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COMPARISON OF THE SONAR RECORDING METHOD AND THE AERIAL PHOTOGRAPHY METHOD FOR MAPPING SEAGRASS MEADOWS

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Underwater image of a meadow in Semedela Bay.

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Comparison of the sonar recording method and the aerial photography method for mapping seagrass meadows

ABSTRACT: This article presents a new perspective on the study of the spatial distribution of seagrass meadows, which – due to their sensitivity to coastal hydrodynamics, sediment transport, changes in nutrient content, and disruptions due to human intervention in their environment – are a good indirect indicator of the properties of seawater. Monitoring their extent and characteristics is essential for determining the properties of seawater, but this requires developing a precise methodology that involves acquiring data on the occurrence of seagrass meadows and mapping them. The base data for the survey presented are sonar recording and aerial photography data, which were utilized to create a seabed classification using geographic information systems (GIS). This provided information on the extent and characteristics of the seagrass meadows. Spatial analysis offers a new look at the coastal belt and reveals some new features.

KEYWORDS: geography, Semedela Bay, seagrass meadows, multibeam sonar data, aerial photography, GIS, line transect method, coastal area

Primerjava metode sonarskega snemanja in metode zračne fotografije za namen kartiranja morskih travnikov

POVZETEK: Prispevek prikazuje nov pogled na preučevanje prostorske porazdelitve morskih travnikov, ki so zaradi njihove občutljivosti na obalno hidrodinamiko, transport sedimentov, spremembe vsebnosti hranil in motnje zaradi človekovega poseganja v njihovo okolje, dober posredni pokazatelj lastnosti morske vode. Spremljanje njihovega obsega in lastnosti je namreč bistveno pri ugotavljanju lastnosti morske vode, zahteva pa natančno izdelano metodologijo, ki vključuje pridobivanje podatkov o razširjenosti morskih travnikov in njihovo kartiranje. Izhodišče za izvedeno raziskavo so bili podatki sonarskega snemanja in zračne fotografije, na katerih smo z uporabo geografsko informacijskih sistemov izvedli tipizacijo morskega dna, kjer je bila posebna pozornost posvečena morskim travnikom. S tem smo dobili podatke o obsegu in lastnosti morskih travnikov. Prostorske analize so omogočile nov pogled na obalni pas in razkrile nekatere nove značilnosti.

KLJUČNE BESEDE: geografija, Semedelski zaliv, morski travniki, podatki večsnopnega sonarja, zračna fotografija, GIS, metoda linijskih presekov, obalno območje

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1 Introduction

Seagrass meadows are one of the most important marine ecosystems in the world in terms of the goods they produce and ecosystem services they provide (Telesca et al. 2015). Due to their characteristics and sensitivity to coastal hydrodynamics, sediment transport, changes in nutrient content, and disruption due to human intervention in their environment, seagrasses are important species in determining the quality of a coastal ecosystem (Krause-Jensen et al. 2004; Ralph et al. 2007; McMahon et al. 2013; Peterlin 2013; Vacchi et al. 2014). Despite their importance, they are constantly threatened by numerous human activities that eventually lead to their degradation and rapid loss (Duarte 2002), estimated at a rate of 110 km²/year since 1980 (Waycott et al. 2009). Consequently, seagrass meadows are regularly included in monitoring programs, both for their protection and for their value as a bioindicator (McMahon et al. 2013). To understand the dynamic nature of seagrass meadows and to predict their response to future environmental changes (Unsworth et al. 2014), it is necessary to synoptically monitor the changes in the composition of a meadow, its spatial distribution or cover, and its biomass. Therefore, developing an effective methodology for monitoring meadows is a very topical issue (Comas Gonzales 2015).

This study focuses on mapping seagrass meadows and thus examining their spatial distribution as one of the parameters of monitoring seagrass meadows (Hossain et al. 2014). Because the changes in spatial distribution occur on small (< 1 km²) and large (> 100 km²) spatial scales, traditional field surveys (diver observations, sampling using rakes or scrapers, and other methods) are often inconvenient for mapping large areas (McKenzie 2003; Hossain et al. 2014). With the development of geographic information systems (GIS) and technical improvements in remote sensing techniques (Robbins 1997), indirect methods have become more popular. Due to the ability of remote sensing to detect changes in the spatial distribution of seagrass meadows on larger spatial and time scales, it is among the most important tools in the management of seagrass meadows because of time efficiency, speed of use, large coverage, and reproducibility of observations (Hossain et al. 2014).

On a global scale, mapping seagrass meadows using remote sensing techniques is already well known (Hossain et al. 2014), whereas in Slovenia mapping seagrass meadows is still carried out using only field surveys (Turk et al. 2002; Lipej et al. 2007). Despite the fact that there have been some individual attempts to map the seabed using remote sensing techniques (Berden Zrimec, Poklar and Moškon 2015; Berden Zrimec et al. 2015; Moškon et al. 2015), the traditional approach is still predominant. In order to reduce the constraints imposed by this approach, this study compared the sonar recording method and aerial photography method, and it verified this with the already established line transect method for determining the spatial distribution of seagrass meadows. The aim of this research was to evaluate the selected methods based on the obtained data quality and to determine their suitability and opportunities for use in further research. Of particular interest was the accuracy of both methods, especially aerial photography, for which it was assumed that the significant water turbidity typical for Slovenian waters and for a large part of the northern Adriatic Sea would be a limiting factor.

