general work process. Another partner group involved is the local fisherman community. Seagrass meadows are nursing grounds for many of the fish species they make a living off of, so the protection of these habitats will benefit fishermen as well.

Target audience

The main target audience for this thesis report is Archipelagos, Institute of Marine Conservation. The report serves as an advice concerning the development of various seagrass mapping methods. The Archipelagos Marine and GIS research teams will be using parts of this thesis as a methodology guide whilst further adjusting and improving it. Furthermore, the Marine team may benefit from the included kayak survey methodology guidelines for their further studies on other subjects, where surveying per kayak can be a viable option to gather data. Besides Archipelagos, other institutions with an interest in the conservation of marine ecosystems can benefit from the information provided.

Report structure

The first chapter of this report describes the materials and methods used. After that, in chapter 2, the results are described for each sub-question. In chapter 3, conclusions are drawn, answering all of the research questions and discussing the results and the effectivity of the used methodology. Lastly, chapter 4 includes recommendations for methodology improvements and further research.

Chapter 1: Materials and methods

In this chapter, the methods and materials used while conducting this study are described. Firstly, the used materials are listed. After that, this chapter describes the research methods for the data collection, data processing and data analysis phases.

1.2 Materials

- Boat-based sidescan sonar (Lowrance StructureScan HD)
- Archipelagos two person kayak
  - GPS device (Garmin eTrex 10)
  - Compass
  - Bathyscope
  - Depth-measuring sonar (Echofish 300)
  - Wetsuits
  - Life jackets
  - Waterproof writing gear (white slates and pencils)
- Software: ArcGIS 10.2, Dr Depth
- External source data used in GIS
  - Google Earth imagery
  - Bathymetric lines from the Greek Hydrographic Service

1.3 Data collection methods

Boat surveys
Sidescan sonar data was collected using the research equipment on board of the Archipelagos vessel, during a series of boat-based surveys in cooperation with Cardiff University staff and students. The surveys were carried out along the Mesokampos area coastline, following transects perpendicular to the coastline with roughly a 300m spacing in between.

Sidescan sonar
The sidescan sonar emits sound signals sideways from the boat to the seabed. These signals are then reflected by the seabed and returned to the sidescan sonar equipment to form an acoustic image of the seafloor. This sonar has an expected effective depth range of about 50m and has been used before in seagrass mapping studies (Pasqualini et al. 1998).

Kayak surveys pilot
Kayak surveying served as a method pilot for mapping seagrass. Initially, several test surveys were carried out to establish an effective way of moving through the targeted study area grid cells and investigate the depth range of equipment. It is not possible to bring heavy or large objects on board, so the surveys were conducted with small and light equipment. Before each survey, an efficient survey route was established, navigating through the target points in straight lines as much as possible, to facilitate easier navigating (annex 1 shows the routes and includes a photo of the fully equipped kayak and survey team during the first test survey). The coordinates of the target points were listed on a waterproof slate, leaving space to note *Posidonia* coverage percentages and depth measurements for each point. The kayak survey team was wearing wetsuits and life jackets for safety purposes. A phone in a waterproof bag was brought to enable the team to call for assistance in case of any emergency. Although the kayak surveys were generally not highly physically demanding, a

basic level of physical fitness is required for kayak team members, to be able to cover as many points as possible in a limited time window. After several days of surveys, muscle soreness and fatigue may become issues, therefore it is recommended to rotate the surveys between research team members to prevent injury and ensure a sufficient survey pace.

Kayak- based data collection

The surveys were conducted in the Mesokampos bay by moving through the 250m grid, visually assessing the *Posidonia* coverage percentage for each square. The GPS device and compass were used to navigate the kayak through the study area. In the centre of each grid cell, the coverage was recorded by studying the seafloor with the bathyscope and the depth was measured using the Echofish 300 sonar device. Two Archipelagos research team members were on board for each survey to operate the equipment.

1.4 Data processing and analysis methods

General seagrass area grid

A 250m base grid was created around the entire coastline of Samos for mapping purposes. The grid concept was set up for time-efficient mapping and as a base for compatibly mapping different sources of data, while still allowing for sufficient accuracy to assign protected areas in the future. The grid area was narrowed down to the areas with a depth of 50m or less, the maximal depth range of *Posidonia oceanica*. Excess grid cells were removed using the 50m line of the bathymetric dataset, leaving a total of 2544 grid cells with possible seagrass presence.

Google Earth imagery: processing

For mapping the general *Posidonia* extent around the entire island, Google Earth satellite imagery was used. 67 satellite images were exported from Google Earth and imported in ArcMap. These were then georeferenced, a process required to position the imagery in the correct spatial location. A satellite imagery basemap was used as a reference. Control points were added, linking a position on the Google Earth image to the corresponding position on the basemap. After the addition of a control point, ArcMap automatically adjusted the image, always requiring four or more control points for optimal results. The coastal zone is the most important part to be in the correct position for mapping seagrass. Therefore, for every image, several control points were placed at or nearby the coastline. After georeferencing the material, it was mosaicked into one image. The 50m bathymetric line was used to clip off excess data.

Google Earth imagery: seagrass coverage mapping

Based on the imagery, a seagrass coverage percentage value was added to the grid cells. The coverage was visually assessed, provided the image area was clear and bright enough to actually distinguish seagrass from other seafloor habitat types. Examples of the coverage classification are shown in table 1.

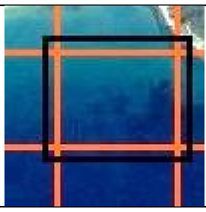
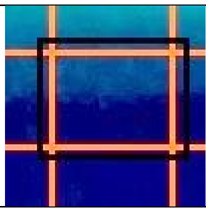
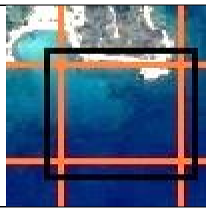
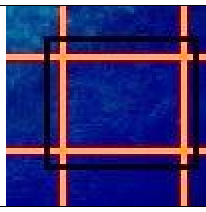
Imagery example				
Specified coverage	25%	50%	75%	100%

Table 1: examples of imagery-based seagrass coverage percentages

The effectivity limit of this method is about 15m, up to 20 meters in clear and sheltered waters (Pasqualini et al. 1998; Fornes et al. 2006). As the Aegean waters are generally quite sheltered, especially the relatively shallow areas in between islands, the 20m bathymetric lines were used to set a limit for this part of the methodology. The specified coverage was multiplied by 0,0625 (the surface of a grid cell in km^2) for each cell, to calculate the total area vegetated by seagrass.

Sidescan sonar data

The raw sidescan sonar data was first processed using Dr Depth, a freeware program, providing the data with a spatial reference. After this, the data was exported as grid files and imported in ArcMap. In ArcMap, the imagery was displayed using brown and yellow colours, clearly showing the boundaries of barren areas and vegetated areas. *Posidonia* is visible as roughly spotted areas, slightly darker than sandy or rocky areas. In a similar way to the Google Earth imagery, the sidescan sonar data was checked for the presence of seagrass. However, because the sidescan sonar data was not aligned to the 250m grid, separate polygons were drawn for areas with different coverage percentages. Examples are shown in the table below.

