UAV, satellite data and GIS for reef monitoring in Prokopos Lagoon

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ABSTRACT

Lagoons and coral reefs are of great biological, ecological, and economic value, while suffering from anthropogenic and environmental pressures. Until a few years ago, monitoring methods for shallow water ecosystems were limited to in situ surveys and/or analysis of satellite remote sensing data. However, in situ methods are time consuming and expensive while they are liable to space limitations. Moreover, high-resolution satellite imagery is equally costly in terms of data acquisition and strongly dependent on meteorological conditions (rain, clouds, tides etc.). The advent of Unmanned Aerial Vehicles (UAVs) provides new opportunities to monitor large-scale coastal ecosystems through the ability to capture centimeter-resolution 3D data, which is impossible with conventional approaches. At the same time, UAVs have the advantage of performing low-cost repeated campaigns during the lowest tides. In this framework, the current study compares UAV imagery to very high-resolution satellite data covering lagoon reefs and investigates the role of UAV-derived products such as Digital Surface Models (DSMs) and orthophotos in the evolution of such environments over time. Prokopos Lagoon located in Western Greece was selected as a study area. In recent decades, it has been observed that the POLYCHAETE Ficopomatus enigmaticus has formed large reefs, covering a significant part of the lagoon extent. In light of this, images collected with a vertical takeoff and landing UAV were compared to Pleiades multispectral data. Both data sets were evaluated in terms of accuracy and long-term monitoring capability. As expected UAV data proved to be more effective than the Pleiades data for the precise monitoring of polychaete expansion. Within a year, the polychaete formations extent was doubled in the north part of the lagoon.

Keywords: UAV, Pleiades, GIS, monitoring, reef, polychaete

1. INTRODUCTION

Coral reefs are considered as one of the most significant and diverse marine habitats, so that the life of almost 25% of marine ecosystems is dependent on them [1]. Unfortunately, as many others coastal ecosystems around the world, coral reefs are facing degradation, due to increasing water temperatures (consequence of global warming), pollution and anthropogenic pressure as more than 10% of the world's human population lives along the coastal region. Monitoring coastal habitats could be performed with a variety of data collection methods, from traditional in situ observations and measurements on intertidal and subtidal rocky reefs, and sandy beaches, to use of marine remote sensing technologies, such as underwater video monitoring, bathymetry from ship based sonar, and aerial based LiDAR approaches [2,3,4]. Satellite remote sensing [5,6,7,8], sound navigation ranging techniques [9,10,11], acoustic backscatter measurements [12], use of autonomous underwater vehicle [13], as well as aerial photography [14,15,16,17] have demonstrated their own capacities for coral mapping. Remote sensing data (airphoto or satellite images) technology has been gradually adopted as an efficient and accurate alternative for reefs monitoring. The large area coverage, the synoptic view and the repeatability (less than two weeks revision time) have made the remote sensing approach a preferable methodology for the monitoring. The most commonly used multispectral satellite images are from NASA's Landsat program [18]. As described in [18] Landsat 8 OLI, Landsat 7 ETM+, Landsat 6 ETM and Landsat TM have been widely used for benthic habitat mapping. Sentinel-2 [19], or SPOT multispectral imagery has been also used [20]. The synergy of the previously mentioned methods in order to improve the accuracy of the monitoring has been also described in previous studies [21, 22].

Generally, methods based on field observations are considered as more accurate and reliable but they are the more expensive and may merely cover a small area. The alternative solution of satellite imagery has the advantage of

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covering large or difficult accessible areas; however, their results are less accurate in comparison to the in situ measurements.

The advent of Unmanned Aerial Vehicles (UAVs) provided new opportunities to monitor large-scale coastal ecosystems through the ability to capture centimeter-resolution 3D data, which is impossible with conventional approaches. At the same time, UAVs have the advantage of performing low-cost repeated campaigns during the lowest tides in almost every environment [23,24,25,26].

The potentiality of UAVs in accurate monitoring of intertidal reefs has been proved in a previous study [27]. In another research novel technologies such as deep learning neural networks and object-based image analysis, were applied in UAV imagery in order to develop a system that can assess the distribution, cover, and extent of corals [28]. Another practical methodology, where consumer-grade UAVs were used to improve the knowledge of conservation of three coastal ecosystems (rocky shores, mangroves and coral reefs) and facilitate the monitoring process in marine protected areas was presented [29]. A consumer drone was used to construct an orthophotomosaic and a bathymetric digital elevation model (DEM) and map shallow-water coral reefs [30]. Very high resolution (17 cm pixel size) multispectral UAV imagery was used to classify biogenic reefs at the largest European intertidal biogenic reefs, located in the middle of Bay of Mont-Saint-Michel. The combination of the Digital Surface Model, with the red and near infrared bands was evaluated for the reef classification [31]. The enormous potential of UAV data coupled with SfM and OBIA analysis as a tool to monitor shallow-water coral reef assemblages over time was demonstrated [32].