2 Methods

2.1 Research area

The research area covered Semedela Bay as the southeasternmost part of Koper Bay between Žusterna and the old town of Koper. This is a shallow bay with an average depth of 6 m (Harpha sea 2013), and, despite its strong anthropogenic transformation, its coastline has the characteristics of a depositional coast. Due to its erodible flysch hinterland (Zorn 2009), the Badaševica River carries sediments that are deposited in the sea (Malačič 1994; Orožen Adamič 2002). The area is a unique habitat because it differs from the central part of Koper Bay in its natural characteristics. The mixing of seawater and fresh water varies considerably over the course of the year (Poklar 2016). Due to this variability, the area is suitable for researching the impact of changing water properties on seagrass coverage. Two types of seagrass are found in Semedela Bay: little Neptune grass (*Cymodocea nodosa*) and common eelgrass (*Zostera marina*; Lipej et al. 2006).

2.2 Definition of a seagrass meadow

Because the perimeter of a seagrass meadow, which is the basis of determining its entire area, cannot be absolutely determined, problems may arise in defining it. In measuring phenomena that are not directly measurable, the need for an operational definition arises. This ensures that the understanding of phenomena and the data collection method are unified and repeatable (Adanza 1995). Therefore, for the purpose of this survey, the operational definition of a seagrass meadow and thereby the minimum mapping unit of 0.01 ha were defined. Even though very sparse seagrass may indicate that seagrass appears in a certain area, such areas were excluded from the operational definition of the seagrass meadow. There are several reasons for this: very sparse seagrasses have very little ecological value and also visually do not correspond to the idea of a meadow. In addition, monitoring very sparse seagrass and tracking its changes is very difficult (Virnstein et al. 2000).

2.3 Mapping seagrass meadows using the sonar recording method

Sonar data, which are essential for this survey, were obtained from bathymetric measurements with a Reson SeaBat 8125 multibeam echosounder. Measurements were conducted within seven working days (August 28th, September 26th, October 15th, 17th, 23rd, and 25th, and November 5th, 2013) in the morning in clear to cloudy weather with precipitation with winds from 0.0 m/s (smooth sea level) up to 5.9 m/s (small waves, peaks already breaking; Internet 1; Internet 2). The measurements provided a georeferenced point cloud, which was manually examined in order to avoid incorrect data that occasionally arise due to disturbances in measurements. From processed and systematically organized data, a bathymetric model with a resolution of 0.5×0.5 m was created, which served as a basis for mapping seagrass meadows. Based on this mapping, a spatial seabed slope analysis was made. Seagrass meadows are higher than the seabed and it was

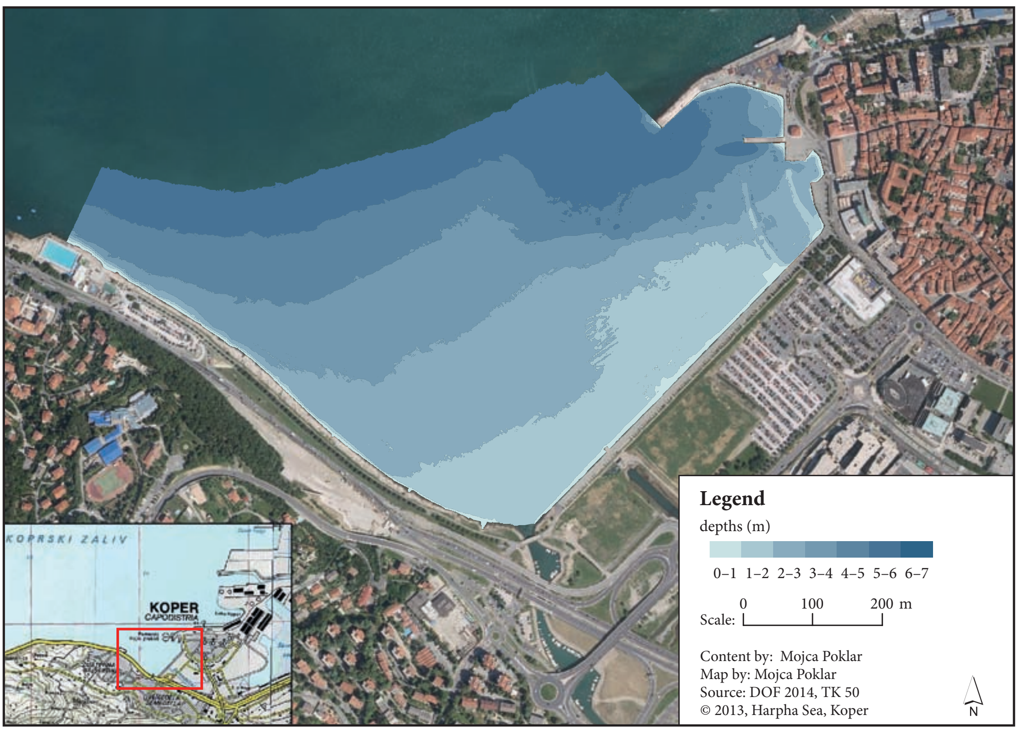

Figure 1: Depths of the Semedela Bay research area (Source: Podatki snemanja morskega dna z večsnopnim sonarjem 2013).

expected that the slopes at the transitions between silt and meadow would be quite high. The resulting layer was examined in detail. Because the area of seagrass meadow occurrence was previously recognized from an orthophoto (Digitalni ortofoto 2012), it was known in advance where they could be expected. In these areas, an attempt was made to identify key patterns or edges of seagrass meadows. A vector layer of seagrass meadows was acquired from the seabed slope raster by exporting all contours of slopes greater than 40°, which was completed and verified with raw sonar data at the end.