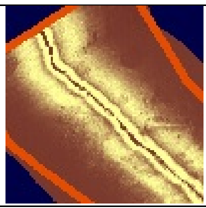
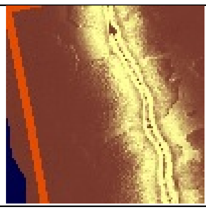
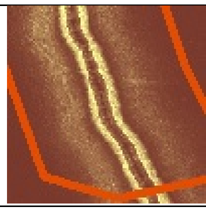
Imagery example				
Specified coverage	25%	50%	75%	100%

Table 2: examples of sidescan sonar-based seagrass coverage percentages

The sidescan sonar data was gathered during the Cardiff Field Course, where Archipelagos and Cardiff University joined forces to map seagrass in the Mesokampos bay, providing hydrography experience to Cardiff students and collecting useful data for Archipelagos' conservation efforts. The field course took place in September 2014, before the setup of the base grid concept for mapping seagrass, thus the collected sonar data was not aligned to the grid.

Kayak survey data and ground truthing

After each kayak survey the findings were added to the base grid, for the purpose of producing both a grid-based polygon map of seagrass coverage and a point dataset for ground truthing purposes in the Mesokampos bay study area. The ground truthing was done by connecting the different kinds of mapped data to the kayak survey data, using ArcMap's Spatial Join function. For the Google Earth-based map, the points were used. However, the sidescan sonar data is not aligned to the point data so the kayak polygon map was used. After that, deviations in coverage values between the ground truthing points and different types of mapped data were calculated and mapped.

Chapter 2: Results for each sub-question

This chapter presents the research results that were found per sub-question. The maps of Samos and the Mesokampos bay resulting from each method are shown. After that, the results of the ground truthing process are presented.

2.1 Sub-question 1: The extent of *Posidonia* habitat around Samos

Figure 3 shows the general extent grid map of *Posidonia oceanica* around Samos island. For 880 grid cells the seagrass was distinguishable, in the remaining 1664 base grid cells the imagery was too dark to reliably tell different seafloor habitat types apart.

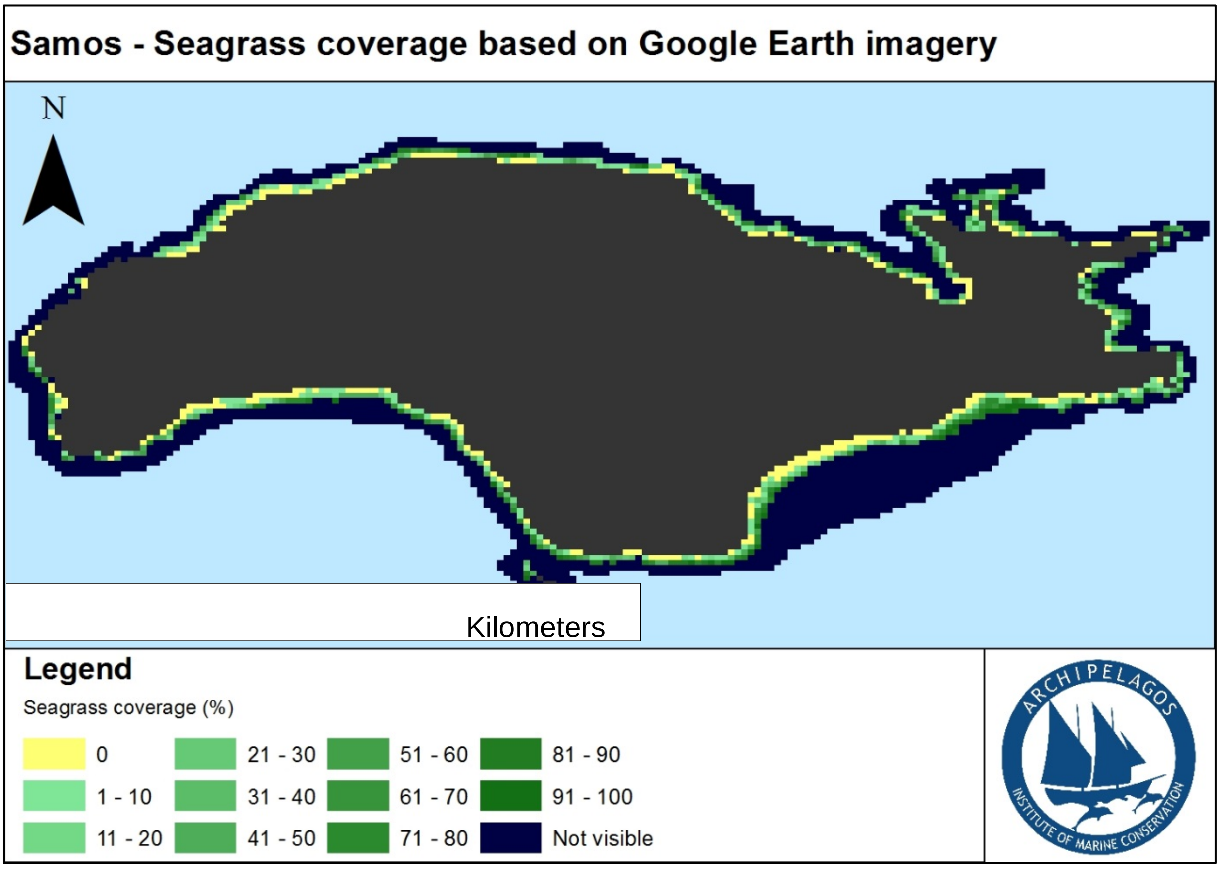


Figure 3: the island-wide seagrass coverage map

2.2 Sub-question 2: Satellite imagery

Figure 4 shows the processed and georeferenced Google Earth satellite imagery after exclusion of the areas deeper than 50m. Due to a projection difference between the images and the basemap used for georeferencing, the resulting image displays a marginal shift in the coastline in few areas, where borders of the separate images were located. Examples of this are shown in annex 2.

