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ANTHROPOGENIC IMPACTS IN DISTRIBUTION AND HEALTH OF THE SEAGRASS MEADOWS AROUND LIMNOS, GREECE

Bachelor's thesis

Bachelor of Engineering

Environmental Engineering



South-Eastern Finland
University of Applied Sciences

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| Degree title | Bachelor of Engineering |
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| Thesis title | Anthropogenic impacts in distribution and health of the seagrass meadows around Limnos, Greece |
| Commissioned by | Dr. Tim Grandjean – Archipelagos Institute of Marine Conservation |
| Year | 2025 |
| Pages | 41 pages, 5 pages of appendices |
| Supervisor | Dr. Shakil Regmi |

ABSTRACT

The seagrass meadows around the world are threatened by natural and anthropological impacts. Seagrass species, *Posidonia oceanica*, is especially vulnerable to human disturbance due to its slow recovery. The biggest seagrass meadow in the Aegean Sea is estimated to be around the island of Limnos in Greece.

The objective of the study was to evaluate the distribution of seagrass meadows in the coasts of Limnos based on the drone imagery collected there in November 2024. Moreover, the potential anthropogenic impacts on seagrass were assessed. The aim was to provide information which could support the conservation actions in Limnos.

Collected and pre-processed drone imagery data was analysed in geographical information system (GIS) application to produce quantitative information about seagrass distribution. Data analysis methods, such as Principal Component Analysis (PCA) and image classification were used. The dataset visualizing seagrass meadows and their patchiness was generated. The distribution and shapes of fragmentations were assessed to identify possible anthropogenic impacts.

Seagrass distribution correlates with the previous studies. Seagrass coverage in the survey sites was generally high. Only small patches of seagrass were present in the sites with coastal infrastructures indicating possible impacts of human activities. More extensive information about the impacts and the health of the meadows could be obtained by combining the ground-truth data with remote sensing.

Keywords: seagrass, distribution, anthropogenic, impact, anchorage,

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1 INTRODUCTION

Seagrasses all over the world play a major role in marine ecosystems supporting also life on earth with the wide variety of ecosystem services (UNEP 2020, 11). The Mediterranean Sea hosts its own endemic seagrass species, *Posidonia oceanica*. EU Habitat Directive (92/43/EEC) states in Annex I *Posidonia* beds, habitat type 1120, to be primarily protected habitat. The EU conservation status of *Posidonia* beds all over the Aegean Sea, the eastern part of the Mediterranean Sea, were evaluated to be poor in the latest 2013-2018 assessment. Poor status means the *Posidonia* beds are not disappearing but to achieve restoring the desired status, the policy and management need to change. (EEA 2019.)

In the Greek seas, the North Aegean Sea hosts the largest amount of seagrass meadows, total coverage of 996 km² (Panayotidis 2022, 6). Around the island of Limnos there is estimated to be one of the biggest undivided seagrass meadows in the Aegean Sea covering the area of 124 km² (Topouzelis et al. 2018). However, the seagrass is widely present in all coastal areas of the island (Figure 1).

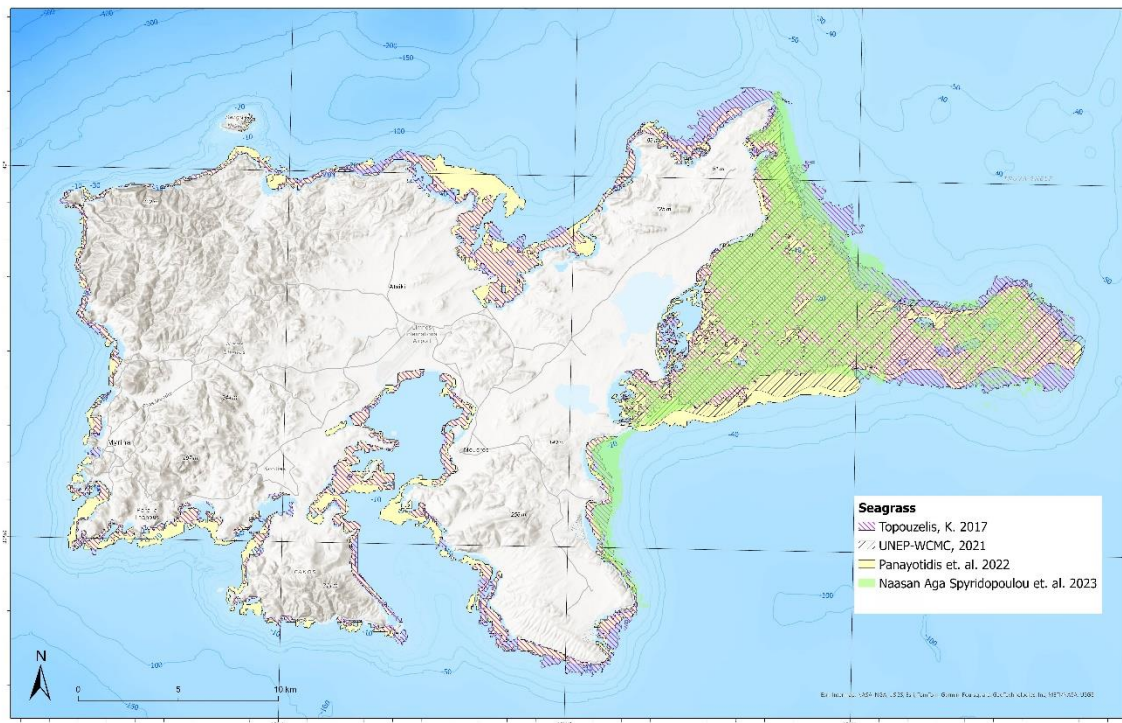


Figure 1. Presence of seagrass around Limnos based on previous research

Seagrasses are valuable to underwater ecosystem, providing important habitat for many other species. Furthermore, seagrass prevents coastal erosion and provides multiple ecosystem services. (Campagne et al. 2015, 391-392.) Despite its ecological importance, seagrass meadows are facing threats due to anthropogenic reasons, such as fishing and anchoring. *P. oceanica* recovers poorly from human impacts and grows slowly. (Telesca et al. 2015, 2.) Thus, human disturbance can cause long-term impacts in these vulnerable ecosystems.

Anthropogenic impacts could be evaluated based on scarring of seagrass meadows but also by the patchiness. Seagrass patchiness is happening due to natural reasons. It is also studied to be increasing because of the anthropogenic impacts. Patchiness is an indicator of the health of seagrass. (Barcelona et al. 2020, 1.) However, the reason for patchiness without clear sharp lines as in anchorage scars, is sometimes hard to confirm without further information about pressures in the area.

Remote sensing, such as satellite imagery, has been widely used and utilized in spatial mapping technologies. However, the visibility can be restricted due to cloud coverage or resolution of images. Unmanned aerial vehicles (UAVs), such as drones, could be used to fill out the gaps in local spatial mapping. Data from UAVs are often high resolution and cost-effective. (Ventura et al. 2023, 3.) Previous research about seagrass abundance around Limnos are widely based on satellite imagery (Panayotidis et al. 2022; Topuzelis et al. 2018; Naasan Aga Spyridopoulou et al. 2023; UNEP-WCMC 2021). The information has been supplemented in some places with the data from side scan sonar (SSS) and SCUBA surveys (Panayotidis et al. 2022; Naasan Aga Spyridopoulou et al. 2023). These results could be validated with data from UAV- and SSS-surveys (Topuzelis et al. 2018).

The objective of the thesis is to supplement the existing information of seagrass distribution based on the drone imagery collected around Limnos in November 2024. Furthermore, any impacts on seabed and more specifically on seagrass

caused by human impact will be evaluated. The aim of the study is to provide information to support future marine conservation efforts around the island.

2 THEORETICAL BACKGROUND

2.1 Study area

Limnos is a Greek island located in the Northern Aegean Sea. The shoreline of the island reaches 259 km (Visit Greece n.d.). In the northeast side of the island is a large shallow area, which depth is less than 20 m. This area is characterized by one of the largest *P. oceanica* seagrass meadows of the Aegean Sea (Topouzelis et al. 2018). Nevertheless, seagrass is widely distributed all around the island (HCMR et al. 2015; Topouzelis et al. 2017, UNEP-WCMC 2021; Panayotidis et al. 2022). Total seagrass coverage around Limnos is estimated to be around 254 km² with the observations made up to 40 m depth (Traganos et al. 2018, 9).

Most of the coastal areas of Limnos are designated Natura 2000 -sites: GR411006 and GR411001 (Figure 2). However, only the latter is designated under the Habitats Directive (96/43/EEC) aiming to protect habitats such as Posidonia beds (EEA n.d. a). GR411006 was designated under the Birds Directive (2009/147/EEC). Despite the presence of habitats that should be protected, none of these are recognized in the fact sheet of the Natura 2000 -site. (EEA n.d. b.)

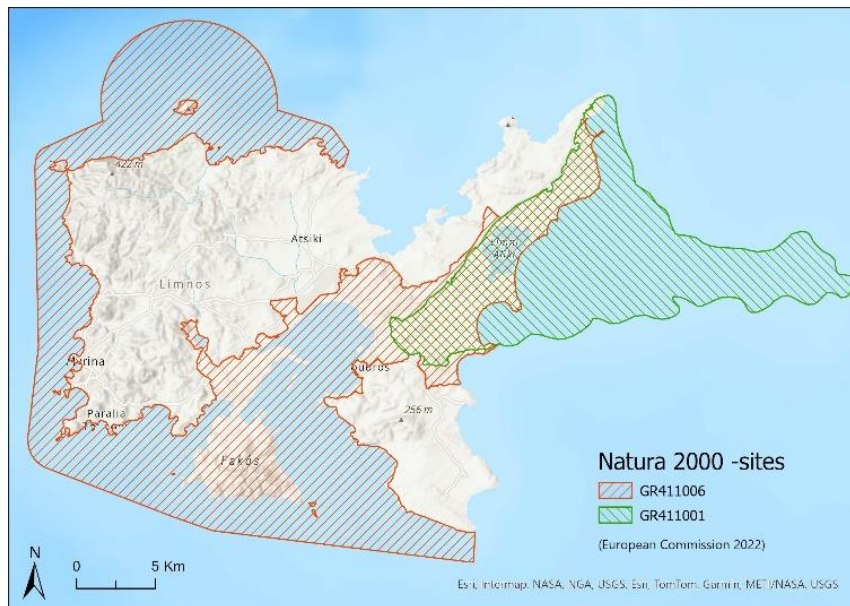


Figure 2. Natura 2000-sites around Limnos. GR411006 is designated under the Birds Directive (2009/147/EEC) and GR411001 under Habitats Directive (96/43/EEC). (European Commission 2022).