In the current study ultra-high resolution imagery acquired by a Vertical takeoff and Landing UAV and very high resolution imagery acquired by Pleiades satellite are compared for diachronic evolution mapping of a reef in Prokopos Lagoon western Greece. Both data sets were evaluated in terms of accuracy and long-term monitoring capability.

2. STUDY AREA AND DATA SETS

The current study was performed in Prokopos lagoon (38.14698 N, 21.39659 E, North-West Peloponnese, Greece). Prokopos lagoon has an approximate area of 1.5 km2 and the water depth ranges from 0.5 m to 2 m. The lagoon receives fresh seawater from the Ionian sea through a 2km long and 20m wide channel in its northeast part as well as river inflows in the south part during the winter months. During at least the last two decades, the polychaete F. enigmaticus has rapidly colonised Prokopos lagoon and therefore the lagoon has been covered to a large extent by massive reefs. As described in details in [33] Ficopomatus enigmaticus sensu lato is a reef-building tubeworm and suspension feeder serpulid polychaete which is considered invasive in brackish waters in the temperate/subtropical zone worldwide [34, 35]. The spread of this species led to reduced access by boat, impeding fishing activities, and probably also affects water circulation within the lagoon.

To map the evolution of the polychaete, UAV data with ultra high resolution and satellite data with very high resolution were used. Two Pleiades images with 50cm spatial resolution acquired on 24/3/2019 and 26/6/2021 were used for the mapping of the polychaete expansion. Pleiades imagery is orthorectified and no further processing is required. In addition, two UAV flights were performed on March 2021 and March 2022 respectively collecting thousands of RGB images. The Vtol UAV Trinity F90+ equipped with a 42MP camera (SONY RX1RII) has collected more than 3500 images following a photogrammetric grid (Figure 1). As it can be observed in Figure 1, an area of 311 hectares (3110000 m^2) was mapped in only 2 hours and 40 minutes. A characteristic example of the image resolution is presented in Figure 2. The images were processed in Agisoft Metashape and a Digital Surface Model and an orthophoto map were produced (Figure 3). The processing procedure is described in details in two previous studies [36, 37]. All the orthophotos are georeferenced in the Greek Geodetic Reference System. ArcMap was used in order to detect and map the changes and the polychaete evolution through time.

3. POLYCHAETE EVOLUTION OVER TIME

3.1 UAV data

As it is quite difficult and time consuming to digitize all the polychaete formations in the entire extent of the lagoon two representative subareas were selected in order to measure the evolution of the specific species at the north and the south part of the lagoon. Each sub-area has an extent 50 to 50 meters ie each area covers an area of 2500 square meters. In Figure 4 the two subareas are presented for the years 2021 and 2022. Moreover, these areas are also investigated via in situ measurements. In ArcMap environment the polychaete formations were manually digitized (polylines) and subsequently transformed in polygons (as presented in Figure 5). Then, the extent of each polygon was automatically calculated via the 'Calculate area' command in ArcMap. The increase of polychaete extent is very easily detectable especially in subarea A.