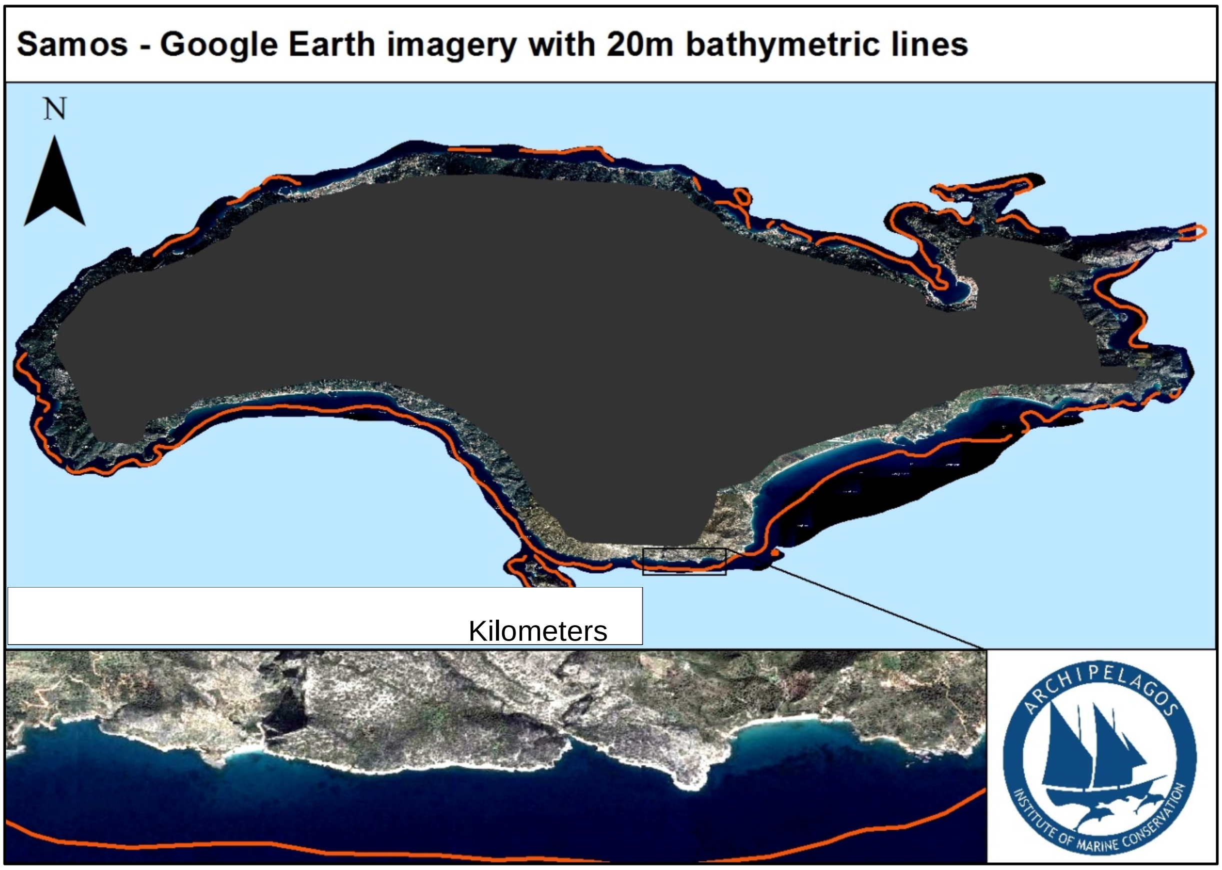


Figure 4: georeferenced Google Earth imagery with the 20m bathymetric line

Seagrass is visible as darker areas, with the smaller seagrass patches typically showing up as roughly circular dark blue spots. The detail example included in figure 4 shows dense seagrass as a dark blue area, whereas closer to the coast, a number of separate patches are visible.

2.3 Sub-question 3: Sidescan sonar

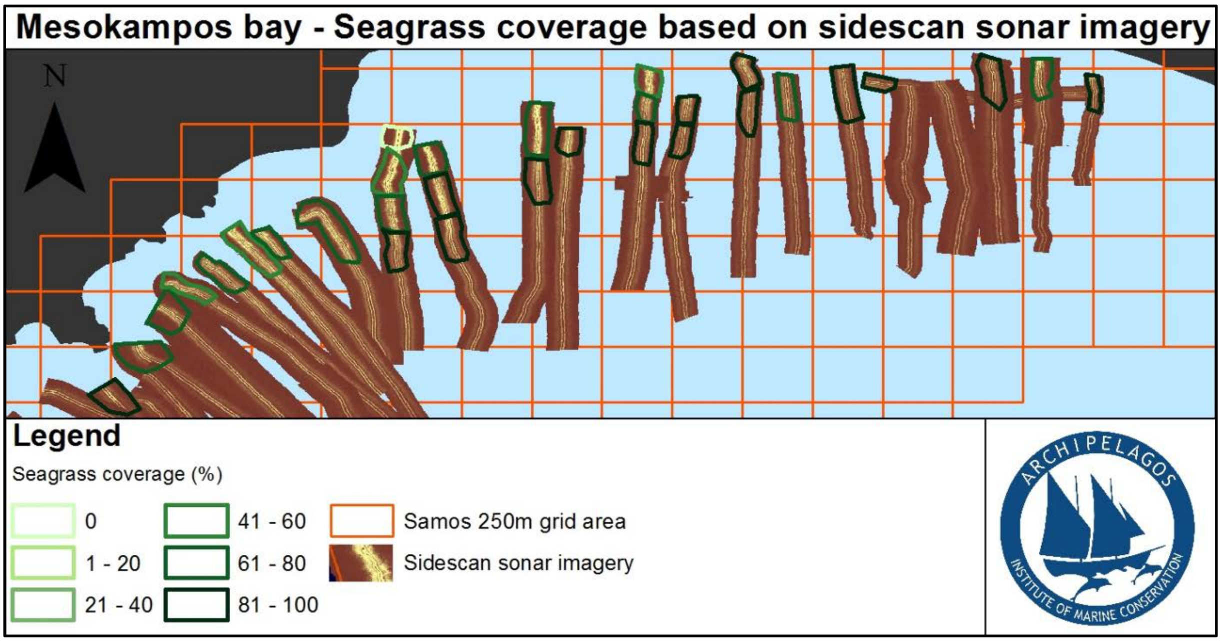


Figure 5: sidescan sonar imagery with seagrass coverage classification polygons

Figure 5 presents the processed and mapped sidescan sonar data. Seagrass was only mapped for the parts of the imagery where the habitat type was reliably distinguishable. At the displayed zoom level the high resolution of the imagery is not discernable, but when zoomed in further, seagrass patches and meadows are well distinguished from other seafloor habitat types. High detail examples of sidescan sonar imagery are shown in annex 3. The deepest areas with distinguishable seagrass were approximately 13m deep, according to results of spatially joining the polygon layer to the kayak point data. At greater depths most of the imagery showed a uniform brown fuzz, which could possibly be dense seagrass meadows, but the lack of definition impeded proper distinction.

In addition to these results, the studied sidescan sonar imagery showed a great amount of seafloor damaging in the form of marks caused by trawling. Figure 6 shows the trawling marks; 281 individual marks were identified, several reaching lengths of over 100m. Annex 4 displays a few examples of close-up sidescan sonar imagery, showing evidence of trawling activities and its impact on the seafloor.