The sea east of Limnos is relatively shallow in general, mostly below 50 m. Around 65 km to the east from Limnos there is a channel connecting the Black Sea to the Mediterranean. West to north of the Limnos the Aegean Sea has deeper profile reaching depth of 1500 m. (EMODnet Bathymetry Consortium 2024.)

2.2 Seagrass

Seagrasses are found in every continent except Antarctica (UNEP 2020, 48). The meadows can cover large areas on coastal areas up to 50 m depths. They provide important ecosystem services such as providing habitat for other species and protecting shores from coastal erosion. (Traganos et al. 2018, 1-2.) Approximately 15% of the blue carbon is captured by seagrass. The most efficient seagrass species in carbon sequestration is *Posidonia oceanica* found in the Mediterranean Sea. (Pergent-Martini et al. 2020, 3.)

P. oceanica meadows can be found from shore up to depths of 45 meters (Telesca et al. 2015, 2). The species has a unique characteristic growing vertically on top of the dead rhizomes and thus building a mat (Boudouresque et al. 2015, 26). In the mat, the living parts of seagrass can reach up to 70 cm.

The rest of the matte is composed of dead rhizomes. (ibid. 29). Figure 3 shows the characteristics of seagrass matte in one of the survey points in Limnos.



Figure 3. *P. oceanica* seagrass matte in Paralia Plati Limnos, November 2024. High vertical growth and dead rhizomes can be seen under the living leaves. The scale of the layers on the right is indicative. Photo by Taima Güçlü, Archipelagos Institute of Marine Conservation

P. oceanica has been recognized as a key species in several European legislations. European commission's Habitats Directive (96/43/EEC) Annex I mention *Posidonia* beds (*Posidonium oceanicae*, habitat code 1120) requiring conservation. Moreover, it is defined to be priority habitat for conservation. The importance of *P. oceanica* is acknowledged and guidelines for the habitat protection are provided also in Marine Strategy Framework Directive (MSFD) (2008/56/EC), Water Framework Directive (2000/60/EC) and Common Fisheries Policy (2006). The need for protection of *P. Oceanica* is mentioned in Bern convention Annex I (ETS no. 104) and Barcelona convention (1976) Annex II. In addition to EU legislation and regulations, also Greek national laws, such as 3937/2011 on Biodiversity Conservation, addresses the importance to protect *P. oceanica*. (Chrisholm 2024; Bellissimo et al. 2020, 510.)

MSFD Descriptor 6 states the seabed habitat has a good environmental status, when less than 25% is damaged by human actions and maximum of 2% is permanently lost (2008/56/EC). Characteristics of *P. oceanica* make it a good bioindicator. Presence or abundance of meadows in addition to monitoring the

health of meadows provides valuable information about the quality of environment. (Bellissimo et al. 2020, 510.)

2.3 Anthropogenic threats to seagrass

Seagrass meadows around the globe are declining due to natural and anthropogenic impacts, including climate change and scratching seabed practices such as anchoring and trawling (Elma et al. 2024, 1). According to most recent estimates, annual loss of seagrass habitats is around 7%. In other words, every half an hour the amount of seagrass which could cover a football field is lost. (UNEP 2020, 36.) In the Mediterranean Sea, the seagrass coverage has decreased 20% from 1869 to 2016 in dedicated study areas (ibid. 40). Majority of the world's seagrass meadows are unprotected against human impacts and there is no existing management plans for them. (UNEP 2020, 15.)

Fishing equipment dragged on the seafloor, such as trawls; seafloor modifications by dredging and even small anchors can cause lot of damage while ripping off seagrass leaves and rhizomes (Tyllianakis 2022, 2; La Manna et al. 2014, 160). Besides seagrass, the damage decreases the other species stocks and diversity. Moreover, invasive species may benefit from habitat loss. (La Manna et al. 2014, 160.)

Threats to seagrass habitats are not always caused by direct contact with it (Figure 4). Alternation of living conditions like the sea depth or water quality can harm their growth. In fact, in addition to dredging the highest impact on seagrass comes from land-based stressors. (UNEP 2020, 36.)

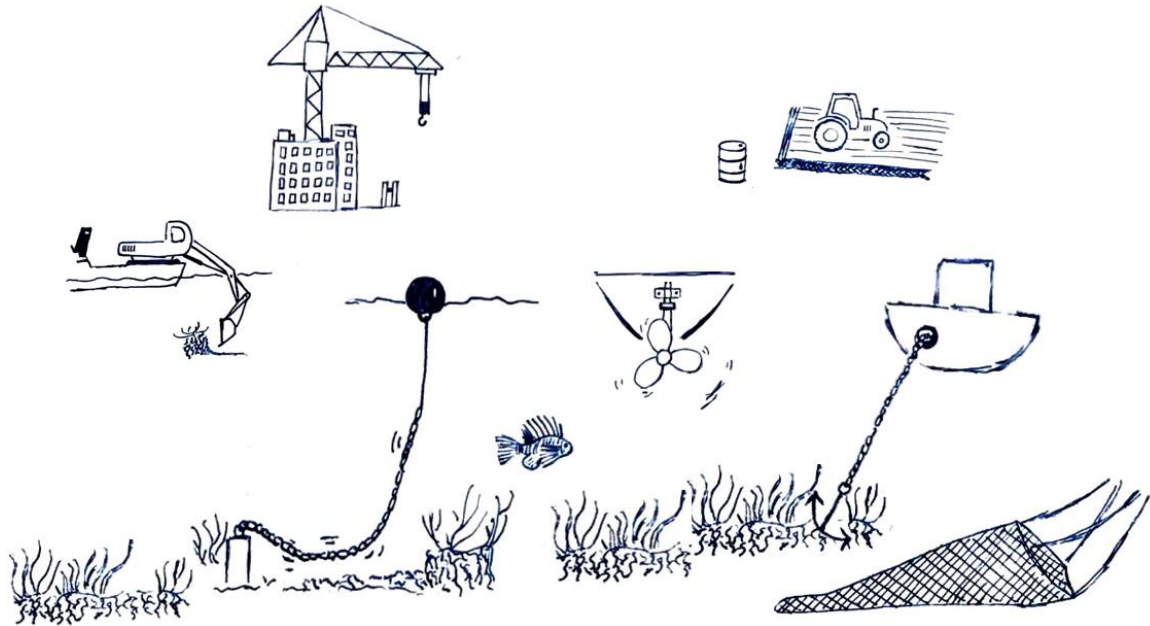


Figure 4. Threats to seagrass meadows are not always through direct contact. Urban and industrial run-offs and coastal development are also threatening seagrass. Figure illustrates some of the potential threats to seagrass meadows.

Storm water from urban and industrial areas and agricultural run-offs transports litter, nutrients and solid matter to the sea. Chemicals might be toxic, and nutrients increase eutrophication. Changes in turbidity may block light penetration and affect photosynthesis of seagrass. Being suitable areas for seagrass, the shallow coast is also likely to be used by humans. (UNEP 2020, 36-37.) For example, on and around the big seagrass meadow in northeast of Limnos was planned four offshore wind farms. However, these projects were all cancelled. (RAE n.d.) Land reclamation from marine habitat and sea level rise due to coastal development takes space from seagrass (UNEP 2020, 37).

Sea-based indirect threats can be caused by aquaculture, shipping accidents or when dumping dredged material into the sea. Impacts are similar to land-based threats: changes in chemical conditions and increased turbidity. Solid matter landing on seagrass can smother the meadows. The water movements due to boating can mix sediment or detach the leaves of seagrass. Mooring, anchorage and fishing equipment dragged or held on the seafloor can cause fragmentations to seagrass meadows. Also, fishing and invasive species can change the

species' composition and for example lead to competition of living space or increased grazing of seagrass. (UNEP 2020, 37.)

Climate change related threats could also be viewed as anthropogenic threats since emissions from human activities are accelerating it. More frequent strong weather events challenge durability of seagrass. Changing physical conditions. ocean acidification and rising sea levels can alter the living conditions be unbearable. (UNEP 2020, 40.)

2.4 Remote sensing in seagrass monitoring

Remote sensing technologies, including satellite imagery, have been used for a long time. Nowadays, data from satellites are widely used worldwide in ecological monitoring. (Ventura et al. 2022, 3.) The most advanced satellite systems can reach even 16-cm resolution (Umbra Space 2023). However, even the most precise satellite imagery has some disadvantages: high spatial resolution could be expensive, clouds might cover the scene or satellite's revisit time is long (Ventura et al. 2022, 3). Utilizing unmanned aerial vehicles (UAVs), such as drones, can be used to overcome these issues in small scale, local research. Differences of freely available Sentinel-2 satellite data and drone imagery are visualized in Figure 5.

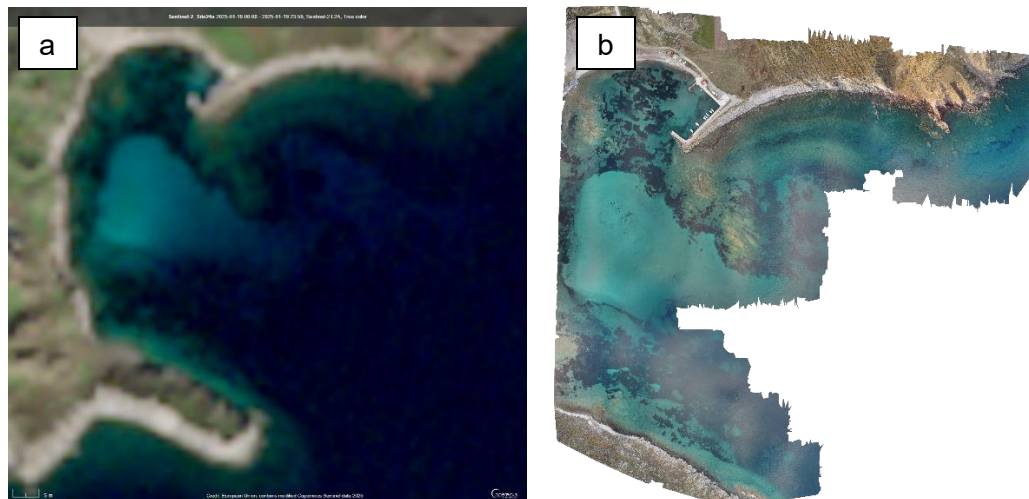


Figure 5. Two remote sensing methods used for same area. a. Sentinel-2 satellite imagery retrieved from Copernicus. Image taken on 19th of January 2025. b. Drone orthomosaic. Images taken in November 2024

Use of UAVs in coastal management has become more frequent (Kvile et al. 2024, 2). UAVs can reach places inaccessible on land (Elma et al. 2024, 2). Compared to traditional habitat monitoring techniques such as aquascopes or underwater cameras, UAVs provides effective ways to cover wide areas and still generate detailed information of species that could be identified from distance (Kvile et al. 2024, 2). Often, UAVs are easily transported to study sites and saved flight paths make studies repeatable (Elma et al. 2024, 2) and therefore more easily comparable.

