Monitoring of seagrass by lightweight AUV: A *Posidonia oceanica* case study surrounding Murter Island of Croatia

***Abstract*— *Posidonia oceanica* (Neptune Grass) is an endemic species to the Mediterranean Sea. It forms dense and extensive green underwater meadows which provide important ecological functions and services and harbour highly diverse communities; as such it is identified as a priority habitat type for conservation under the EU Habitats Directive (Dir 92/43/CEE). Over the last decades many *Posidonia oceanica* meadows have disappeared or have been altered. Efficient monitoring is the key of the ecosystem conservation. Monitoring of vast areas covered by *Posidonia oceanica* is extremely difficult, costly and time consuming and generates pronounced need for new methods and tools. This case study presents potential and promote use of lightweight autonomous underwater vehicles (AUV) with the remote sensing payload as the environmentally non-destructive monitoring method. The study was performed from 2011 to 2013 on the Croatian island Murter during the "Breaking the Surface" - international interdisciplinary field training of marine robotics and applications. Four AUVs equipped with different payloads were performing the missions in the study area. This paper presents results and analysis of different aspects important for the monitoring such as compliance with the existing monitoring indicators and descriptors used to assess the conservation status of *P. oceanica*, performance of the AUVs and their sensor sets, cost and time efficiency of the monitoring and geographical-localisation accuracy of the data collected.**

I. Introduction

Posidonia ocenaica is an endemic species to the Mediterranean Sea and it widely inhabits the sea bottom, relatively close to the Mediterranean coastline. *P. oceanica* beds form dense and extensive green underwater meadows which provide important ecological functions and services and harbour highly diverse communities; as such meadows are identified as a priority habitat type for conservation under the EU Habitats Directive (Dir 92/43/CEE). Recent research also shows that they store more carbon than any terrestrial ecosystem per square meter and have an important role for climate change mitigation. Still, seagrasses are among the worlds most threatened ecosystems. Over the last decades, following increased coastal urbanisation, industrialisation, and tourism development, many *P. oceanica* meadows have disappeared or have been altered. It is estimated that 46% of the underwater meadows in the Mediterranean have experienced some reduction in range, density and/or coverage, and 20% have severely regressed since the 1970s according to [1].

Efficient monitoring is the key of the ecosystem conservation. Monitoring of vast areas covered by *P. oceanica* can be extremely difficult, costly and time consuming and generates pronounced need for new methods and tools with the aid of robust science and remote sensing technology. Diving is most common method used for monitoring at the moment. There are also examples where aerial and satellite imagery is incorporated into the monitoring practices but utilisation of underwater vehicles and remote sensing is area still open for research and application [2], [3]. We are convinced that use of underwater technology for the seagrass monitoring is a promising method which can provide reliable results in a fast and efficient way. This case study investigate and promote use of lightweight autonomous underwater vehicles/robots (AUV) with the remote sensing payload as the environmentally non-destructive method that enables fast area coverage and generates considerable amount of data. It is very important for efficient monitoring that equipment is easy and convenient to use, therefore this study was focused on one person portable lightweight AUVs (20-50kg), which are easy to handle from land or small rubber boats and do not require big and expensive ships for logistic, deployment or recovery.

Hence, section 2 describes the methodology and a resources used during the case study. It is followed by presentation and discussion of the experimental results in Section 3. Finally, a set of conclusions are provided.

II. Methodology and resources

The study was performed during the "Breaking the Surface" - international interdisciplinary field training of marine robotics and applications, from 2011 to 2013. The study area (bay Lucica) is situated in the central part of the Croatian coast on the island Murter (43° 49' 30"N; 15° 34'10"E). The study area occupy approximately $200.000m^2$. During the tourist season the bay is frequently visited by sailing boats and yachts and the meadow is under the pressure from boat anchoring. Apart from the main scope of the paper, evaluation of the potential of the lightweight AUVs for *P. oceanica* monitoring, it was expected that study will reveal extent of mechanical damages and possibly provided data to evaluate long-term mechanical impacts of anchoring.