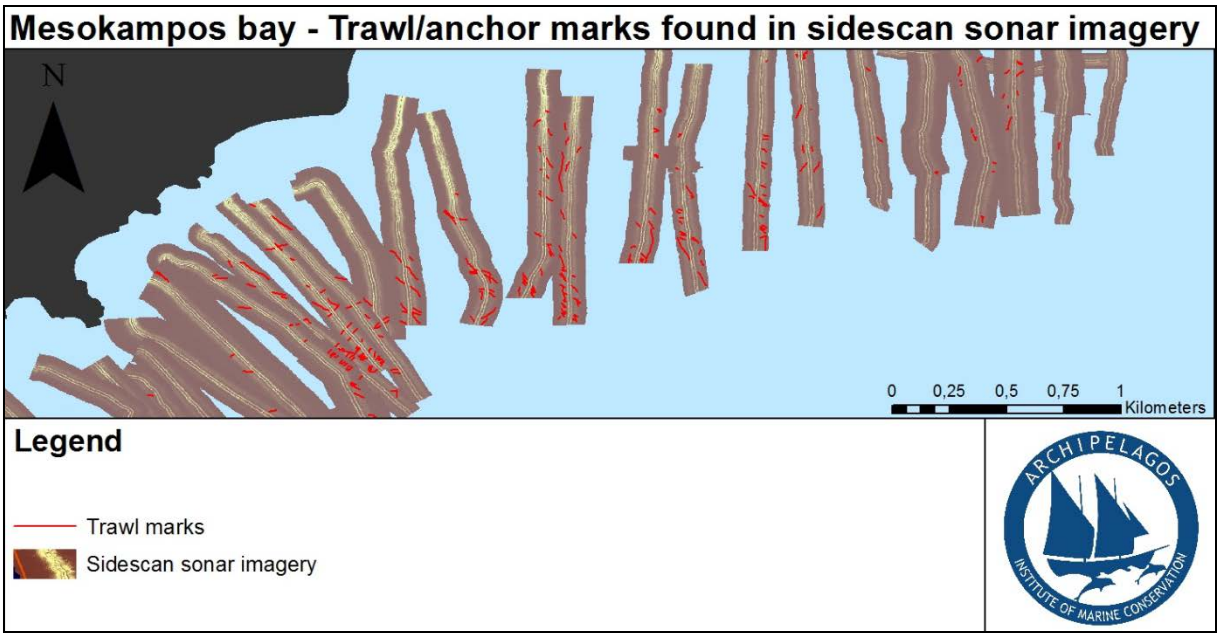


Figure 6: sidescan sonar imagery showing trawling and anchoring marks

2.4 Sub-question 4: Kayak surveys

The maps resulting from the kayak surveys are shown in figures 6 and 7. A total of 49 grid cells was studied for presence and coverage of *P. oceanica*. Close to the coast the coverage was found to be lowest, on a few locations no seagrass was found. The most dense meadows were found at depths of about 12 meters. The results were also mapped into the Samos general grid, presenting a coverage map for the Mesokampos bay.

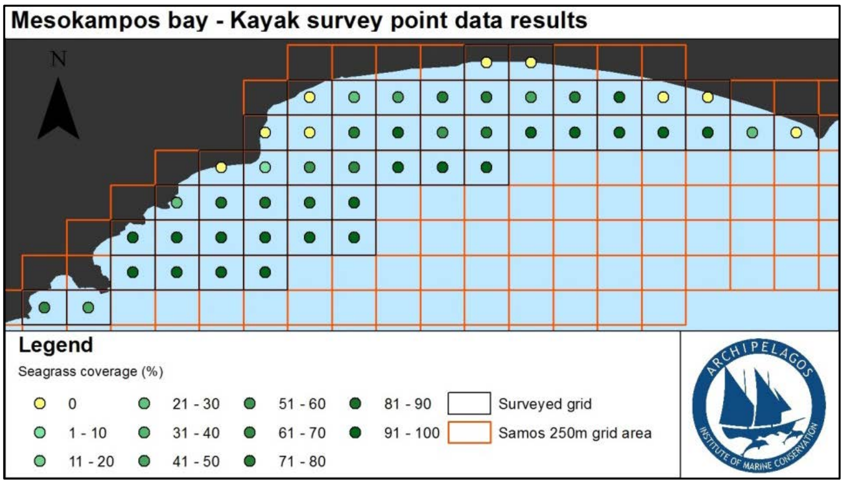


Figure 7: kayak survey point data

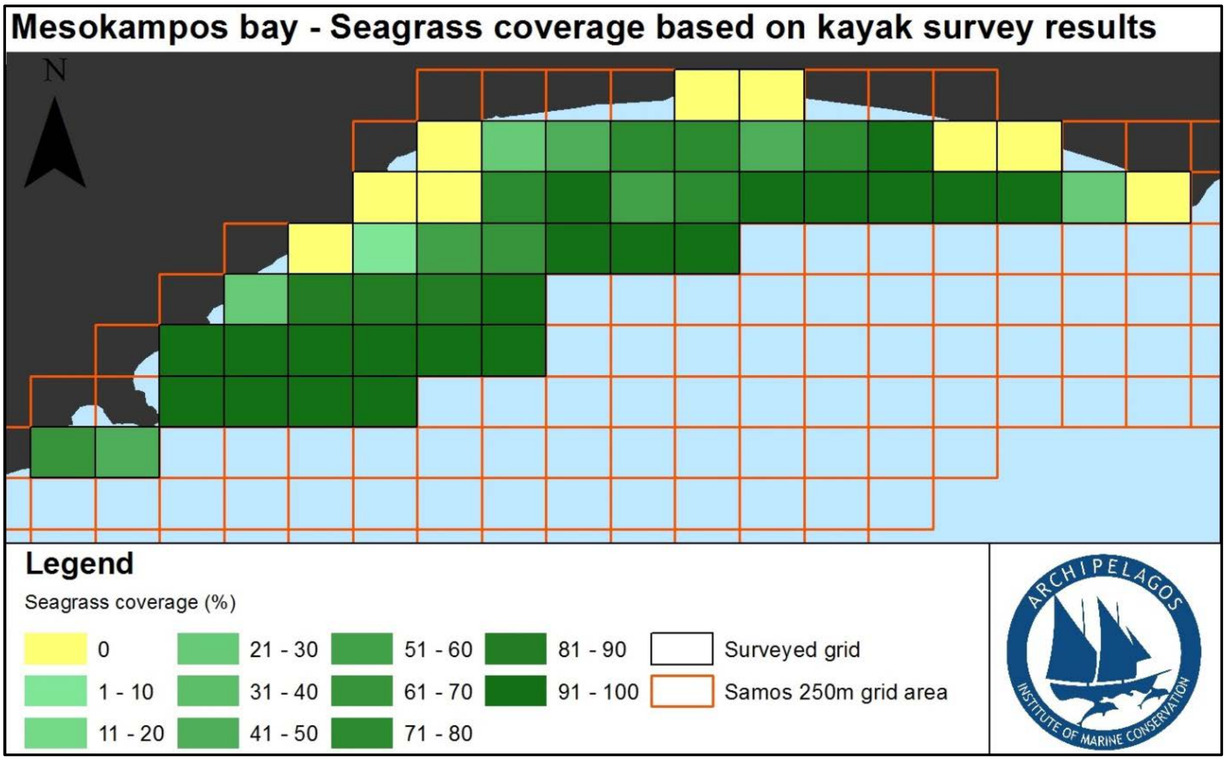


Figure 8: seagrass coverage map in the Samos 250m grid

2.5 Sub-question 5: Accuracy of the mapped data

For validation of the found results, the *Posidonia* coverage maps based on satellite imagery and sidescan sonar data were compared to the point data that was gathered during the kayak surveys.