Weather conditions, such as wind speed, sun's position and thus the light reflection from the sea surface can decrease the image quality and damage the equipment (Kvile et al. 2024, 6). Different types of drones and sensors have their advantages and disadvantages in features such as flight time, speed and resolution. Flying a drone might need special permissions and licenses depending on the area (UNEP 2020, 49). For example, if the drone has a camera, the registration of the operator is needed and if the drone weighs more than 250 grams, the operator of the device is mandated to complete training in EU (Droneinfo 2021).

In habitat mapping, the identification of species can be challenging from the distance. Combination of remote sensing technologies, optical (i.e. satellite, UAV) and acoustic (i.e. side-scan sonar) methods, and field surveys can provide extensive information about the status of seagrass ecosystems (UNEP 2020, 48). This information is a valuable tool to support evidence-based decision making.

3 MATERIAL AND METHODS

3.1 Theoretical background

For theoretical background only material available online was used. Sources were searched from the databases offered by South-Eastern Finland University of Applied Sciences library services. Legislative information was searched directly from the EUR-lex. Also, Google Search was used to find specific information such as the resolution of most advanced satellite technology. The

access for whole text was required. To ensure reliability, peer reviewed and less than 10 years old articles were favored.

3.2 Data collection

The drone surveys were conducted in multiple sites (Table 1) around Limnos during the expedition of Archipelagos Institute of Marine conservation on 17th to 27th of November. Total of 21 surveys were done and 18 were further analyzed (Figure 7). Even more was planned but had to be cancelled due to weather conditions. The surveys were made together with other GIS and remote sensing team members. Two surveys were done simultaneously in two different locations by smaller teams. Three different drones were used: DJI Mini SE, DJI Mini 2 and DJI Mini 3 pro. Flightpaths were planned before field work by using Dronelink software. Same flight paths could be used again in the future.

Colleagues in GIS and remote sensing team created orthomosaics of drone imagery by using WebODM. Orthomosaics were used to report survey actions of the expedition to local partner organization Lemnos Marine Conservation. More specific analysis of the results was not made in this phase. Example of the orthomosaics can be seen in Figure 6a. Orthomosaics were obtained from the Archipelagos Institute of Marine Conservation to deeper analysis for this thesis. All the orthomosaics in relation to the survey location can be seen in Appendix 1.

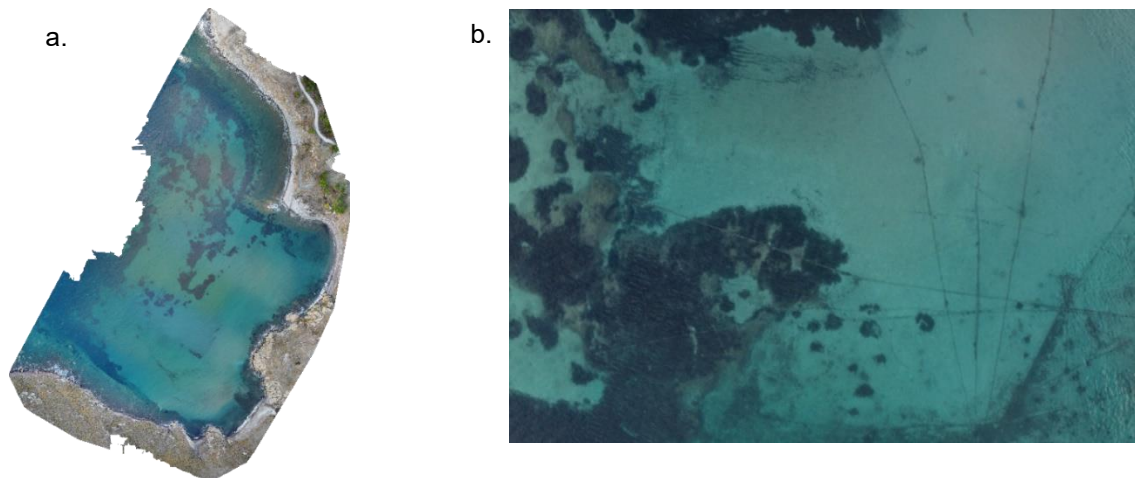


Figure 6. a. Orthomosaic from drone survey. Seagrass patches can be observed from the image. b. Clip from orthomosaic where scars of human impact are visible

During the expedition in Limnos, also the semi-structured interview of local fisher was conducted. The interview was held in Greek to minimize the misunderstandings and to build up the trust between interviewee and interviewer. Locals can provide their own observations which can complement and support the survey effort.

Table 1. Drone survey points where data was collected.

| Site | Location | Date | Drone |
|------|----------------------|------------|----------------|
| 1 | Myrina Church Bay | 17.11.2024 | DJI Mini SE |
| 2 | Myrina Marina | 17.11.2024 | DJI Mini SE |
| 3 | Bay N of Plati | 18.11.2024 | DJI Mini 2 |
| 4 | Bay of Moudros | 18.11.2024 | DJI Mini 3 pro |
| 5 | Bay of Moudros | 18.11.2024 | DJI Mini 3 pro |
| 6 | Bay of Moudros | 18.11.2024 | DJI Mini 3 pro |
| 8 | Myrina Beach N | 18.11.2024 | DJI Mini 3 pro |
| 9 | Myrina Beach S | 19.11.2024 | DJI Mini 3 pro |
| 10 | Bay N of Myrina | 19.11.2024 | DJI Mini 3 pro |
| 11 | Bay N of Myrina | 19.11.2024 | DJI Mini 3 pro |
| 12a | Plati Bay (S) | 25.11.2024 | DJI Mini 2 |
| 12b | Plati Bay | 24.11.2024 | DJI Mini 2 |
| 12c | Plati Bay | 24.11.2024 | DJI Mini 2 |
| 12d | Plati Bay (N) | 25.11.2024 | DJI Mini 2 |
| 19 | Ag. Ioannis N | 24.11.2024 | DJI Mini 3 pro |
| 20 | Ag. Ioannis | 24.11.2024 | DJI Mini 3 pro |
| 21 | Ag Ioannis S | 24.11.2024 | DJI Mini 3 pro |
| 22 | Bay N of Ag. Ioannis | 26.11.2024 | DJI Mini 2 |
| 23 | Bay N of Ag. Ioannis | 26.11.2024 | DJI Mini 2 |
| 24a | Bay E of Thanos | 26.11.2024 | DJI Mini 2 |
| 24b | Bay E of Thanos | 26.11.2024 | DJI Mini 2 |

3.3 Data analysis

Geographical information system (GIS) software, ArcGIS Pro, was used for data analysis. The software allows versatile tools and methods to maintain spatial data. It enables combining and editing data from different sources and visualizing informative maps. (ESRI n.d.a.) Orthomosaics were processed with the software

to create simplified and clear overview of seagrass dispersion. It was also used to create datasets to fulfill existing data of seagrass distribution around Limnos.

3.3.1 Principal component analysis

Principal component analysis (PCA) is a data processing method which allows simplifying the large datasets while retaining the most pertinent information. PCA reduces dimensions of the data by breaking it into principal components which means the smaller set of variables. This filters the non-necessary information of the data as well as compresses the data. (IBM 2023; Greenacre et al. 2023.) PCA was used to preprocess the images to increase contrasts and reduce the distraction of waves. Compressed data was also faster to analyze.

3.3.2 Image classification

Image classification is used to categorize the different features, such as different habitats, in the image. Classification could be done by defining the class for each pixel. With high-resolution images the pixels have more variation even though they represent the same class. Object-based image analysis (OBIA) offers an alternative approach where pixels are grouped into objects which then are classified. OBIA is usually started with the image segmentation following the classification process. (Hossain & Chen 2019, 115.) The size and accuracy of segments can be adjusted for defining spatial and spectral features. Quality of image segmentation affects directly to the accuracy of classification (Hossain & Chen 2019, 115).

Random trees classification, also known as random forest classification, is a machine learning method (ESRI n.d.b). It is one of the different classification methods that could be used after image segmentation. Training data and samples are used to create individual decision trees which create different branches based on random pixels and their classification. For the final outcome, each tree is giving a “vote” on the class each pixel is representing. Random trees classification lowers the chance of overfitting. (ESRI n.d.b.; IBM n.d.)

3.4 Data processing



Figure 7. Analyzed survey sites were on the west coast of Limnos. Three more surveys were done in the Bay of Moudros. Some of the planned surveys had to be cancelled due to bad weather

18 orthomosaics were analyzed (Figure 7) in ArcGIS Pro. PCA was first performed to all the images with three components. The amount of components were chosen by experimenting which number of components seems most usable. Each PCA processed image was segmented separately to choose the features which resulted the best quality, see example in Figure 8. Image classification was therefore conducted on segmented PCA imagery. Imagery of site 22 was decided to be splitted in two images as the light variation confused segmentation.