2.4 Mapping seagrass meadows using the aerial photography method

Aerial photography was used to obtain aerial photos, which were used to digitize seagrass meadows. This was carried out with a professional camera with automatic triggering in terms of aircraft height and velocity, providing 60% overlap of the photos in the forward direction of the flight. The exact location of the aerial photos was ensured by monitoring the position and orientation of the camera on the aircraft using a GNSS receiver and a gyroscope. Aerial photography was carried out in one working day (September 6^{th}, 2013), in the morning during clear weather.

Prior to the digitization of seagrass meadows, pre-processing of aerial photos was carried out, which included geometric and lighting corrections. Aerial photos were then merged into a unique photo of the entire research area, which was orthorectified and georeferenced, and its contrast was improved.

Data on the spatial distribution and therefore edges of seagrass meadows were obtained through a supervised image classification of the RGB layers of the aerial photo, in combination with its visual interpretation. In the process of a supervised image classification, training samples were first created; these are areas with a known type of seabed, on which the spectral signature of the seabed type was calculated. Training samples were marked interactively using the training sample drawing tools and were determined by manual limitation. Twelve training samples were determined for various seabed types and in various situations (shadows, seagrass meadow density, etc.). For the classification, the maximum likelihood classification method was used because it is the most accurate, although it is a very demanding computing process (Oštir 2006). The quality of the classification was improved by visual interpretation of the entire photograph, for which the edges of seagrass meadows were manually corrected by evaluating the basic elements of visual photo interpretation (tone, shape, size, pattern, texture, shadows, etc.); this is the most subjective part of the method.

2.5 Verification of both methods by comparison with the line transect method and the final map of seagrass meadows

Because the sonar recording and aerial photography methods are indirect remote sensing methods, after their implementation they always require ground truth observations to verify the results already obtained (Komatsu et al. 2003).

They are helpful in interpreting the distinctive characteristics of seagrasses from sonar data or aerial photos, where they also serve as a reference point for verifying the interpretation of photos; for example, to check that no macroalgae or shells were misidentified as seagrass meadows (Krause-Jensen et al. 2004).

Accordingly, to verify the spatial distribution of seagrass meadows obtained by sonar data or aerial photography, and to evaluate the accuracy of selected methods, a field survey was carried out, which involved seabed recordings with an underwater camera. Underwater recordings were made directly from a vessel on predetermined line transects and meadow centroids (Figure 2). Because the line transects were plotted by a computer, the precise geographical position and the angles of the recordings were verified with a GNSS receiver and a gyroscope simultaneously with the recordings. The recorded videos of line transects were then processed and converted into underwater photos or raster data.

The raster data obtained represented the reference state for the verification of sonar and aerial photography data. The first phase compared the mapped edges of seagrass meadows and measured deviations from the reference state. Along five line transects, forty-six control points were randomly selected, on which the seabed type was determined (the analysis was limited to two types: silt and seagrass meadows) and then compared with sonar and aerial photography data. A comparison also included four points that represented the centroids of the seagrass meadows. Based on the comparison, the accuracy of seagrass meadows mapped with each method was assessed using a confusion matrix (Mumby and Green 2000).

Based on the evaluation of the accuracy of two remote sensing methods, the polygon layer of seagrass meadows was established. Where the edges of seagrass meadows were detected by both methods, the edge with the greater accuracy was considered. Where the edges were detected by only one method, the available ones were considered. When checking raster data from the field survey, it did not occur that an edge was not be detected by any method. The result was then mapped using the tools for analysis and spatial display of measured data.

3 Results

The multibeam sonar data and the seabed slope analysis showed that seagrass meadows' edges are clearly visible in most cases because the slope at the transition between the silt and the meadow can range from 0° to 80°. Larger and denser seagrass meadows are well visible (Figure 3), whereas the areas where the meadows are sparse are not. Such areas are difficult to separate from the silt, and so accurate mapping requires a review of raw data (the distance between points was about 10 cm) or the combination of sonar data with data from another method.

The seagrass meadow edges in Semedela Bay mapped from sonar data are shown in Figure 4. Not all the edges are connected. The western edge, which lies in the eastern part of the bay, was not completely visible because of a gradual transition between seagrass and silt. In this area, the seagrass is sparse and lower in growth, making it difficult to determine its edge. The same applies to seagrass meadows around the mouth of the Badaševica River. The sonar recording method made it possible to draw the seagrass meadow edges with a total length of 5,310.10 m.