A. Methodology

The monitoring method must be designed to assess the conservation status of *P. oceanica* as well as to identify changes in seagrass meadows. There are two main obstacles for easy introduction of the new monitoring methodologies. The first is reliability of the method, significant effort and amount of time is required to prove the method not only scientifically but also in practice. The second is capacity of the field work practitioners who are trained according to existing methods and protocols. The existing monitoring methodologies, indicators and descriptors are very well developed and scientifically challenged over the decades. They are developed for diving, the main data acquisition method available at the time. Monitoring data set collected by AUV is partially different (type, quality and quantity of data) and not necessarily in line with existing conservation status descriptors and methodologies. That fact generate needs for adjustment of some of the existing descriptors and introduction of completely new descriptors. New methodology needs to be scientifically confirmed and proven in practice.

Existing descriptors suitable for assessing the good ecological status of the *P. oceanica* meadows are identified by [4]. Among the most frequently used descriptors are density, lower depth limit, upper depth limit and bottom coverage. Meadow density is commonly assessed by manual counting the number of leaf shoots per m^2; as such, AUV and its payload is not really suitable for evaluation of this descriptor. The bottom coverage is expressed as percentage of seabed covered by live plants with respect to that made up of sand, rocks and dead matte. Percentage cover can be used to calculate the conservation index CI [5]:

$$Ci = P/(P + D) \tag{1}$$

where P is the percentage cover of live *P. oceanica*, D is the percentage cover of dead *P. oceanica* matte. It is often evaluated by direct visual observation some meters above the bottom using e.g. vertical photography. This makes it a good candidate for meadow monitoring by AUV. Density and the bottom coverage descriptors are used to quantify human impact and dynamics of the meadow. The lower and upper depth limit descriptors represent the bathymetric and the geographical position of the meadow limits/boundaries. Upper depth limit measures human impact and sedimentary dynamics of the meadow while lower depth limit tells us more about water transparency and meadow progression/regression. These descriptors are often combined with evaluation of type of depth limit which can be: progressive, sharp, erosive and regressive. The upper depth limit is located in a shallow waters and can be evaluated using aerial photographs. Other data for evaluation of this descriptor are: in situ underwater photographs and sidescan sonar images. The lower depth limit is located in deeper waters meaning that we have to rely fully on underwater remote sensing data for evaluation of this descriptor.

As we can see not all descriptors are suitable for AUV based monitoring. We recognized upper depth limit, lower depth limits and bottom coverage as the most suitable descriptors for our analysis.

B. Resources

Official Croatian map (DOF5 1/5000) created from 2009 in map projection HTRS96/TM on the ellipsoid GRS80, were used as an source of digital aerial colour photography. The four AUVs performed the field experiments: 2011 - IVER2 (Oceanserver) owned by University of Zagreb and equipped with SportScan-Imagenex sidescan sonar and HERO2 underwater camera, 2012 - IVER2 owned by Oceanserver with

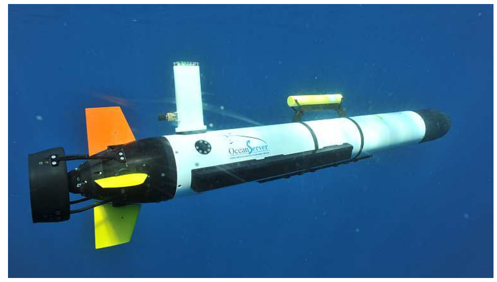

Fig. 1. AUV IVER2 with Klein-3500 side scan sonar in action

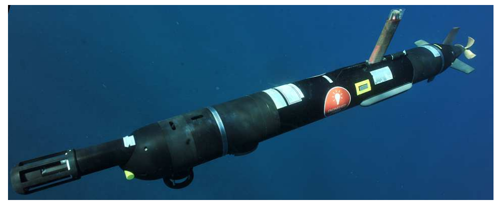

Fig. 2. AUV LAUV with Yellow fin side scan sonar in action

high definition L-3 Klein's UUV-3500 sidescan Sonar, 2012 - LAUV (OceanScan) with YellowFin-Imagenex sidescan sonar and digital camera with illumination module and 2013 - REMUS100 (Hydroid) with high definition EdgeTech 2205 sidescan sonar.