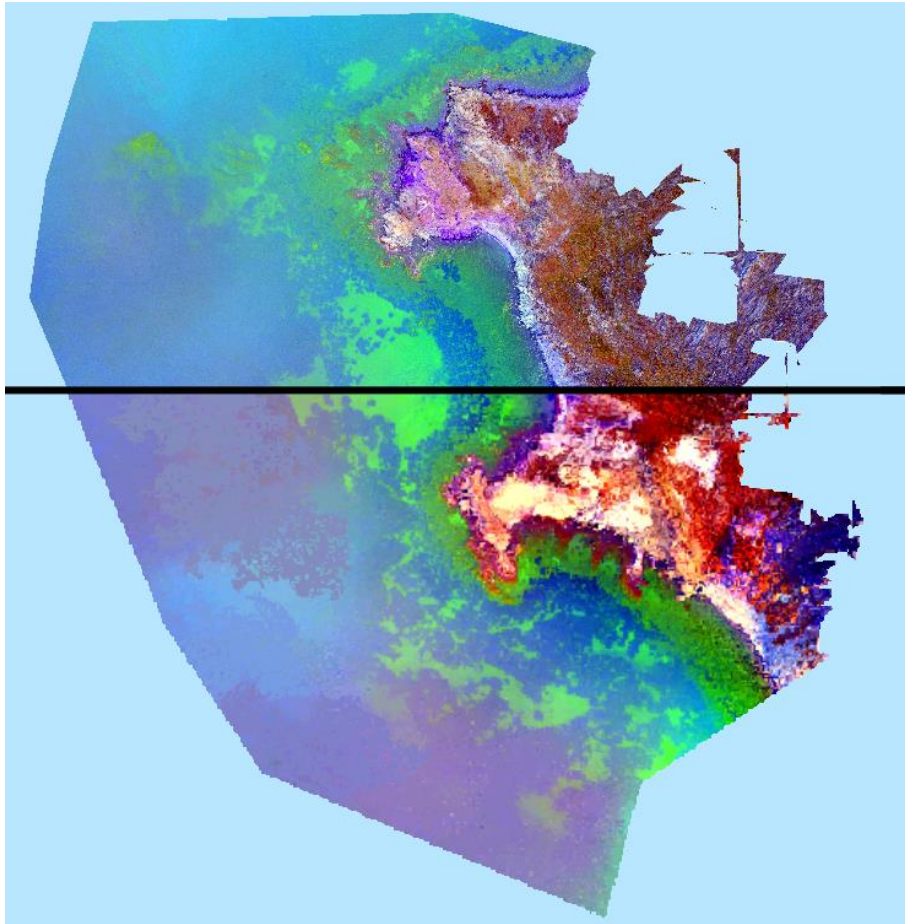


Figure 8. Difference between before and after segmentation of the image. PCA was performed before segmentation. On the upper part is the image before segmentation and on the lower after it. Example is from the site 22

Classification was decided to be done with four classes: seagrass, sand/pebble, rock/pebble and other. Interest was in seagrass distribution which is why more classes were not seen relevant. Later one more class, 'looks like seagrass', was added to distinguish similar colour variations of two classes. Training samples for classification were taken from each image separately as using the samples from all images did not lead to truthful results. After initial classification the reclassification was done to correct the misclassifications and determine whether the 'looks like seagrass' was seagrass or something else.

Classified rasters were converted into polygons. Other attributes but seagrass were rejected. The outcome of seagrass distribution was exported as shapefile to be used in future projects in Limnos.

4 RESULTS

Seagrass was present on every study site (Figure 9). However, sites 9 in the north of Myrina and sites 19-21 in Agios Ioannis had only little patches. Close to the shore the form of seagrass patches indicated to the leaves washed to shallow waters. Seagrass coverage in studied marine areas is approximately 42% (Table 2).

Table 2. Seagrass coverage compared to studied area

| Coverage of orthomosaics | Marine area | Seagrass coverage | Seagrass coverage in the marine area |
|--------------------------|-----------------------|-----------------------|--------------------------------------|
| 3.792 km ² | 2.859 km ² | 1.203 km ² | 42% |

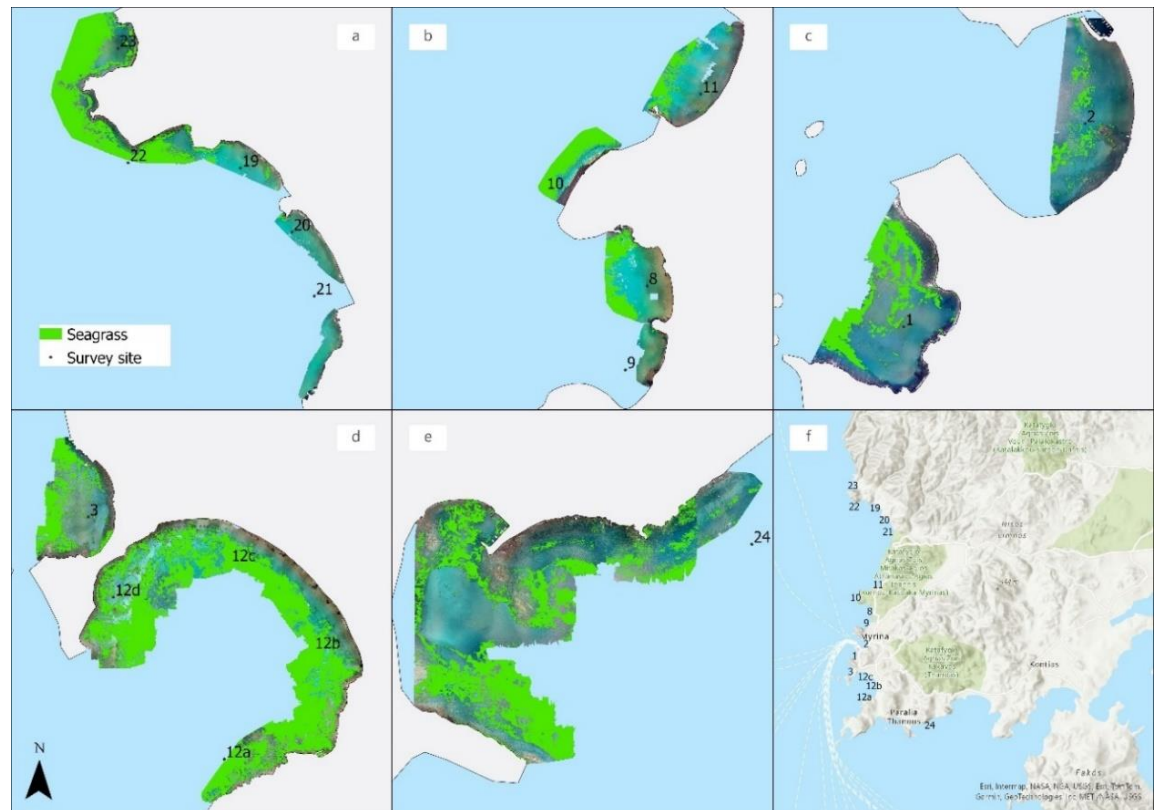


Figure 9. Seagrass meadows visualized on orthomosaics. Surveys 19-23 in and north of Agios Ioannis. b. Sites 8-11 north of Myrina. c. Sites 1 and 2 in Myrina d. Site 3 and four surveys in site 12 in Paralia Plati. e. Sites 24a and 24b in east of Paralia Thanos. f. Survey sites in relation to each other on the west coast of Limnos.

The study sites, where buildings and other infrastructures were close to shore had lower presence of seagrass compared to other sites. Also, the seagrass patches were small or located further away from the beach. Sites 19 and 20 represent beach areas with many buildings and the road going next to the beach (Figure 10). Seagrass patches are small compared to sites with less infrastructure. They also tend to be located on the sides of the beach. This can also be observed in Paralia Plati (site 12), where seagrass is further from the shore in front of the beach whereas other parts of the bay seagrass extended to the shore (Figure 11, Figure 12).

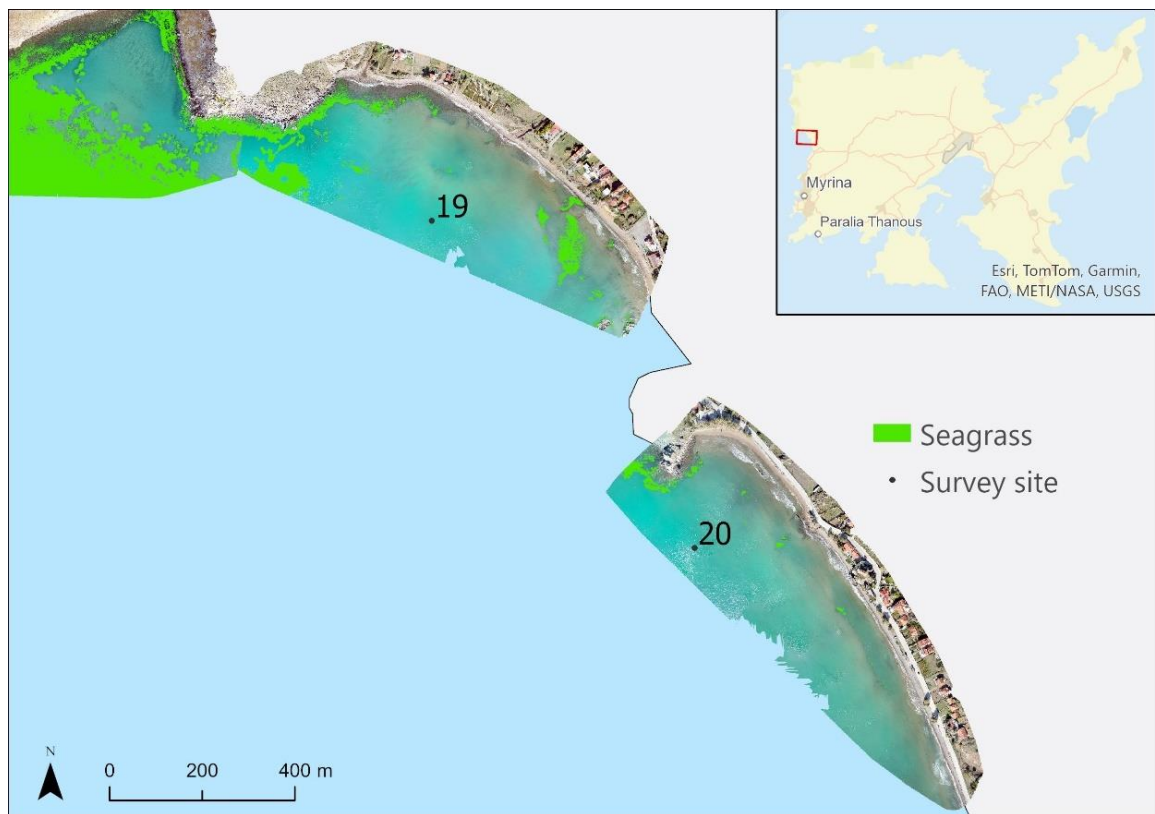


Figure 10. Sites 19 and 20 have a lot of coastal infrastructure and the road. The seagrass patches are small.