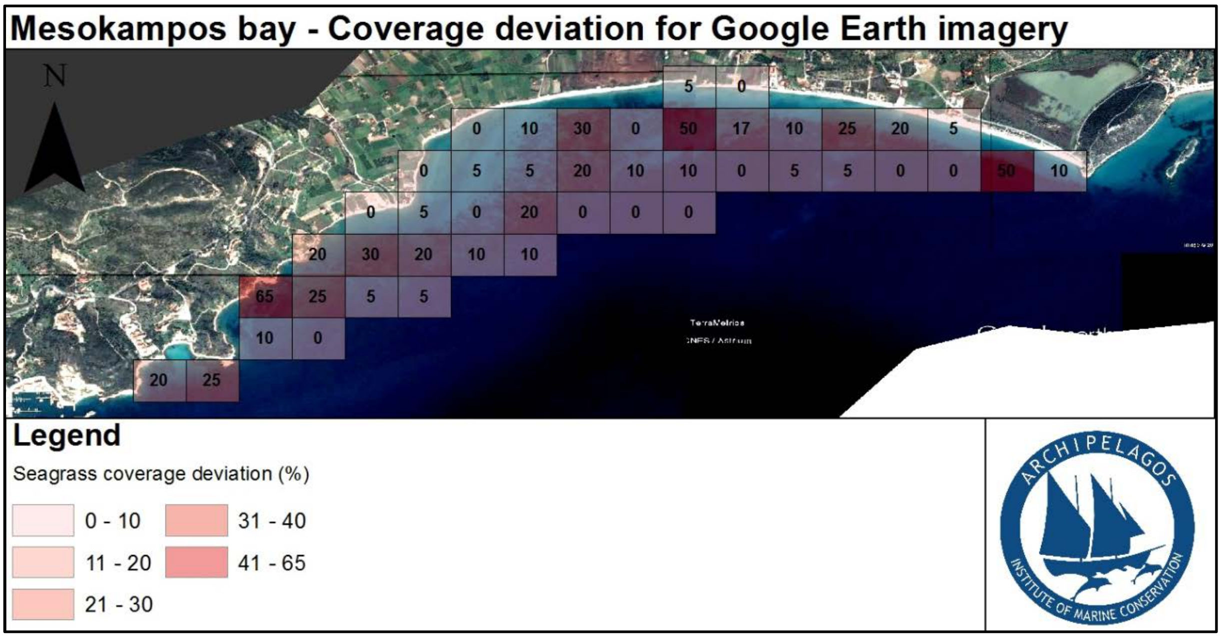


Figure 9: deviation of seagrass coverage between the satellite imagery-based coverage map and kayak points

The 49 kayak survey points served as a ground truthing sample for validating the outcome of the Google Earth-based coverage map of *P. oceanica*. The deviation in coverage values between the two datasets is shown in figure 8, the average was found to be 12,5% with a standard deviation of 14,6%. The three outliers in terms of high deviation (50% and higher) values were all found in areas where borders of formerly separate satellite images are located. In a similar way, deviation in coverage was mapped for the sidescan sonar map (figure 9). For this method, the average deviation in coverage values was found to be 17,5% with a standard deviation 12,3%.

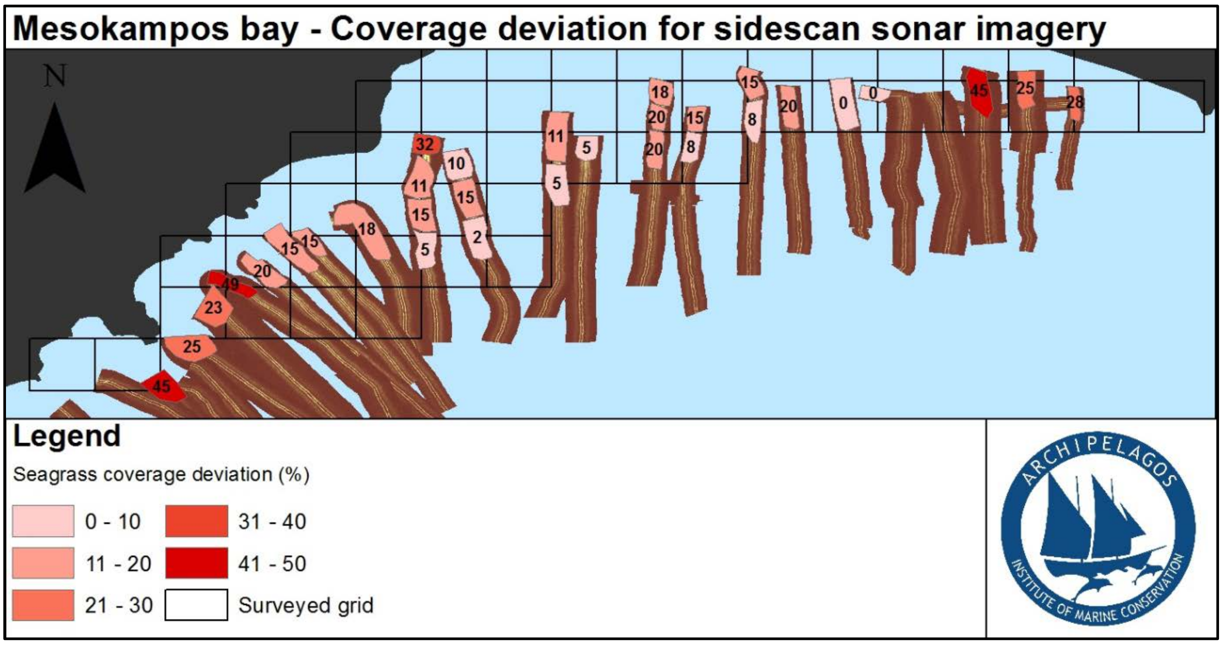


Figure 10: Coverage value deviation for the sidescan sonar map

Chapter 3: Conclusions and discussion

This chapter shows the conclusions that were drawn, based on the results this study yielded per sub-question. Answers to the sub-questions and the main research question are presented and discussed.

3.1 Sub-question 1

What is the extent of *Posidonia* habitat around Samos?

Figure 3 shows that *P. oceanica* is present along almost the entire coastline of the island in varying densities, the Mesokampos bay being one of the few areas with extensive seagrass presence. The seagrass species appears to be more abundant in areas with a less steep seafloor, where the distance between the coastline and the 50m depth limit is greater. The total area covered by seagrass in the mapped region is approximately 16,5km^2.

3.2 Sub-question 2

How effective is the use of satellite imagery for mapping *Posidonia* habitat?

Satellite imagery has proven to be an effective way of mapping seagrass, in agreement with former studies (Fornes et al. 2006; Pasqualini et al. 2004). The cost efficiency is very high: the high resolution Google Earth satellite imagery is freely available online for the entire world. The time investment is marginal compared to the extent of the result. Using the grid method, it took approximately one week for one person to map the coastline of the entire island, including the processing of the imagery. The method does however not include the deeper areas where *Posidonia oceanica* can occur. At a depth of approximately 15m is where the limit for this method lies, 20m is the lower limit for clear and sheltered waters (Pasqualini et al. 1998). By these criteria, the waters of the Aegean Sea are generally well eligible for this mapping approach.