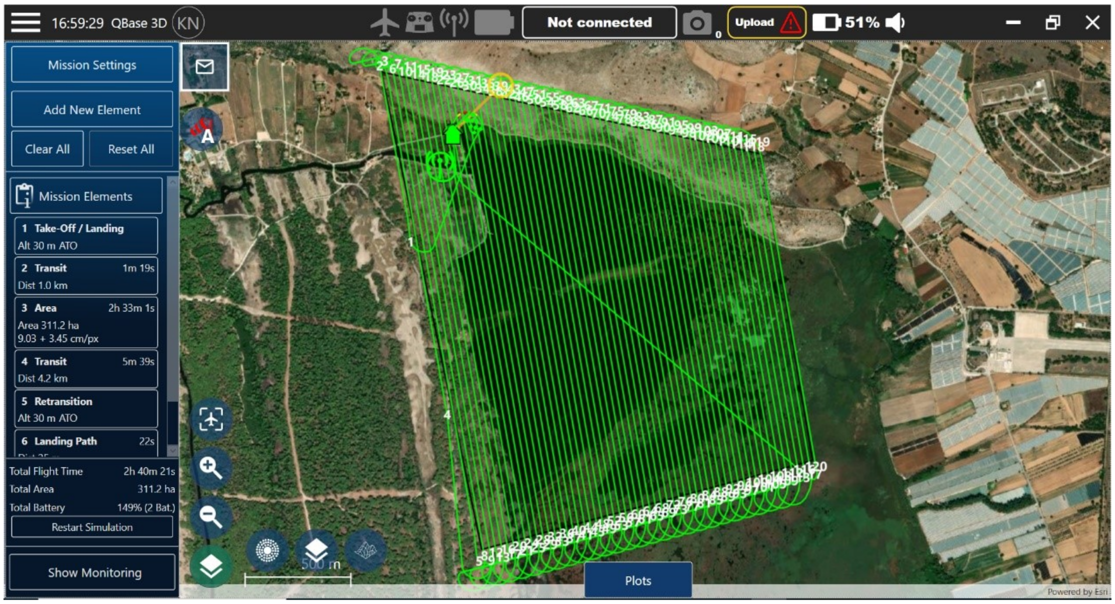

Figure 1. Photogrammetric grid for the UAV flight over Prokopos Lagoon.

Figure 2. An example of the acquired UAV images. Polychaete formations can be easily detected in the water.

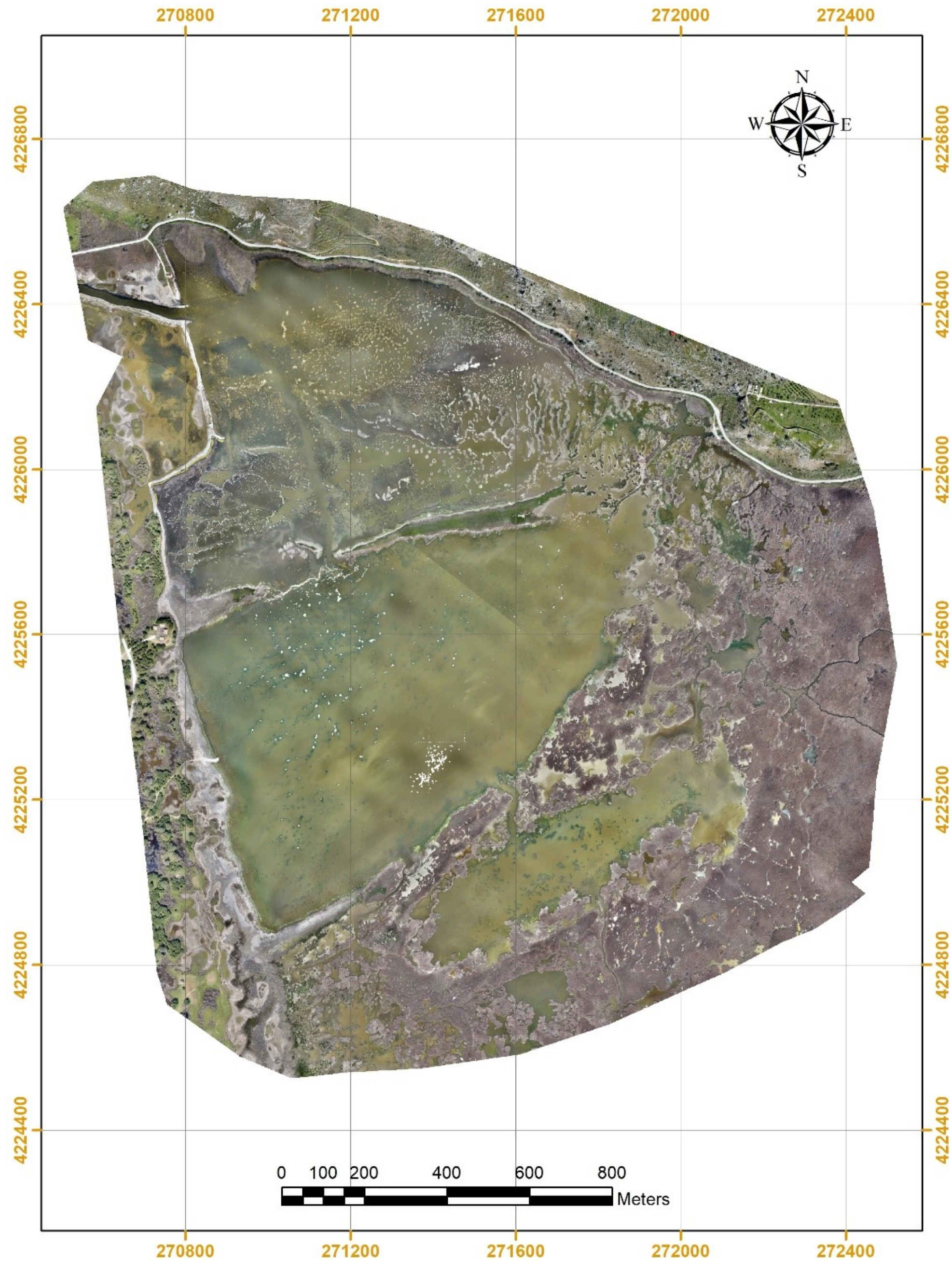

Figure 3. Orthophoto of Prokopos Lagoon as mapped on March 2022.