Both IVER2 AUVs used DVL assisted dead reckoning and GPS on the surface for navigation. Remus100 used Doppler-assisted dead reckoning with Inertial navigation system and GPS. The main disadvantage of dead reckoning is unbounded accumulation of errors. That is why the AUV needs to surface periodically for a GPS fix to bound its position error. That GPS correction creates a shift in a AUV position. To avoid position "jumps", trajectory is usually corrected off-line. University of Zagreb applied the RauchTungStriebel (RTS) smoother [6] for their IVER2 while OceanServer (IVER2) and Hydroid (Remus100) used their own proprietary algorithms. OceanScan LAUV used different localisation method, Long-Base-Line (LBL) system. The system consists of geo-referenced seabed baseline transponders used as reference points for navigation and positioning [7]. The system ensures bounded position error regardless of time

Fig. 3. AUV REMUS100 with Edgetech side scan sonar

spent underwater, there is no need for surfacing. On the other hand, deployment and recovery of the LBL underwater transponders require certain skills and considerable time and effort.

Each of the vehicle is supported by its own mission planning, data visualisation and analysis software. Automatic estimation of bottom coverage is achieved using simple off-line algorithm developed at University of Zagreb based on underwater image brightness segmentation of dark regions of *P. oceanica* and bright regions of dead matte or bottom sediment. Algorithms itself does not perform seagrass identification even though there are some works published about that topic [8], [9]. Seagrass is identified by the human operator. Many applications were tested for video mosaicing, from software's provided or developed by AUV suppliers and universities to the commercial products.

III. Results and Discussion

A. Depth limits

The map of P. oceanica meadow with its limits/boundaries was established using remote sensing data: aerial data (photography in the shallow areas, i.e. up to 10 m of depth) and underwater data (in-situ photography and sidescan sonar data). Upper depth limit is in many cases shallower then 10 meters that allow us to use aerial photography for the analysis, as shown in figure 4. Once the images are available, analysis is easy and fast. The advantage of the method is that it provides big coverage and ensures efficient evaluation of the upper depth limits. The disadvantage of the method is that it does not provide data needed for identification of the seagrasss, evaluation of the limit type, it cannot be used for lower depth limit evaluation and it requires ground truthing to verify that obtained results correspond to the real situation.

Geo-referenced underwater photography is perfect supplement to the aerial photography. In-situ images can help us identify the seagrass and more accurately evaluate type of the limit (see figure 7), they can be used for evaluation of the lower depth limits and they present real situation on the seabed. Example of how to use geo-referenced big-scale video mosaic, created from collected images, for the limit estimation, is shown in figure 5.

Sidescan sonar imagery can also be used to estimate depth limits as shown in figure 6. It works for both limits and have a big coverage. Unfortunately it can not help us identify the seagrass and geo-referenced data suffers from higher localisation inaccuracy. For depth limits estimation, sidescan sonar is very handy to fill the gaps of the limits not covered by other, more accurate means of limit localisation e.g. underwater photography.

Final results of the established upper and lower depth limits for the study area are presented in GIS as map shown in figure 8. Upper depth limits are found to be on the depth of 5 to 10 meters. Type of limit is mostly sharp with few exception where type is regression. Lower limits are located on the depth of 21 to 25 meters and they are mostly of regression type.