3.3 Sub-question 3

How effective is the sidescan sonar for mapping *Posidonia* habitat?

The sidescan sonar is a commonly used method for mapping seagrass (Montefalconea et al. 2013; Pasqualini et al. 1998). The data resulting from the boat-based surveys during the present study, is characterized by a high level of detail when zoomed in to smaller areas (1: 1000 for example). However, when used to make full-coverage maps of larger areas, the method will be less time and cost effective. The cause of this is the fact that a larger boat with heavier equipment is involved. The boat surveys are time consuming and expensive in terms of resources: a team of 3-4 persons is needed at the very least, to operate the boat and the equipment. Besides that, the surveys have to be done at a maximum speed of 3 knots(5,6 km/h) to ensure image quality. This means a 1 kilometer transect would theoretically take little over 10 minutes. The boat does however need to be manoeuvered into the right position for starting a transect. Furthermore, fuel costs are associated with the surveys. The sidescan sonar data as shown in figure 9, took 4 days to collect and process. For collecting full-coverage data for the Mesokampos area, about twice as many transects would be needed. The sidescan sonar is nonetheless a viable methodology option for mapping *P. oceanica* in deeper areas, 20-50m deep, where other methods are no longer reliable.

3.4 Sub-question 4

How effective are kayak-based surveys for mapping *Posidonia* habitat?

The kayak-based surveys have proven to be effective in several ways. Besides the initial purchase of the kayak and the equipment, there are no costs involved. The investment of time and human resources is fairly low as well. It takes two persons to carry out the surveys and 10-15 of the grid cells can be surveyed in one day. For the shallowest areas, up to roughly 8m, this number will be higher (even up to 20 in good conditions) and for deeper areas with more wave action and stronger currents the maximum can be under 10. This similarly depends on the distance between the starting point and the targeted survey area and the associated time required to reach the specified destination. A limitation to this method is the dependance on suitable survey conditions in terms of weather and water currents. The risk of the kayak tipping over has to be minimized since the equipment is splash-proof, but not likely to withstand being submerged. Turbulent waters with strong currents are best avoided, for the safety of the survey team. Therefore, the surveys can only take place in calm weather conditions and in sheltered waters. The effective depth of observations done using the bathyscope during kayak surveys was found to be approximately 12m.

3.5 Sub-question 5

How accurate is the mapped data?

Google Earth satellite imagery

For the satellite and sonar imagery the accuracy was calculated, with the results shown in paragraph 2.5. The satellite imagery-based map showed a 12,5% deviation in seagrass coverage when compared to the kayak survey findings. The greatest portion of this inaccuracy appears to be caused by georeferencing errors, as the outliers with a high deviation rate are found on the slightly shifted edges of satellite images. Next to that, the creation date of the used imagery is 2014, but the exact date is not known for the imagery. It is possible that the are local difference in coverage caused by external factors during the time that was in between the creation of the satellite imagery and the kayak based-surveys. For these reasons, the method will likely be more effective when used with another other source of satellite imagery, preferably recently collected. Furthermore, a 12,5% deviation in coverage values is minor when taken in to consideration that the most important purpose is to map the extent of *Posidonia oceanica* in order to successfully enforce protective legislation. Other studies regarding the mapping of seagrass usually present their findings in terms of presence or absence (Pasqualini et al. 1998; Fornes et al. 2006; Montefalconea et al. 2013). Considering this, an error of 12,5% for coverage will not make a significant difference in terms of *Posidonia* presence.

Sidescan sonar imagery

The sonar imagery showed a larger deviation in coverage: 17,6%. This is most likely caused by the fact that the sidescan sonar data was not aligned with the study area grid, causing parts of the data to be somewhere in between kayak survey points. This means an average coverage value of several adjacent grid cells had to be calculated, which resulted in a less accurate deviation value. Sidescan sonar imagery has a high level of detail and is likely to accurately show the location of seagrass patches and meadows. To more accurately calculate the deviation however, it is required to align future sidescan sonar survey transects to the 250m grid.

Kayak survey data
The accuracy of the kayak point data is high. At the grid cell center points the actual current seafloor texture is recorded. The accuracy of the polygon map that was based on these findings is lower, because over a short distance, Posidonia presence and coverage can vary and the surveys only covered a small area in each grid cell.

3.6 Main research question

What is the extent of *Posidonia* habitat around Samos and how effective is the use of satellite imagery and sidescan sonar data combined with kayak-based surveys for mapping this habitat type?

P. oceanica is widely spread along the coast of Samos island, covering a total of approximately 16,5km^2 in the areas with depths less than 20m. In these regions, a combination of satellite image processing and kayak surveys for validating purposes is a suitable approach for mapping the extent and coverage of seagrass on a larger scale. The sidescan sonar is less suited for this purpose, due to the greater amount of time and resources required for gathering data. Likewise, getting a full coverage map is difficult as opposed to the satellite imagery method. This leads to the conclusion that a combination of processed satellite imagery and kayak survey points is the more effective method for the shallower areas. Grid-aligned sidescan sonar transects will however present a solution to the current lack of data for areas between 20m and 50m of depth around Samos. Next to that, the high resolution of sidescan sonar imagery will allow for small-scale high detail applications, such as local seagrass monitoring. The tested kayak method is especially suited for gathering a sample of ground truthing points for validating data resulting from other methods.

Chapter 4: Recommendations

Chapter 4 offers recommendations on the subject of mapping seagrass, based on the results and conclusions presented in the previous chapters. Recommendations are focused towards improvements of used methods and possible future applications contributing to the conservation of seagrass meadows.

4.1 Methodology improvements

General
The current methodology does not cover the deeper areas where *Posidonia oceanica* can be found. Therefore it is needed to set up a way to map deeper areas to map the extent and coverage up to 50 meters. Either sidescan sonar, additional kayak equipment or the boat-based underwater camera system can provide the necessary additional data.

Satellite imagery
A number of adjustments can be made to the satellite imagery method, to reduce processing effort and increase the reliability of the results. Imagery consisting of a singular satellite photo would be ideal, to avoid the inacurracies inherent to the georeferencing process. An improvement to the used Google Earth processing method would be an upgrade to Google Earth Pro, which enables the export of significantly larger size images. This would reduce both the time investment and the inaccuracies in the results. A Google Earth Pro licence normally costs €320 per year, but non-profit organisations such as Archipelagos can apply for a free licence (Google 2014). Further sources of high-resolution satellite imagery that were successfully used in previous seagrass mapping studies are SPOT 5 imagery (Pasqualini et al. 2004) and IKONOS imagery (Fornes et al. 2006). These are however not freely available and would require a financial investment.

Sidescan sonar
The sidescan sonar has been proven to be an effective seagrass mapping tool in a number of studies. In the present study the added value of the sonar data was moderate, because it was used in a shallow area, where the satellite imagery-based mapping outperforms the sidescan sonar in terms of time and cost efficiency. Besides that, the imagery was not aligned to the base grid, impeding accurate ground truthing. Boat-based sidescan sonar surveys will however be the most suitable method for mapping the deeper areas around Samos, using the 250m grid to make the results compatible with other grid-based maps resulting from further seagrass mapping efforts. To achieve efficient mapping, it is advised to conduct surveys along straight transect lines through the centre points of grid cells.