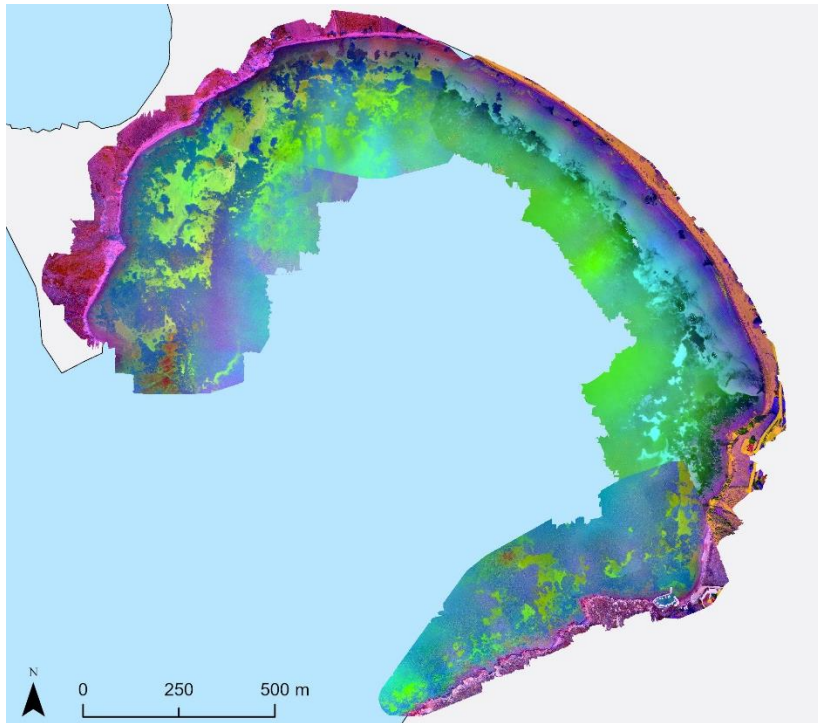


Figure 11. Performed PCA on sites 12a-d in Paralia Plati

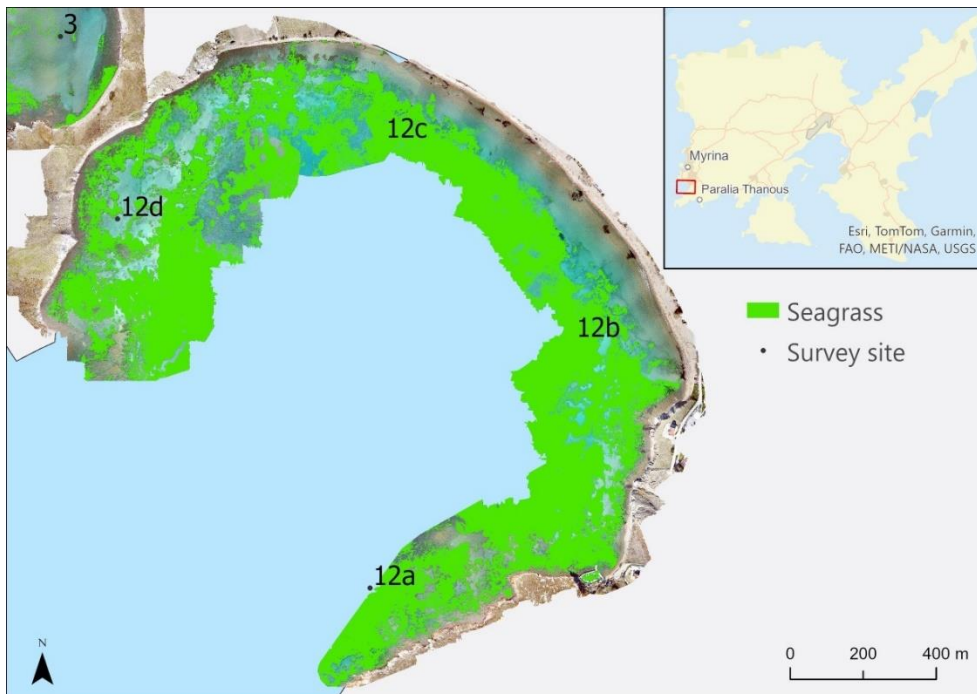


Figure 12. Seagrass in Paralia Plati. Paralia Beach is in the northeast (sites 12c and 12b). On the other side of the bay, seagrass meadow started from the shore.

Underwater structures, such as rocky paths and underwater mooring system or cables can be seen in some of the images. For example, site 11 has underwater

structures on the north end of the image. Observed structures had only small seagrass patches close to them. Thus, the destruction that happened during the assembly is difficult to evaluate.

Anchorage marks were visible inside the ports. Site 24a made an exception where clear anchor scars had fragmented the seagrass patches (Figure 6b). However, elongated distribution of seagrass meadows, for example on site 11 could indicate anthropogenic impacts such as trawling (Figure 13, Figure 14). The fragmentations differed distinctly from the patchiness of other study sites. Lot of patchiness were observed also in sites 1, 3, 12 and 24. Also these could be due to directly or indirectly caused by anthropogenic activities.



Figure 13. Site 11 has elongated fragmentations in meadows. These could be the result of human activities.

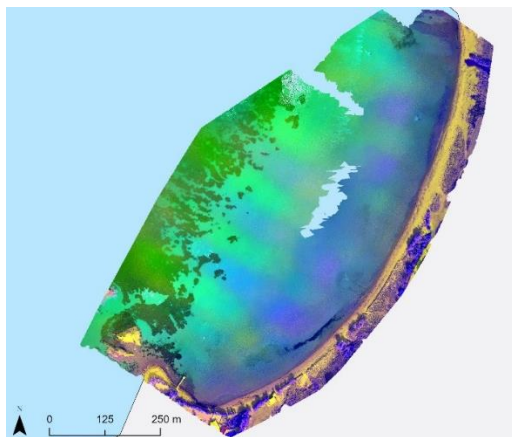


Figure 14. PCA of site 11. Underwater structures in the north end of the image

As the product of the process, the dataset representing seagrass distribution was created. Overlook of the entire dataset on a map can be viewed in Appendix 2. The dataset was shared with the Archipelagos Institute of Marine Conservation and could be used in future expeditions or research about seagrass in Limnos.

Local ecological knowledge

During the Limnos expedition in November 2024, one interview of local fisherman was conducted. The interview was carried in Greek. The fisherman provided and drew on map the information about fishing and recreational activities and benthic habitat types (Figure 15). Fisherman provided also information about anchoring sites which was taken in consideration when analysing the imagery.

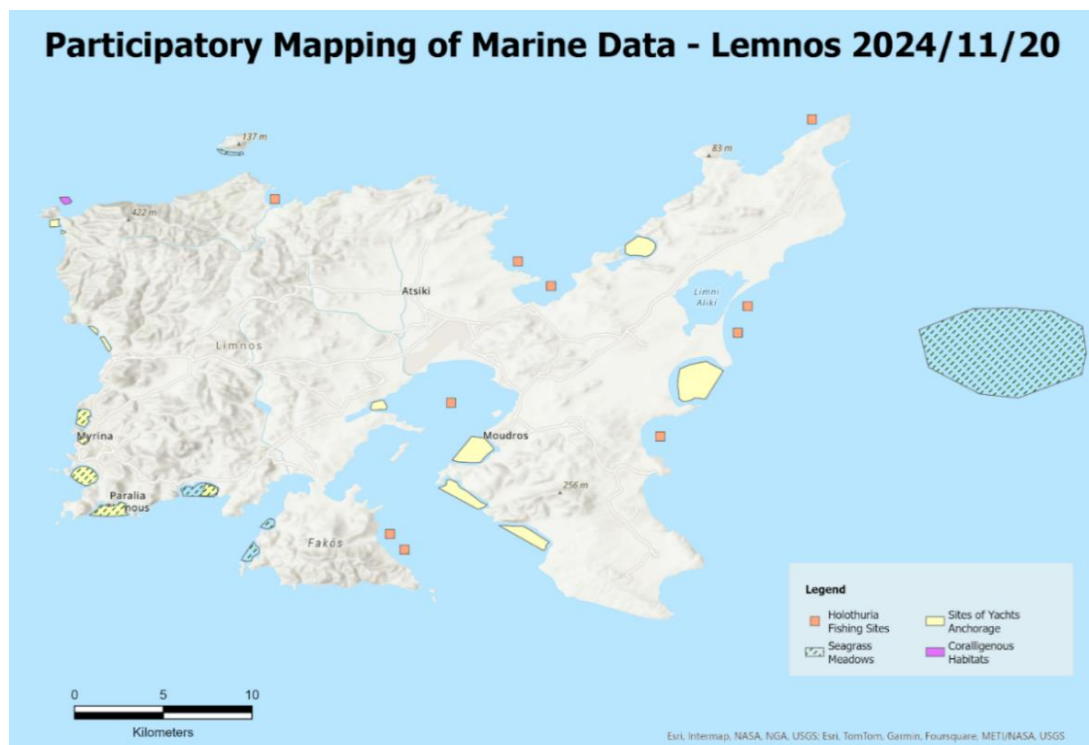


Figure 15. Information provided by local fisherman. The yellow areas present the sites where yachts anchor. Seagrass meadows are in dotted areas. Map created by Nelson Krebs for the expedition report.

5 DISCUSSION

All the impacts of anthropogenic actions are hard to assess solely based on drone surveys. Contaminants can travel with water movements or be

resuspended by human activities and have impacts far from original source (UNEP 2020, 37). Direct impacts on seagrass can be evaluated with remote sensing technologies. Especially when it comes to shallow areas where smaller scars on the bottom are easier to notice. Impacts in deeper areas and uncertain findings could be verified with ground-truthing data.

Local ecological knowledge should not be dismissed when evaluating anthropogenic impacts. Locals have long-term information about their surroundings, and the changes the environment has gone through (Silas et al. 2022, 2). Their knowledge is especially valuable when researchers come outside of the community. The likelihood of anthropogenic impacts on seagrass could be compared to the information provided by locals. For instance, the local fisher in Limnos marked sites 8, 9 and 12 to be used in boating activities (Figure 15). Both sites have fragmented seagrass distributions which could be formed due to human impacts (Figure 12; Figure 16).