From aerial photography data (i.e., classified aerial photos), it was determined that the edges between the seagrass meadows and silt were mostly visible. However, there were areas where the photo did not make

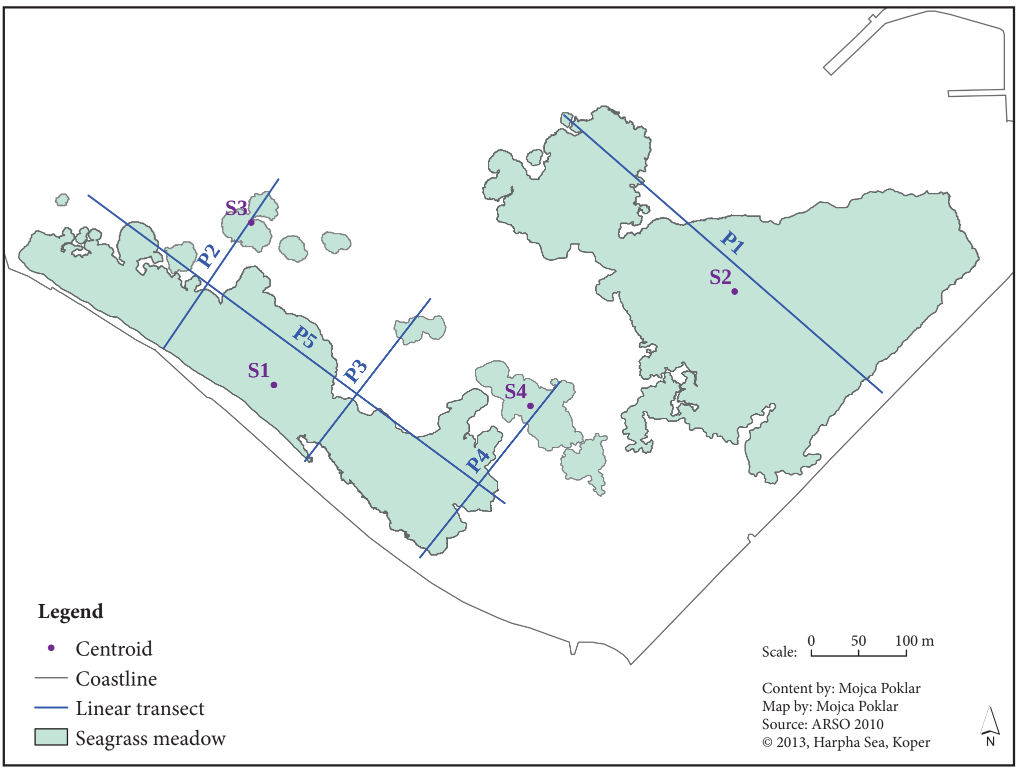

Figure 2: Selected line transects and sampling points (centroids) for verifying seagrass meadow occurrence.

it possible to recognize whether there is a meadow or not. This is especially true for deeper areas, where the lower edge of the meadow is often difficult to determine due to the smaller proportion of light that can penetrate to the seabed or to the meadow. Problems also occurred in areas where the meadow edges were less visible due to reflection of light from the sea surface. The problem was solved by changing the direction of the flight. For the research area, it turned out that the reflection of sunlight from the sea surface is less visible in the aerial photos, which were taken by flying in a north–south direction. Nevertheless, it was not possible to completely solve these problems, and so in the previously described areas the meadow edges were difficult to determine. Figure 5 shows edges of seagrass meadows mapped using the aerial photography method and with a total length of 5,727.30 m.

An overview of the underwater photos of the field survey showed the presence of both types of seabed as predicted with the sonar recording method and aerial photography method (silt and seagrass meadows). In addition, other species were also found in underwater photos; specifically, various macroalgae that appeared closer to the mouth of the Badaševica River and the noble pen shell or fan mussel (*Pinna nobilis*), found on the outer part of the seagrass meadow along the harbor at Koper.