Kayak surveys
The bathyscope is effective up to depths of about 12m. Kayak surveys with additional equipment can improve the extent of the results found in the present study. Test runs have been done lowering a waterproof camera with an attached weight towards the seafloor to collect footage at the central point of each grid cell, which is a promising approach although it will slightly reduce the time-efficiency of the kayak surveys. Furthermore, gathering a greater amount of ground truthing points in various areas around the island will increase the reliability of the ground truthing calculations. Using the kayak will however still be limited to the sheltered waters without strong currents and wave action for safety reasons.

GIS-mapping
Regarding the GIS-mapping process, there are several options for displaying the results. In the present study, each cell was given a single color according to the coverage of seagrass that was found. Especially on a smaller scale, this results in quite a coarse image, although it does objectively display the observed value for that grid cell. Another option is generating an interpolation map, using the point data. This results in a more fluent display of the data, which looks more realistic than grid cells with a solid color. The interpolation map for Mesokampos bay is shown in annex 5. However, seagrass coverage can be 100% in one spot and drop to be 0% over a few decimeters of distance, it does not grow in a coverage gradient. This means that both methods have their advantages and disadvantages, but neither method is an exact representation of reality.

4.2 Future studies

Mapping
In the future, after refining the studied methodology and including ways to map seagrass in the deeper areas, the methodology can be used to map seagrass in similar areas, starting with other Aegean islands within the operating area of the Achipelagos institute. The best approach, based on the results and conclusions of the present study and other mentioned studies, is to use satellite imagery to map the shallow areas up to 15-20m and use the sidescan sonar for the areas up to 50m, combined with kayak surveys for ground truthing purposes.

Monitoring
Another future application is the monitoring of seagrass presence and coverage, to specify trends and to timely identify declines. This would consist of repeated mapping once every five or ten years. For large scale monitoring for entire islands the method can be a combined use of satellite imagery, sidescan sonar data and kayak survey points. Monitoring case studies can also be done on a smaller scale, using sidescan sonar or drone imagery to map seagrass on a higher detail level. The most suited areas for monitoring case studies are those where *P. oceanica* is most likely to be pressured, mainly areas with a high level of anthropogenic influence. Similar to large scale studies, deeper areas will need to be surveyed with sidescan sonar and kayak-based surveys can provide ground truthing sample data.

Trawl and anchor marks
It is recommended to carry out future studies investigating and quantifying the effects of trawl marks on the presence and the condition of *Posidonia oceanica* meadows. Trawl and anchor marks are among the greatest threats *Posidonia oceanica* faces, causing direct damage to the meadows. The fact that so many of these marks were found in the study area is a reason for concern, especially since a large portion of its seafloor is vegetated by seagrass. Trawling is prohibited within 3 nautical miles (5,56 km) from the coast (Leriche et al. 2006), meaning it is strictly forbidden in the Mesokampos bay. The marks found in the bay illustrate how regulations are ignored and that there is a need for effective enforcement of protective measures. Maps of trawl marks can be helpful for public awareness about marine conservation and in convincing authorities that action is required.

Implementation of protective measures
Regarding future seagrass conservation efforts, it is advised to include a plan to translate the knowledge of seagrass distribution and coverage into the implementation of protective measures and the effective enforcement of said measures.

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Annexes

1. Kayak-based surveys: equipment and routes

2. Examples of georeferencing inaccuracy

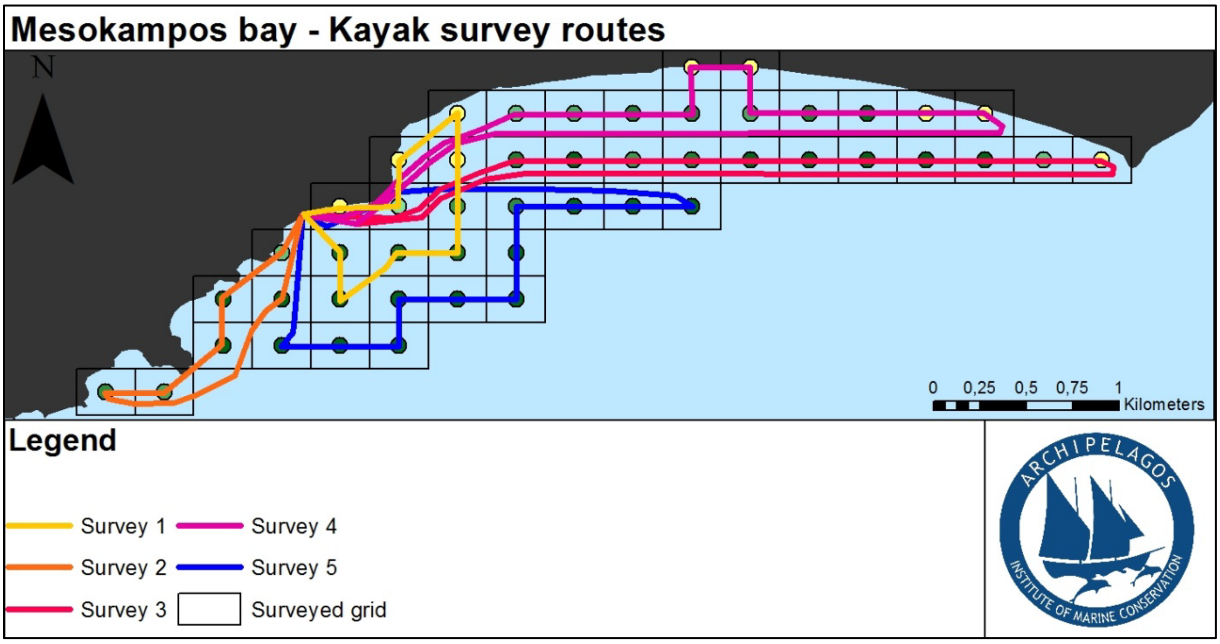
3. Examples of sidescan sonar imagery showing *P. oceanica*