Fig. 4. Aerial image of the study Area with the detected part of the upper depth limit

Fig. 5. Underwater Videomosaic overlaid over aerial image (white square in figure 4), used for upper depth limit detection

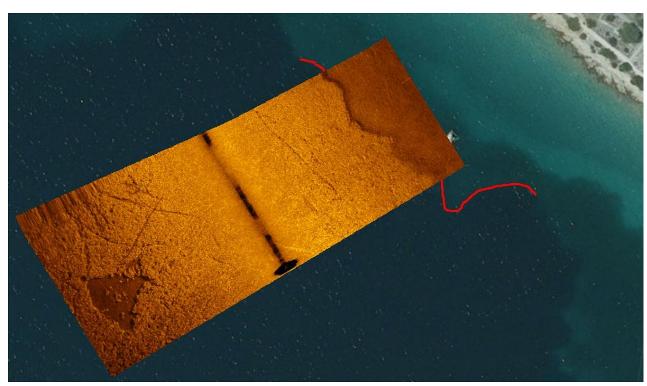

Fig. 6. SideScan Image overlaid over aerial image, used to detect upper depth limit

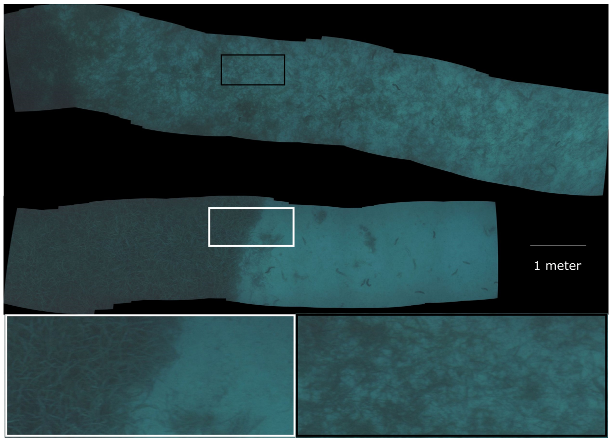

Fig. 7. Underwater video mosaic of two types of depth limit: sharp and regressive

B. Bottom coverage

Meaning of bottom cover descriptor is explained in chapter II-A and it is closely related to the conservation index (1). By diving, bottom cover is commonly assessed using the Line Intercept Transect (LIT) technique [10]. In short, the LIT is usually 10m long line (measuring tape divided into centimetres), positioned on the randomly selected seabed transects. The percentage cover of the *P. oceanica* for that particular transect is established by measuring the points where the key attributes (*P. oceanica* or sand, rock, dead matte) change and comparing the determined regions.

Quantity of the underwater images, provided by the AUV, allows analysis and calculation of this descriptor in a different manner. Underwater images, if properly calibrated, preserve geometrical relationship between the objects on the image. It would be easy to apply virtual measuring tape on the single image or videomosaic of the transect of arbitrary length and calculate percentage cover. The method used in this case study is as follow: first, image processing algorithm is applied to segment, classify and calculate percentage cover of *P. oceanica* on a single underwater image, as shown in figure 9, then linking geographical position of the image and it's coverage percentage, geo-referenced bottom coverage data set is obtained. Data set is supplemented by the coverage data extracted from the sidescan images. SideScan sonar scans large area of the sea bottom. Its role and contribution related to the bottom coverage is to provide "big picture" of the meadow and to identify and map patches of the dead matte missed by video transect as shown in lower left corner of the figure 6. To produce final bottom coverage map 10, missing data is obtained by interpolation of the available field data. Different tones of green represent different percentage of the bottom coverage (0% to 100%) and accordingly the map is segmented in regions of different coverage.

The fact that AUV collects huge number of meadow images gives us a possibility to generate very dense meadow coverage grid. We are confident that AUV is capable of providing good and reliable data to assess the bottom cover.