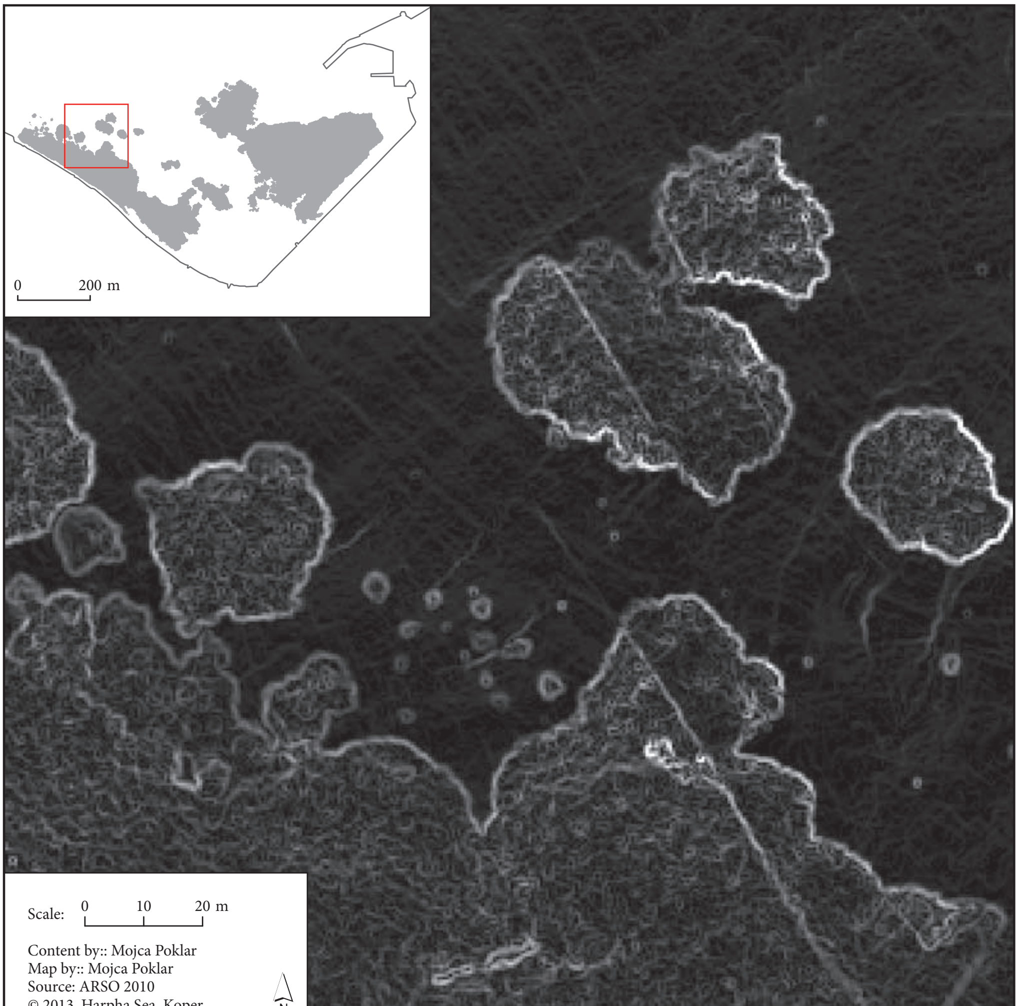

Figure 3: Example of a seagrass meadow on a seabed slope raster.

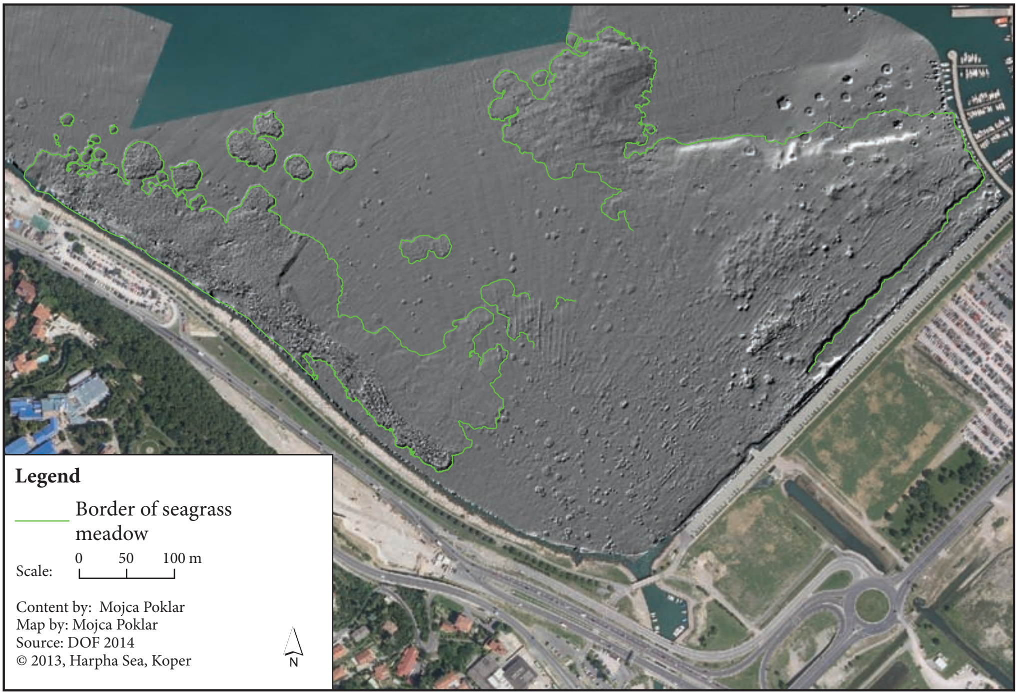

Figure 4: Seagrass meadow edges in Semedela Bay obtained using the sonar recording method.