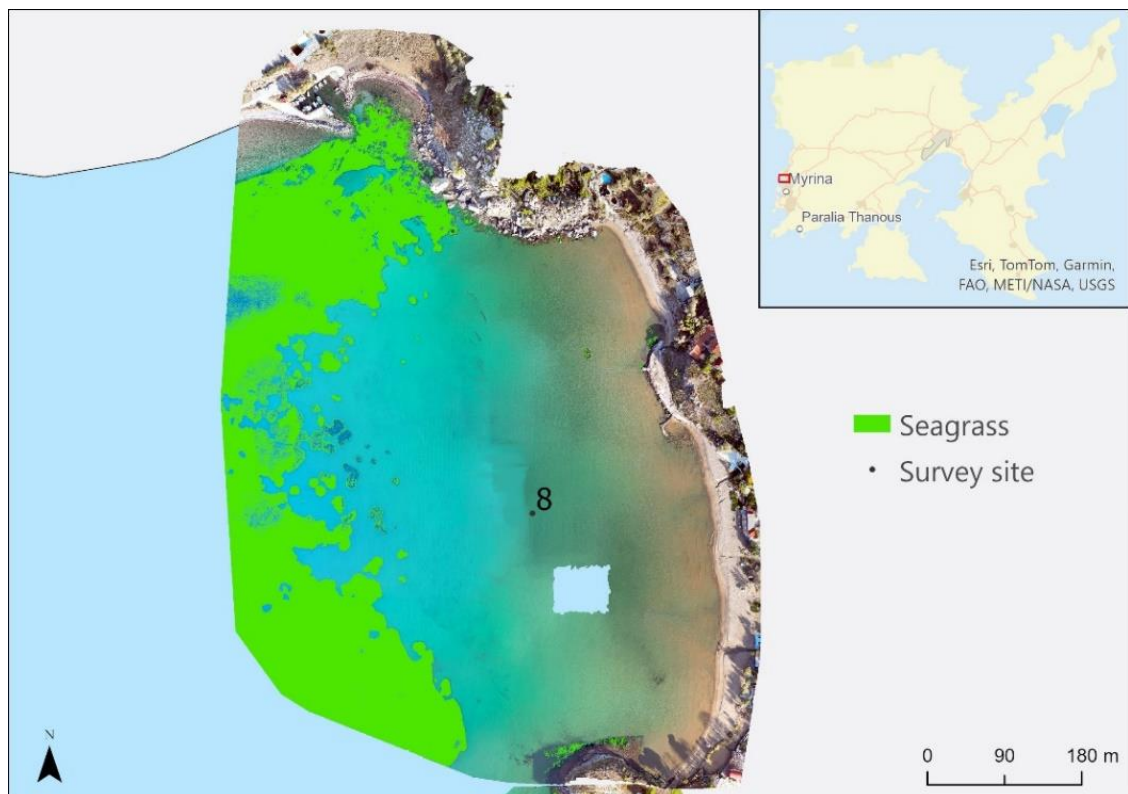


Figure 16. Seagrass meadow on site 8. No clear scars of destructive human behavior are visible. Seagrass meadow is fragmented which could be due to natural or anthropogenic reasons

5.1 Seagrass distribution and fragmentation

Seagrass meadows are fragmented due to natural but also due to anthropogenic reasons. However, the increase of fragmentation is highly connected to human activities such as coastal development and excessive use of marine resources. (Barcelona et al. 2020, 1.) Human pressures are directly or indirectly affecting the health of seagrass meadows (UNEP 2020, 36; Barcelona et al. 2020, 1). For evaluating the health of seagrass meadows, the effective method is to analyze shoot density. Moreover, it is an indicator for anthropogenic impacts. (Bacci et al. 2015, 199). Unstable and decreased shoot density are reason for patchy seagrass meadows (Barcelona et al 2020, 1).

Generally, seagrass prefer soft substrates, such as sandy bottoms, as their living ground. *P. oceanica* can anchor its roots also into the cracks of rocky bottom and grow colonies on them. (Montefalcone et al. 2016, 120.) However, rocky bottom causes some natural patchiness to the seagrass. This can be seen in orthomosaics as well: the cliffs extending under the water were generally seagrass free. For example, site 22 (Figure 8) has these natural fragments due to rocky bottom.

Seagrass meadows were reaching the entrances of ports (Figure 5; Figure 12; Figure 16). However, the patchiness close to the ports can be observed. Besides anchoring and mooring systems, also boat propellers can destruct the seagrass meadows (UNEP 2020, 37). Water movements, chemicals, such as oil spills, and other coastal development, i.e. constructions at the port, can undermine the health of seagrass and therefor result in patchiness there.

Town of Myrina has three ports in front of it. These include small fishing boats, bigger boats staying in guest marina and port for ferries. Bay, where study site 2 is located, has also beach. Here seagrass patches are small and distributed away from each other (Figure 17). Anthropogenic pressures are high.

In addition, site 1 south of port for ferry boats has also very fragmented seagrass. There is no significant coastal infrastructure. Bay could be used for boating or

fishing activities. However, this bay was not highlighted in the interview of local fisher. More information is needed to confirm the reasons for fragmentation. The fragmentation is partly parallel to the coastline. Abadie et al. (2015) studied the different types of fragmentations inside the seagrass meadow. Their findings indicated fragments with sandy bottom parallel to the coast were most likely to be due to water movement. Exception was the funnel shaped fragmentation which was formed because of anchorage. (Abadie et al. 2015, 439-440.)

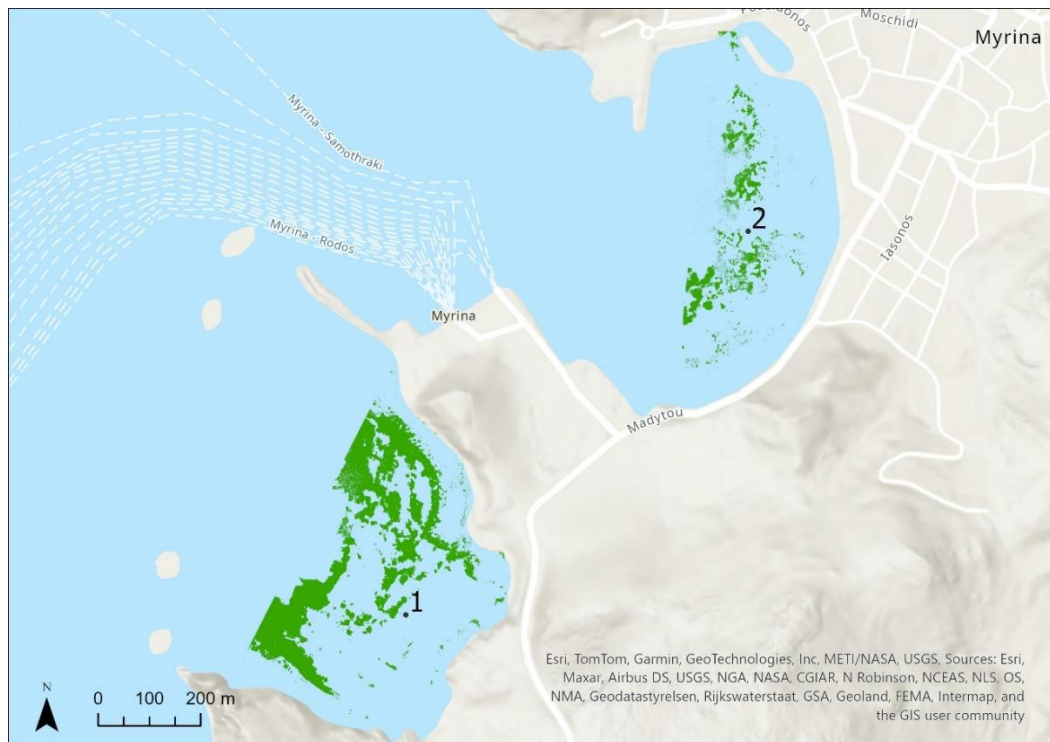


Figure 17. Sites 1 and 2 right next to Myrina. The area has a lot of marine traffic entering and leaving the ports

The elongated marks on site 11 could be assumed to be resulted by trawling action. From orthomosaics, any other indicators for trawling, such as marks on sandy bottom, cannot be seen. The width of the marks varies approximately between 3 to 18 meters (Figure 18). Bruns et al. (2020) studied trawl marks in the North Sea sediments and detected beam trawl marks being 4-22 m and otter board marks widths 1-6 m (Bruns et al. 2020, 21-22). The origin of the fragments could be better assessed by having the length of fragmentations. Trawling marks can be long. In this case the imagery did not reach all the way to the end of the

elongated fragment. This could be tried to evaluate by analyzing the satellite imagery of the same area.



Figure 18. The width of elongated fragmentation varies between approx. 3-18 meters

The results of seagrass distribution correlated with the previous studies of seagrass coverage around Limnos (Figure 19) but also provided more specific information about patchiness. In the future expeditions the recovery of the fragmented seagrass meadows could be evaluated. Surveys from the same study sites would also give valuable information if the size of the seagrass meadows are having significant changes.

SEAGRASS MEADOWS AROUND LIMNOS

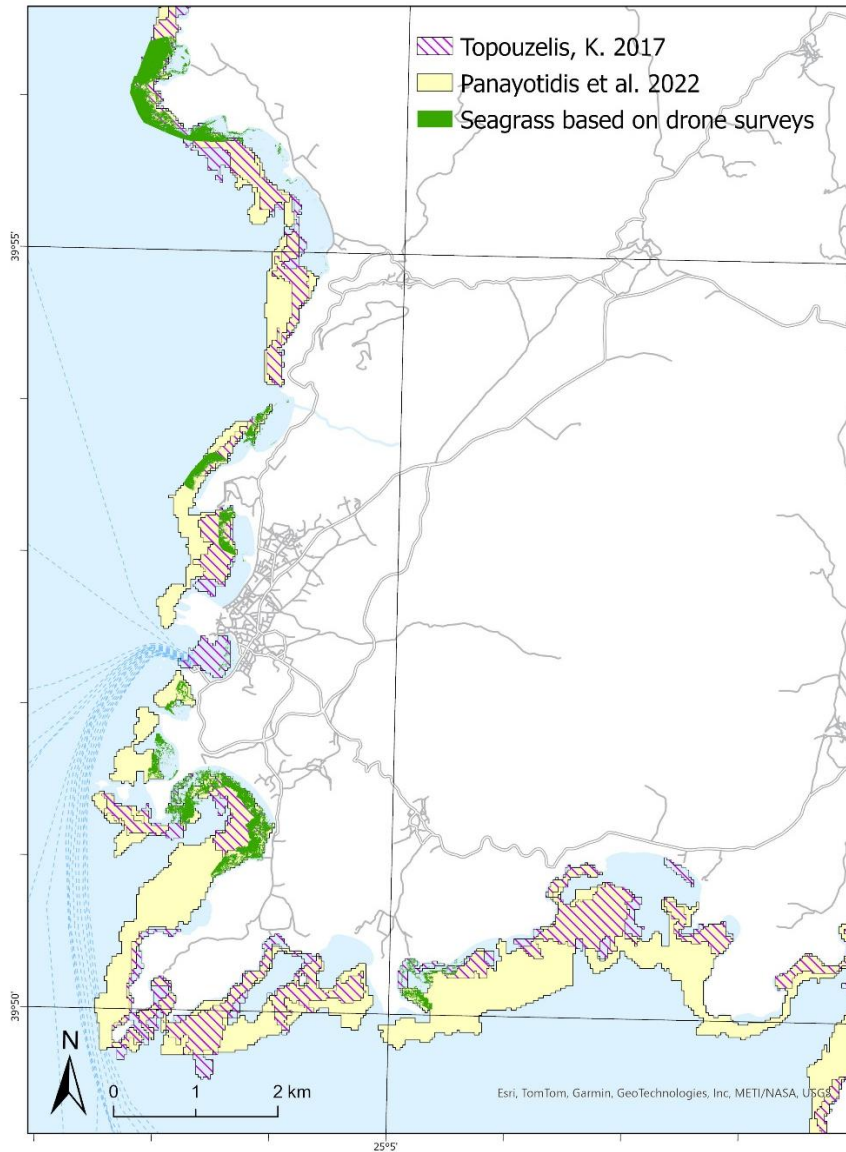


Figure 19. Produced dataset in correlation to previous seagrass studies in Limnos.