Fig. 8. Evaluated upper and lower depth limits of the study area

Fig. 9. Camera image segmented to regions covered by live plants and dead matte

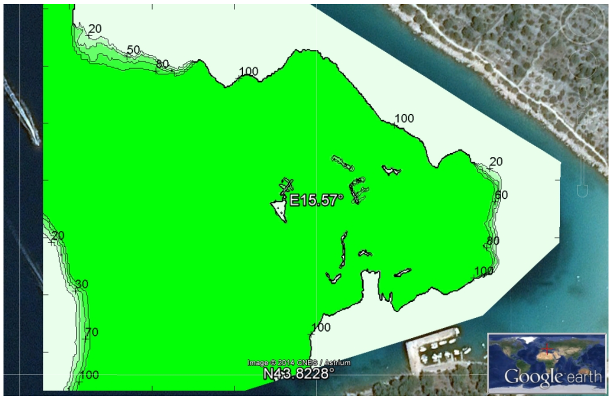

Fig. 10. Bottom coverage map of the study area

C. Localisation accuracy of the collected data

Monitoring program defines repeating interval of the state of conservation assessment. Reliable monitoring method needs to be able to detect a even slight negative trends of conservation status of the *P. oceanica* in a consecutive assessments. Accordingly, it is of ultimate importance to geo-reference monitoring data as accurate as possible.

Geographical accuracy of aerial photography depends on map used. Croatian DOF5 map has an accuracy of 1 meter. Registration of the underwater images depends on accuracy of the AUV navigation/localisation performance. Navigation specifications of the vehicles are given in II-B. Localisation accuracy of the dvl-aided dead reckoning does not depend that much on environmental disturbances but quality of the navigation measurements, primarily AUV altitude and velocities over ground. Accuracy can be further degraded by improper calibration e.g. compass or inaccurate parametrization e.g. speed of sound for DVL. For dead reckoning based AUVs, localisation error is kept limited by regular surfacing during the mission. Our experience says that low-cost AUV may accumulate error of 1m per 100m of transect, meaning that if we want to keep an error below 2m, AUV needs to surface after every 200m long transect. Vehicle's localisation accuracy could be further improved by fusion of the visual odometry with navigation data, application of simultaneous localization and mapping (SLAM) technique or using localisation relative to fixed geological and anthropological features.

Sidescan data suffers from higher localisation error due to fact that total error summarize navigation error and sidescan related errors. Bathymetric measurements are usually not available for the mission area and therefore sidescan assumes a locally flat bottom when localizing seabed features. There are number of errors associated with sidescan sonar, for more information the interested reader is referred to [11], but the most distinct error is across-track error caused by flat bottom assumption. For steady slops the across-track error increases with slant range resulting in position errors on the order of meters when surveying over sloped bottoms. Just as an example, for AUV flying on low altitudes, with slope steepness of 10 degrees and slant range of 50 meters, across-track error caused by flat bottom assumption is 0.8 meters but for steepness of 25 degrees error increases to almost 5 meters. Quality of the sidescan sonar data could be improved by using the information about the bottom topography, instead of the flat bottom assumption. In that case, the image is corrected geometrically providing correct position of bottom features.

D. Efficiency

Monitoring should primarily provide reliable data for assessing the state of the ecosystem but it should also be time and cost efficient. In terms of time efficiency and based on our experience during the case study, AUV can easily travel 10 to 20 km per day. Assuming that sidescan image quality of the high-definition sonar and localisation accuracy for meadow mapping is acceptable up to 50m of slant range, AUV is capable of scanning 1 to 2 km^2 per day. Underwater photography covered approximately 3 meters wide track of the sea bottom or 3000 to 6000 m^2 per day.

In terms of cost, a lightweight AUV crew consist of 2 persons and need only small rubber boat for operations. Preparations and post-processing took us approximately 3 man days for one effective field day. Ratio between effective sea days and total days spent at sea primarily depends on the weather, geography of the monitoring area and the logistics. These time variables combined with the size of the monitoring area, cost of man power, cost of AUV depreciation and cost of operations, transportation and logistics provide cost estimation for monitoring of the targeted area using lightweight AUVs.

For the purpose of this case study, data from numerous short demonstration and hands-on mission for the students and the participants of the BtS workshop was fused together. Otherwise, data for the study area can be collected in a half a day including mission planning, deployment, recover and mission data retrieval.