4. Examples of trawling and anchoring marks

5. Kayak data interpolation map

Annex 1: Kayak-based surveys: equipment and routes

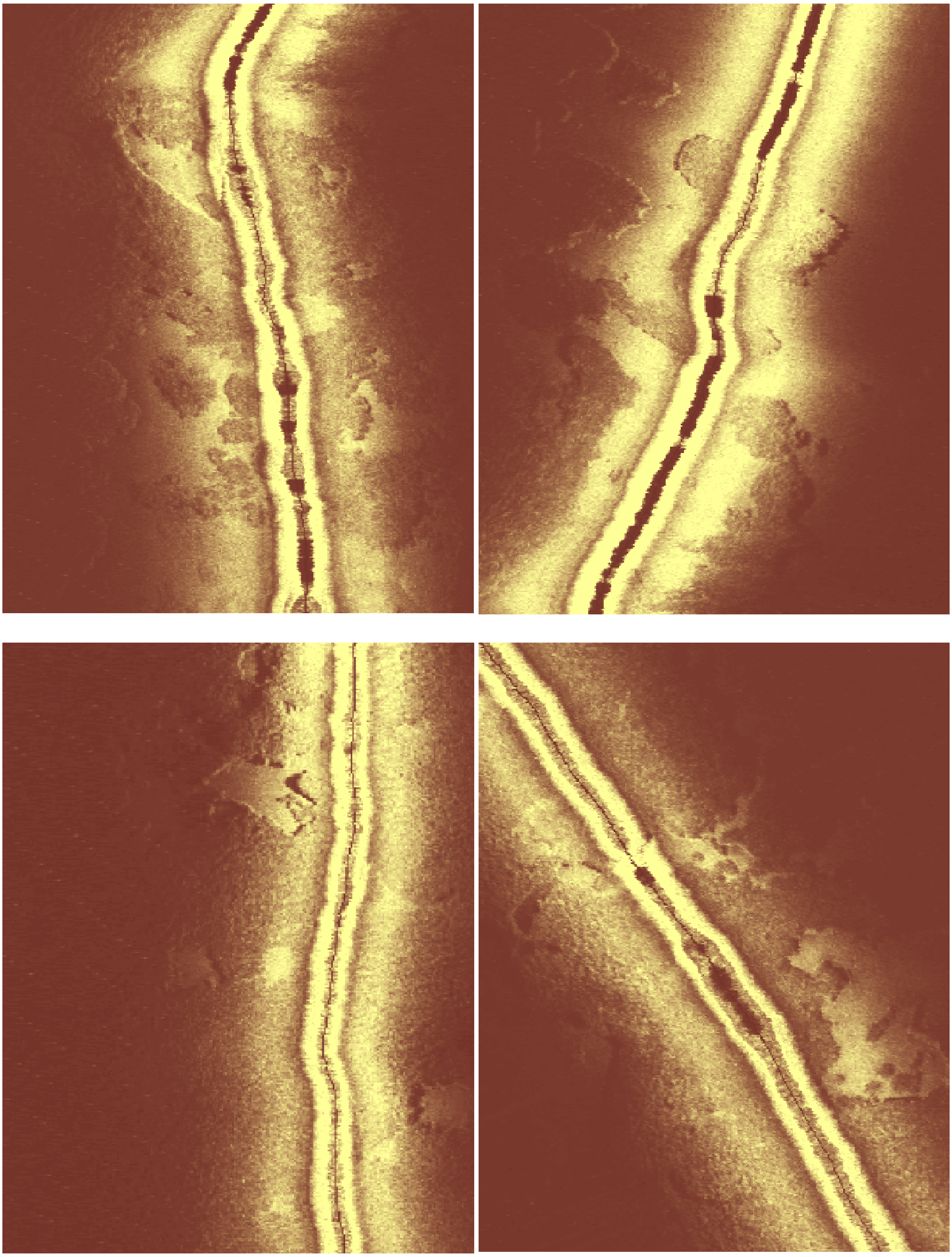
(Photo by Richard Kirschbaum, Archipelagos GIS team)



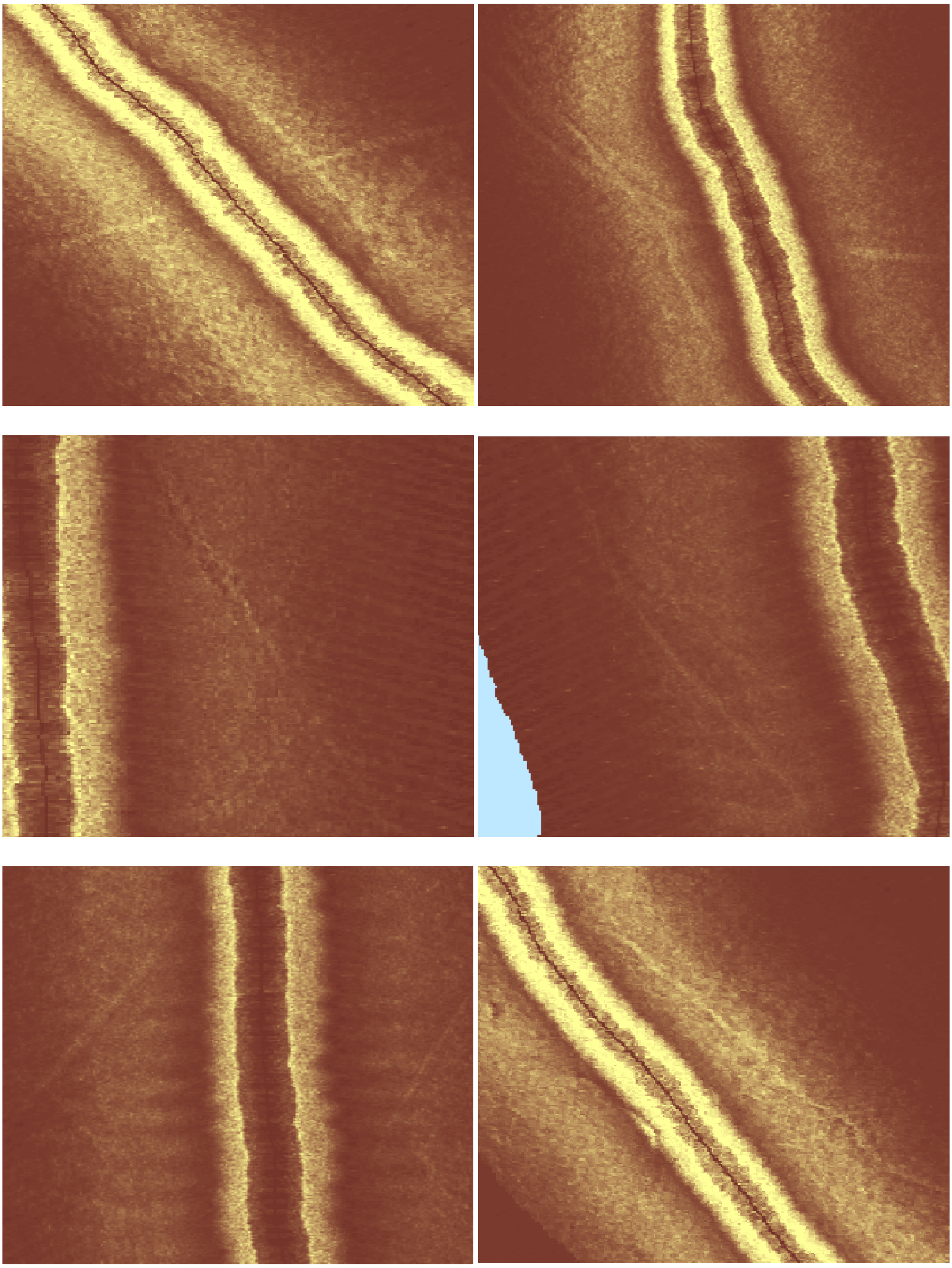
Annex 2: Examples of georeferencing inaccuracy

Annex 3: Examples of sidescan sonar imagery showing *P. oceanica*

Scale 1:1000



Annex 4: Examples of trawling and anchoring marks



Annex 5: Kayak data interpolation map