5.2 Limitations and future perspectives

The weather conditions are always affecting the results of UAV-surveys (Kvile et al. 2024, 6). Achieving results as good as possible requires good planning and flexibility for field work. Still, the aerial imagery of marine habitats is strongly affected by the water movements which could occur, for example due to wind gusts or boat activity nearby. These are creating some uncertainties in analyzing the images.

Despite the effective method to assess the health of seagrass (Bacci et al. 2015, 199) the shoot density is difficult to measure solely with UAV imagery. To add more accuracy to the results, ground-truth samples would be good to collect (UNEP 2020, 48). Ground-truth data could be used to evaluate the shoot densities and furthermore to improve the classification of seagrass into subclasses of different densities. In future surveys, the co-operation with the Marine Ecology team could be utilized in this purpose. Besides getting the ground-truth samples, the overall evaluation of the habitat quality could be implemented. The shoot density of seagrass meadows is affecting its biodiversity as well as abundance of species (Bacci et al. 2015, 200). Therefore, monitoring biodiversity in seagrass meadows provides valuable information about its health. Extensive information of the impacts and the state of seagrass meadows could provide effective tools to support policy making and conservation work.

Whether the more extensive field surveys are done or not, the changes in seagrass distribution and fragmentation can be observed by repeating the drone surveys. Used flight paths can be used again to cover the previously studied area (Elma et al. 2024, 2). Repeated surveys would also give information about the speed of changes. In terms of conservation efforts, possible delayed influences after protection actions could be monitored.

6 CONCLUSION

Seagrass meadows are valuable marine habitats providing ecosystem services important to human and marine ecosystems. Increasing demand for food sources and on the other hand increasing extreme weather events highlight the urgent need to preserve the seagrass meadows. Although the seagrass meadows are resourceful places for fishing, the fishing activities could lead to destruction which will take decades to recover.

Patchiness of the seagrass meadows is giving information about their health state. Possible anthropogenic pressures can be observed by looking at patchiness. Combining the local ecological knowledge, remote sensing technologies and on-site research could give even more extensive information

about the trends of seagrass and marine conservation. Providing evidence-based scientific facts can increase knowledge and the will to make impactful decisions and if not stop, at least slow down the loss of seagrass meadows.

The protection of seagrass meadows in Marine Protected Areas (MPAs), such as the Natura 2000 -sites around Limnos, are taking a step forward in following years. Greece is going to be the first European country to ban all trawling in its MPAs by 2030. The implementation is going to be started by 2026 in marine national parks. This will strengthen the existing trawling regulations. (Our Ocean 2024, 3.)

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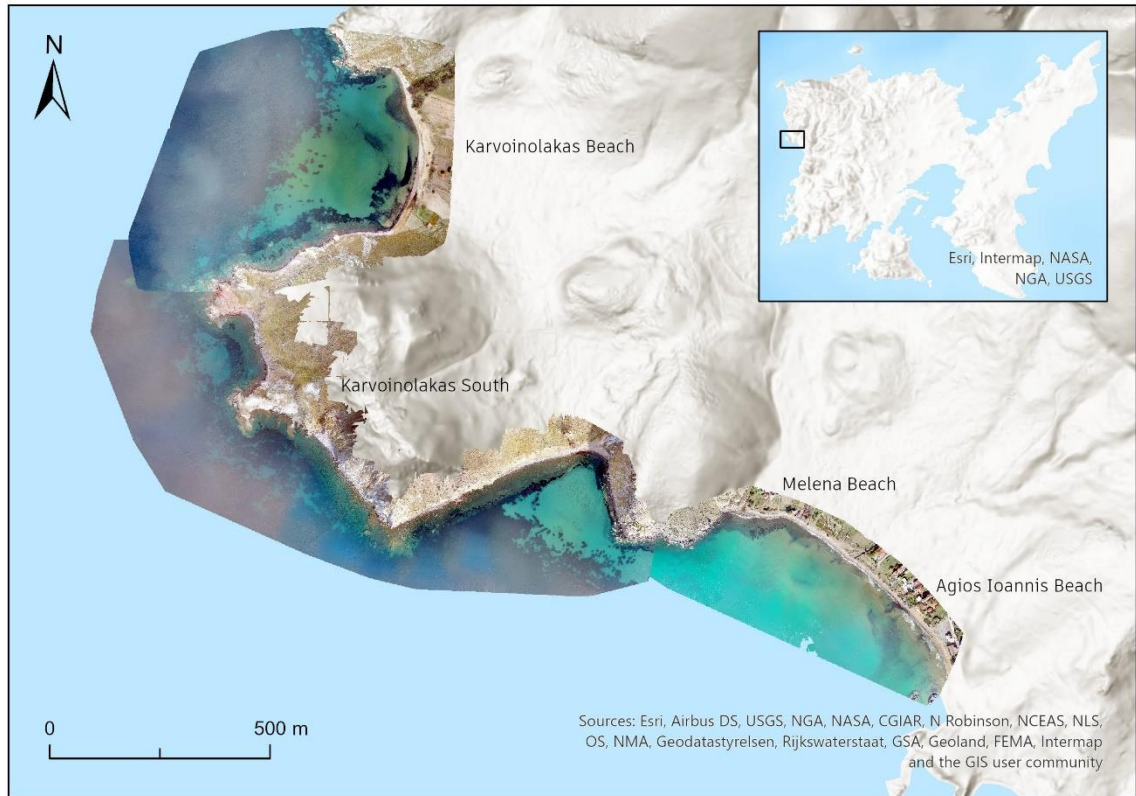
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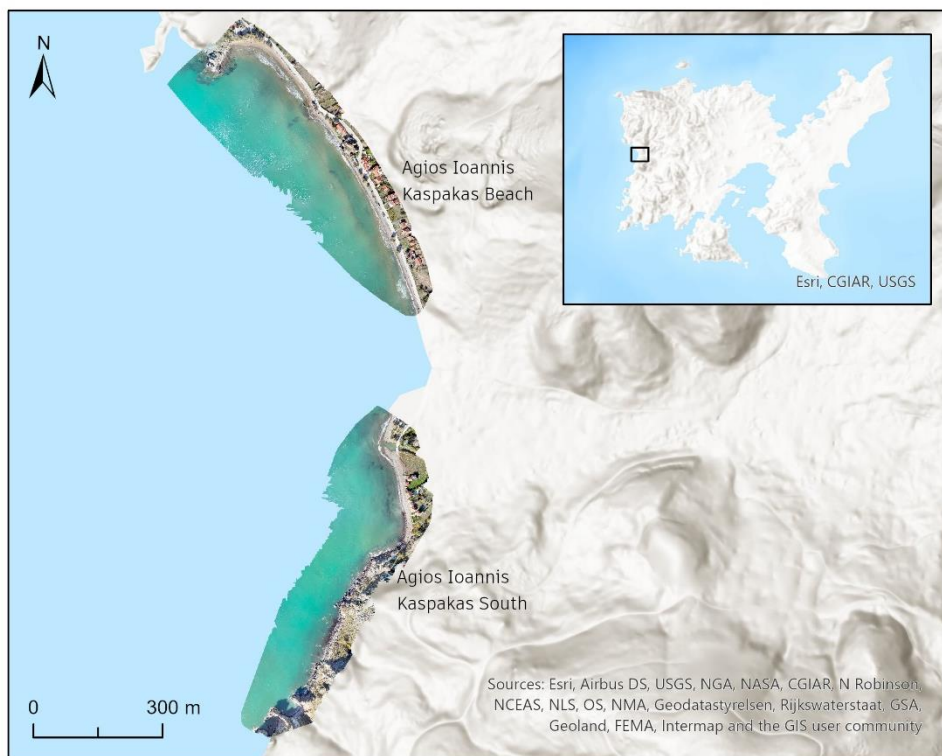
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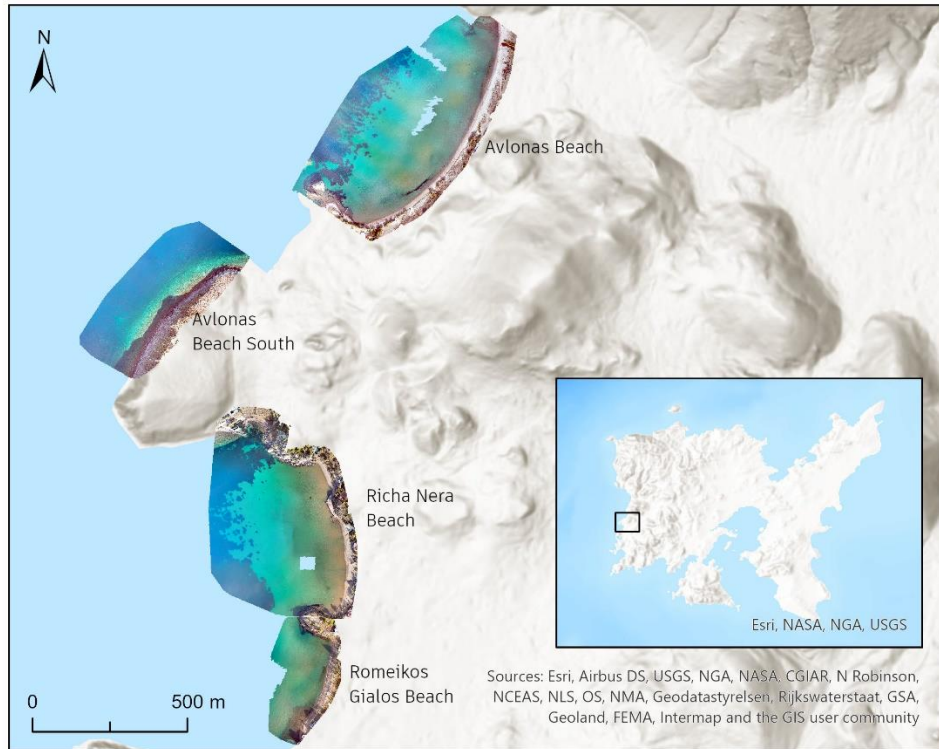
Sites 23, 22 & 19