E. Added value

An AUV with appropriate sensor suit is capable of collecting variety of data without additional effort and during the single mission. Data interesting for long term monitoring are certainly data related to the seabed sediment texture and bathymetry of the monitoring area, presented by sidescan mosaic and bathymetry map respectively, in figures 11 and 12.

The valuable insights into water quality data (physical, chemical and biological characteristics of the water) can be provided by measurements of e.g. oxygen or chlorophyll concentrations or salinity.

Sidescan imagery, collected by an AUV, can be used to reveal evidence of mechanical damages of the meadow done by anchoring, example is shown in figure 6 where damages are easily recognised as a lines or scars in the meadow. Comparison of the images from consequents monitoring periods, provides information related to progression or regression of damage.

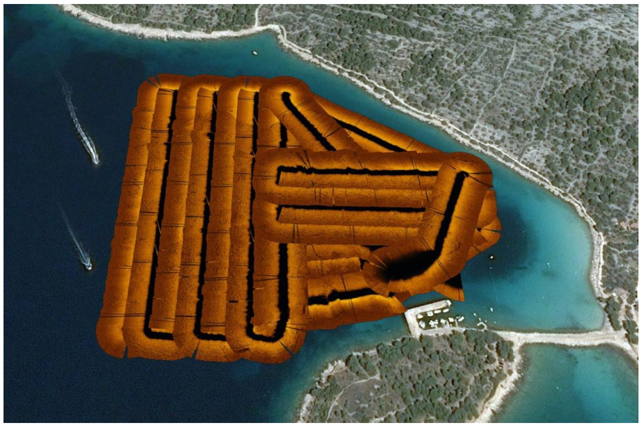

Fig. 11. SideScan mosaic of the study area

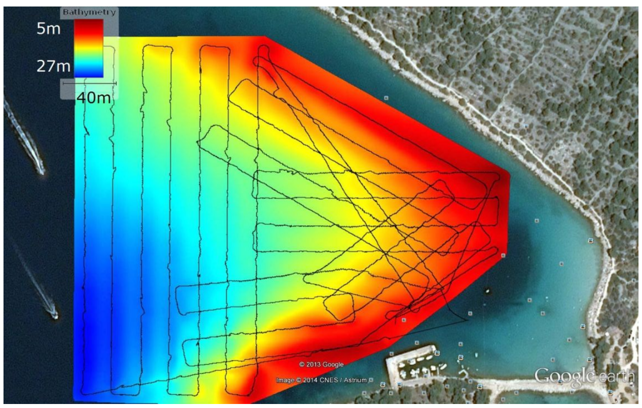

Fig. 12. Bathymetry of the study area

IV. Conclusions

Monitoring process should cover representative but broad areas covered by *P. oceanica* annually, should be able detect habitat losses of 10% or less and should be economically sustainable. This case study shows that AUV can be efficiently used to evaluate depth limits, type of limits and bottom coverage descriptors for assessing the good ecological status of the *P. oceanica* meadows but also that AUV is capable of providing valuable data e.g. meadow in-situ images, bathymetry of the area, water quality measurements, to support subjective evaluation of other descriptors. AUV has a great potential to be supplement to diving for seagrass monitoring or in some cases the main monitoring resource. Study also demonstrates that main benefit of using AUV is possibility to acquire huge amount of data relevant for assessment, in a cost- and time-efficient way. Practical advantage of using lightweight AUVs is the fact that they do not require specially certified technical personnel and expensive and complicated logistic. Therefore, AUV can be operated by biologists/ecologists after the basic training and with simple logistics. Precondition for widespread use of AUV for seagrass monitoring is establishment of scientifically proven monitoring methodology adapted for the AUV capabilities and capacity building of the fieldwork practitioners. To help that process, future work in robotic research should focus on improvement and development of tools and applications for seagrass recognition, identification, segmentation and classification, mission planning for optimal meadow coverage or sensor development in domain of biomass measurement. This is an interesting but challenging research area requiring a multidisciplinary approach.

V. Acknowledgment

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