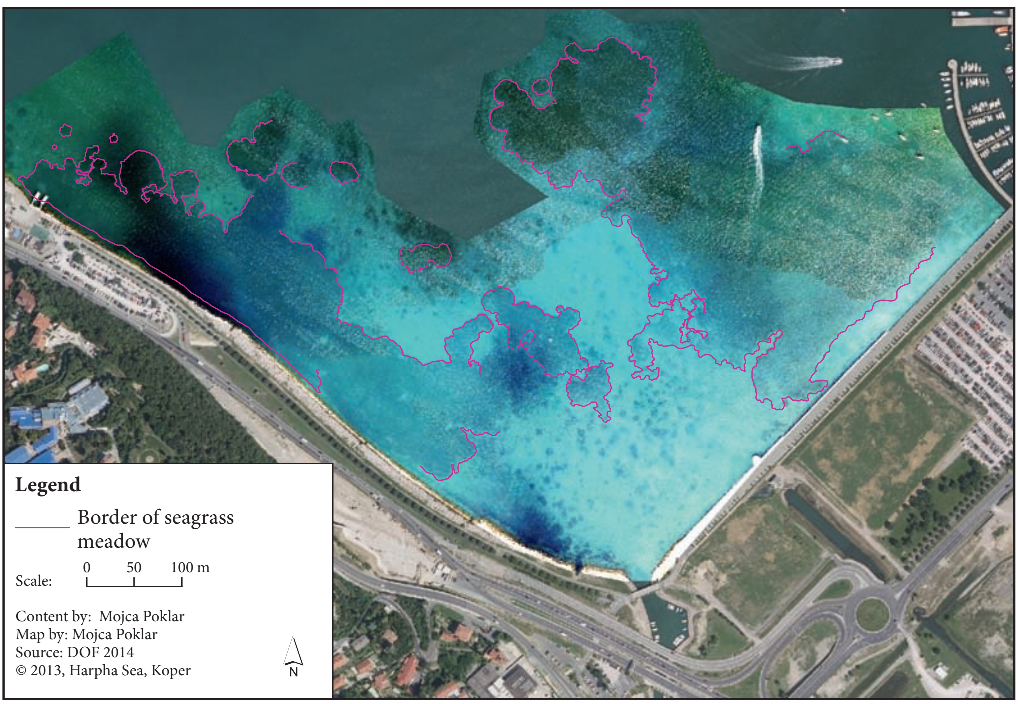

Figure 5: Seagrass meadow edges in Semedela Bay obtained using the aerial photography method.

A comparison of the seagrass meadow edges in underwater photos with meadow edges obtained using the sonar recording method showed deviations of up to 1 m, whereas at the meadow edges obtained through aerial photography deviations of up to 3 m occurred. Considering the position errors – which were estimated between 0.2 and 0.3 m (sonar data), between 0 and 1 m (aerial photography), and between 0.2 and 0.3 m (line transect data) – deviations occur for various reasons. In the case of sonar data, deviations occur in areas of gradual transition between seagrass and silt, whereas at the sharp edges of seagrass meadows the contours are completely coincident (centimeter-level accuracy). Major deviations in aerial photography data can be attributed to errors in georeferencing of aerial photos, as well as the poor visibility of seagrass meadow edges from the aerial photo in areas of greater depth and in areas where light reflected from the sea surface during the shooting.

To assess the classification accuracy of selected methods (Lillesand and Kiefer 1994), two confusion matrices were produced, comparing the predicted data of the sonar recording or aerial photography method with ground truth (reference) data of the field survey.

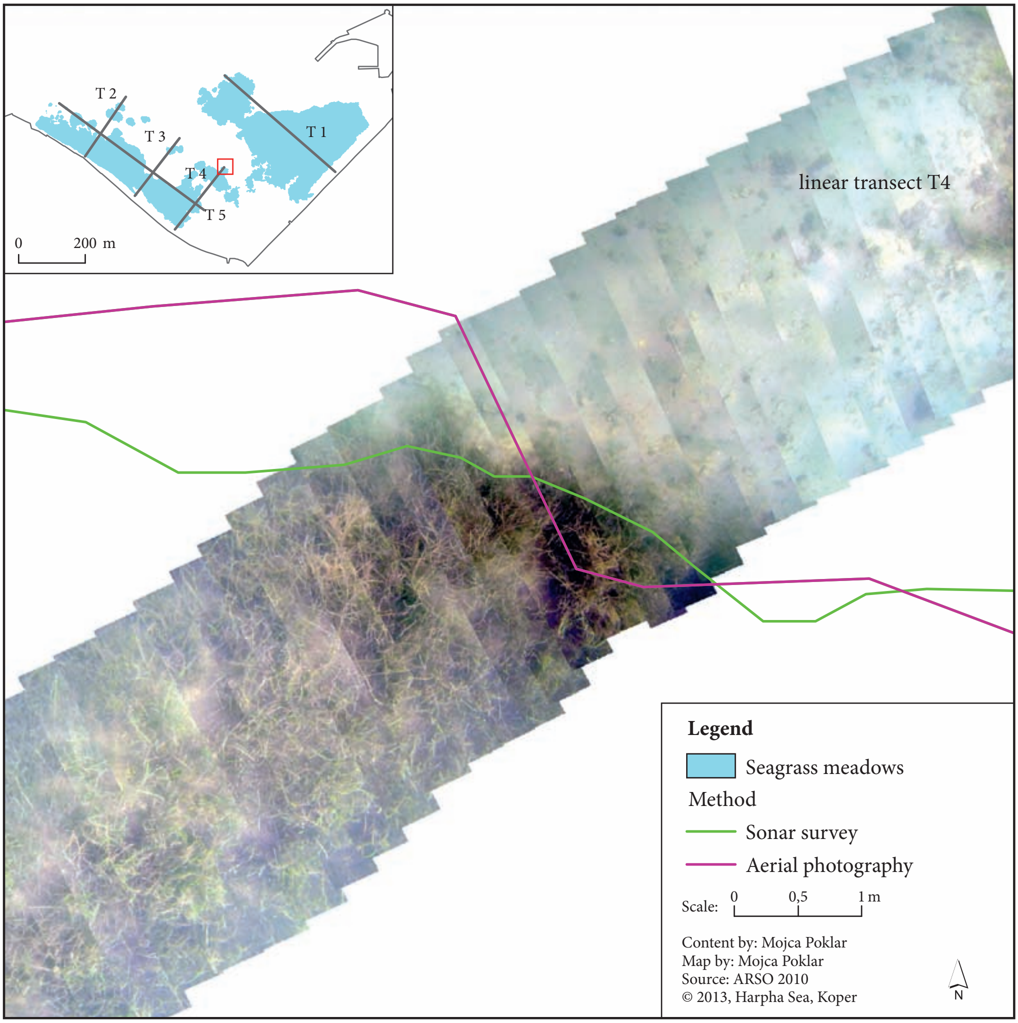

Figure 6: Example of verifying the sonar recording and aerial photography method by using the line transect method, recorded with an underwater camera on line transect T4.