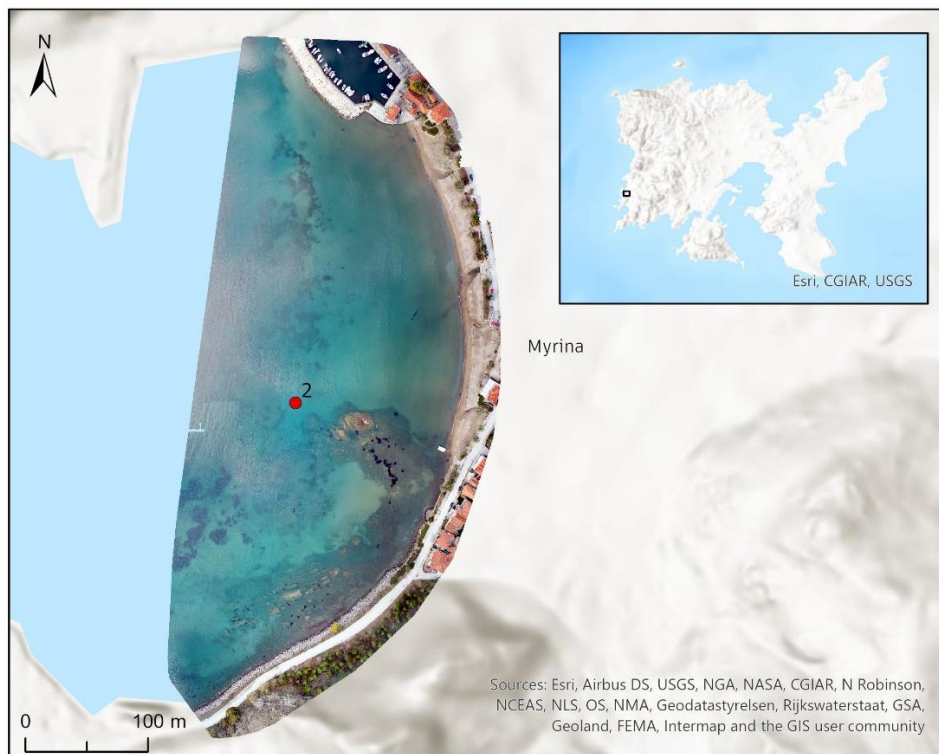
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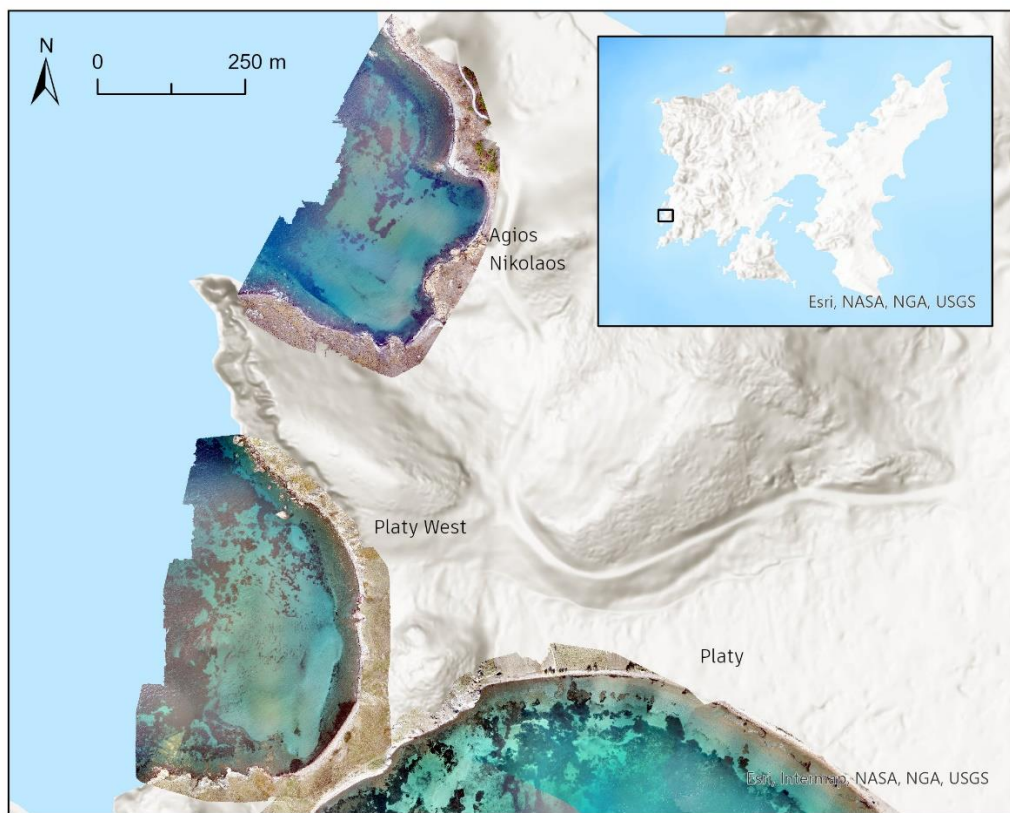
Sites 11, 10, 9 & 8



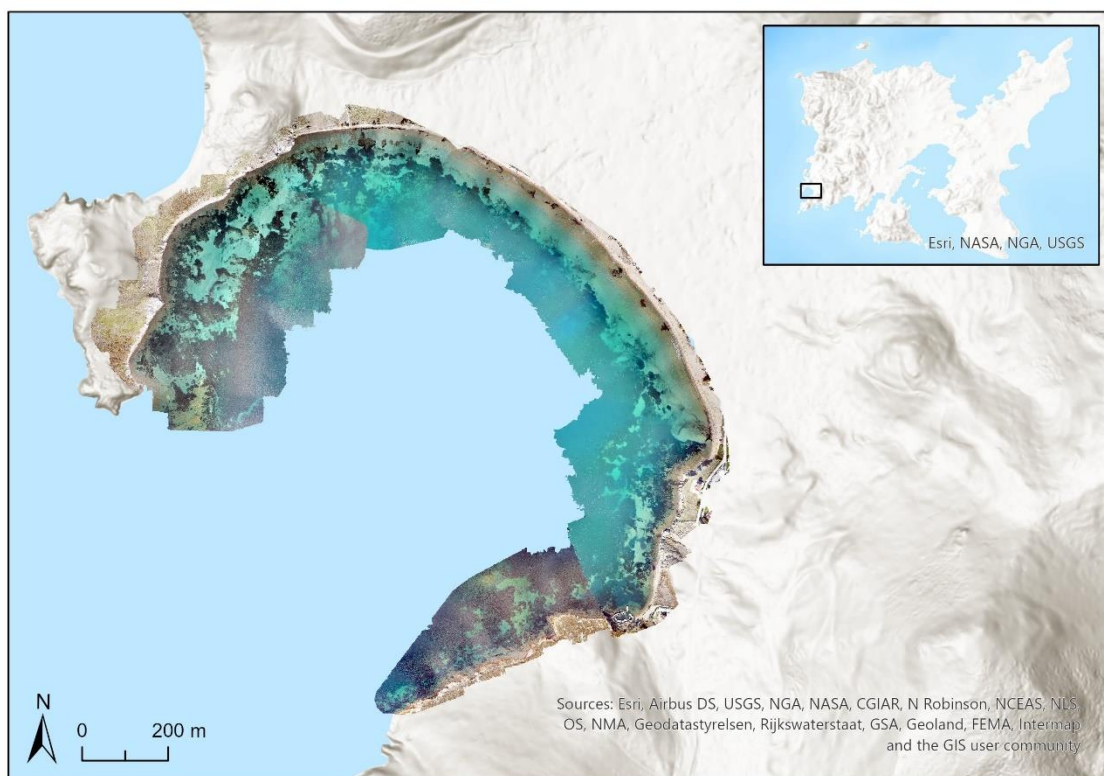
Site 2



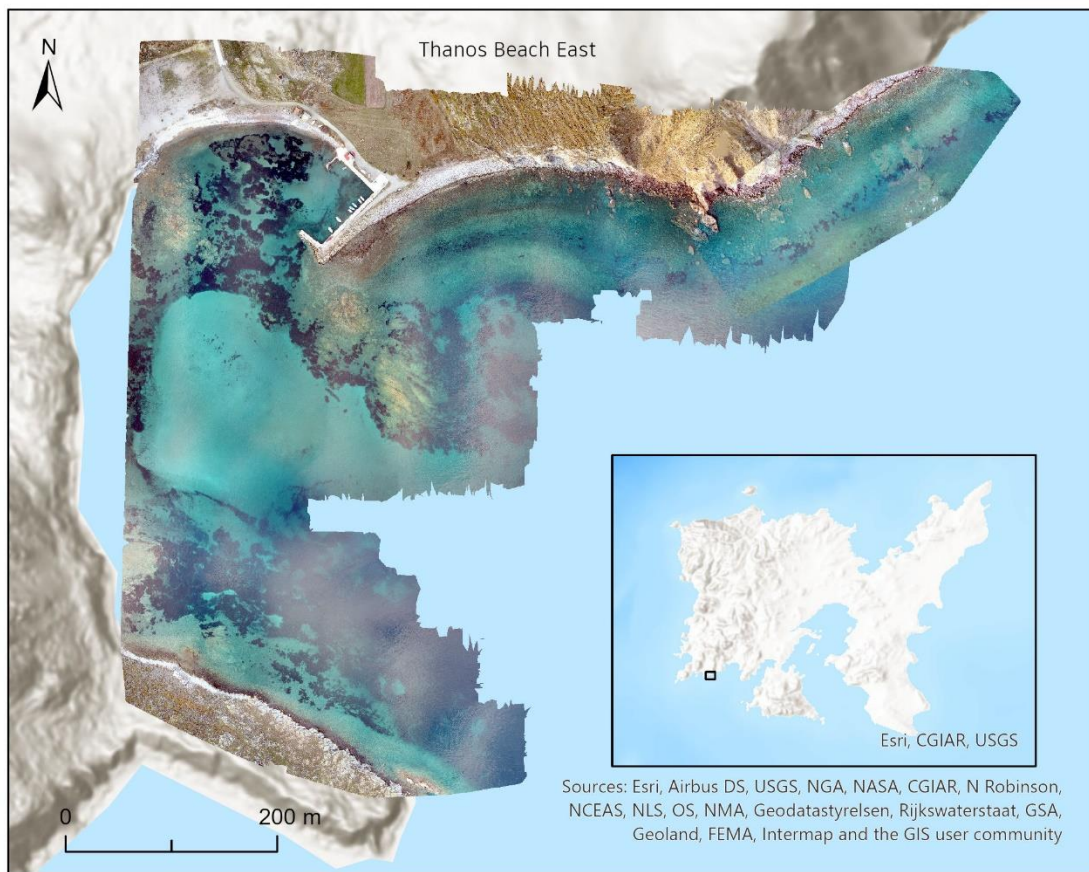
Sites 1 &3. Part of site 12.



Sites 12a-d



Sites 24a & 24b



SEAGRASS DATASET VISUALIZED ON MAP