Table 1: Confusion matrix of the a) sonar recording method and b) aerial photography method.

a)

		Reference data		
		Seagrass	Silt	User accuracy
Sonar recording method	Seagrass	30	3	90.9%
	Silt	1	26	96.3%
	Total number of sampling points	31	29	
	Producer accuracy	96.8%	89.7%	Overall accuracy = 93.3%

b)

		Reference data		
		Seagrass	Silt	User accuracy
Aerial photography method	Seagrass	24	13	64.9%
	Silt	7	16	69.6%
	Total number of sampling points	31	29	
	Producer accuracy	77.4%	55.2%	Overall accuracy = 66.6%

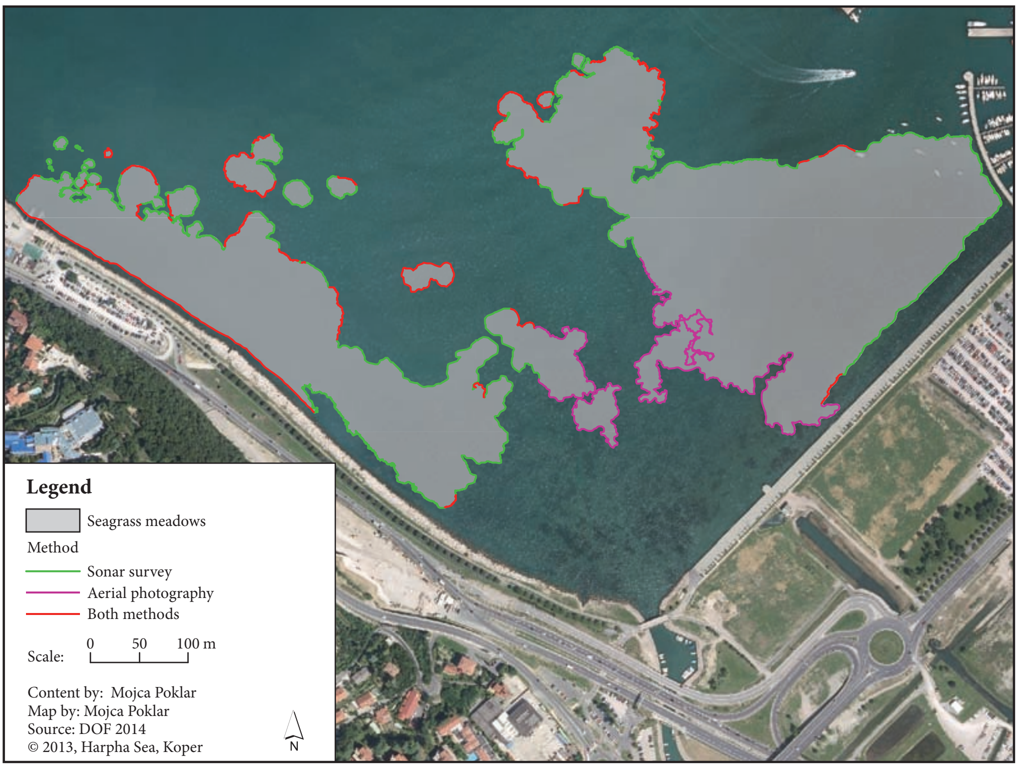

Figure 7: Seagrass meadow edges in Semedela Bay based on the mapping method used, and the final map of the meadows in Semedela Bay in autumn 2013.

Table 1 shows that sampling points labeling seagrass were more correctly classified than those that labeled silt. The difference is small (7.1%) for the sonar recording method, whereas for the aerial photography method it is considerably larger and amounts to 22.2%. In contrast, user accuracy, which serves as a guide to the results' reliability as a prediction tool, shows that in both the sonar recording and aerial photography methods the silt class is more correctly classified (96.3% by sonar recording and 69.6% by aerial photography). Nevertheless, the most noticeable information in Table 1 is the difference between the overall accuracy of the methods by which the seagrass meadows were detected. For the sonar recording the overall accuracy was 93.3%, and for the aerial photography it was 66.6%.

Based on the accuracy of both methods, a spatial data layer of seagrass meadows was created using complete sonar data (because in this case it is more accurate than aerial photography data) supplemented with aerial photography data. Based on the mapping method, a map of seagrass meadows edges was created (Figure 7). Most of the meadow edges (52%) were plotted using the sonar recording method, and the aerial photography method was useful for 24% of the plotted edges. Some edges were detected by both methods, which is shown as an independent category in Figure 7 (24%).

Figure 7, which also shows the spatial distribution of seagrass meadows in Semedela Bay, shows that seagrass meadows are distributed along the coast and in the inner part of the bay. There are two major seagrass meadows as well as a number of minor ones, constituting »islands,« separated from major meadows. Seagrass meadows were not detected at depths exceeding 5 m, where light conditions do not allow the growth of seagrass, and directly along the coast, especially at the mouth of the Badaševica River. In the past, the Badaševica deposited contaminated and nutrient-rich water in the bay, which contributed to the extremely depleted vegetation at its mouth. Because both *Cymodocea nodosa* and *Zostera marina* are sensitive to elevated levels of nutrients in the water column (Lipej et al. 2006; Orfanidis et al. 2007), this could be the main reason for the lower coverage of the seabed with seagrass in the area. Lower coverage of the seabed with seagrass directly along the Semedela promenade in the eastern part of the bay can be attributed to the renovation of the promenade in 2010. The renovation works also consisted of deepening the seabed, which led to physical damage to the seabed and associated vegetation.

4 Discussion

Measurements of the spatial distribution of seagrass meadows with the methods presented for Semedela Bay provided some key findings regarding their characteristics. The first relates to the timeframe for making the measurements. The aerial photography method is faster in comparison to the sonar recording method because photographing the entire research area was carried out in one day, whereas sonar measurements lasted several days.

Another characteristic investigated was the spatial and temporal dependence of the method. It was determined that the sonar recording method, in contrast to the aerial photography method, is a spatially and time-independent method because the data capture with a multibeam sonar is independent of water transparency and sunlight, and with accurate GNSS and INS receivers it is possible to perform quality measurements in the undulating sea. In contrast, the use of the aerial photography method in the Slovenian sea is limited due to high water turbidity. It turned out that the greatest problems arise in the bays (the sea currents are not so strong, the influence of waves is greater than in the open sea, and siltation is prominent), where the largest share of seagrass meadows is located. In addition to increased water turbidity, the problem also lies in the refraction and reflection of light on sea surface, which makes it necessary to capture photos at the best time of the day and under the best environmental conditions.

The greatest weakness of the aerial photography method is certainly its subjectivity in determining the distribution of seagrass meadows. In order to determine seagrass meadows from aerial photos, an image classification was made, partially also with a manual capture of the edges of seagrass meadows, where it was necessary to visually evaluate the basic elements of photo interpretation (such as tone, color, contrast, texture, shadows, etc.), which each individual can recognize differently.

Because the multibeam sonar spreads beams at ± 60° steering angles (Fridl, Kolega and Žerjal 2008), the method is useful for flat and for more morphologically diverse seabeds, and in addition it is also possible to measure the height of seagrass and its biomass above the seabed. However, if one is only interested in information on the occurrence of a meadow in a certain area or if the required precision of the mapped meadows is low, the aerial photography method is more appropriate from a user perspective. This is especially true when analyzing already existing aerial or satellite images (in this case, one must take into account the lower resolution and thus the lower quality of such images), which, in contrast to the methods described, are more accessible.

In addition to these characteristics of both methods, their accuracy was of primary interest. Considering position errors – which were estimated between 0.2 and 0.3 m (sonar data), 0 and 1 m (aerial photography), and 0.2 and 0.3 m (line transect data) – the overall accuracy of the sonar data was 93.3%, whereas the overall accuracy of the aerial photos was only 63.3%. Considering that accuracy of classification over 90% is good, and that over 80% is satisfactory (Oštir 2006), the sonar recording method was good in this research case, whereas the aerial photography method did not yield the most accurate results. In this study, sonar recording is a more reliable method of data acquisition on the spatial distribution of seagrass meadows. Of course, this does not apply to less turbid waters and thus to more accurate visibility of seagrass meadows, where the aerial photography method can achieve the same accuracy as the sonar recording method. In the case at hand, this was noticeable in determining the edges of seagrass meadows in the area from the mouth of the Badaševica River to the inner part of the bay. In that area, seagrass meadows were poorly visible on sonar data due to the aforementioned gradual transition between sparse seagrass and silt, whereas they were clearly visible in aerial photos due to shallow water (0 to 2 m in depth) and thus increased light penetration through the water column to the seabed.

5 Conclusion

The purpose of this study was to show that the use of modern remote sensing technologies and GIS techniques makes it possible to obtain new and more useful results in mapping seagrass meadows, yielding better knowledge of the ecological status of the sea and a better understanding of the processes in its coastal area. Comparison of the sonar recording and aerial photography methods with the already established line transect method for determining the spatial distribution of seagrass meadows in part of the Slovenian sea showed that both methods allow efficient mapping of seagrass meadows, but they differ significantly in certain characteristics. The sonar recording method proved to be more accurate, more objective, and, in contrast to the aerial photography method, spatially and temporally independent, which is a consequence of the higher water turbidity typical of the Slovenian sea. In terms of affordability, both methods are expensive because high-precision data require high-priced equipment.

If the required precision of the mapped seagrass meadows is low or one is only interested in the occurrence of seagrass meadows in a certain area, the aerial photography method is more appropriate from a user perspective because already existing aerial or satellite images are much easier to access.

However, the choice of methodology primarily depends on the purpose of research/mapping, and then on the environmental conditions, where the water transparency or turbidity, bathymetry and morphology of the bay, weather conditions, and available resources must be taken into account. It should also be noted that the remote sensing methods used alone are not enough. Regardless of the choice of the mapping method, after applying it ground truth observations are always required in order to verify the results obtained and to explain the characteristics of seagrass recognized by remote sensing images or sonar measurements.

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