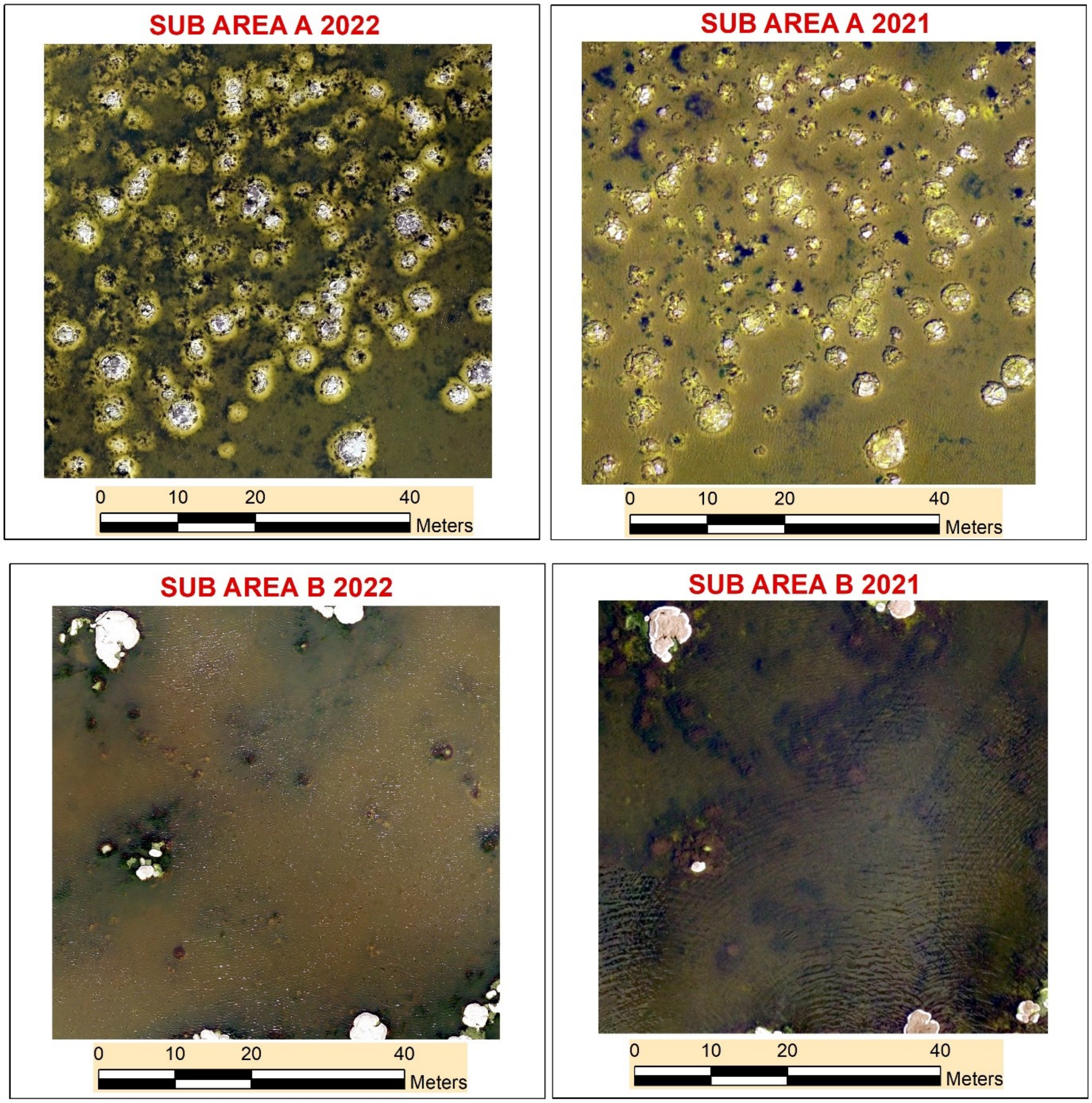

Figure 4. The two representatives sub areas of 2500 square meters where the polychaete evolution was measured in ArcMap environment.

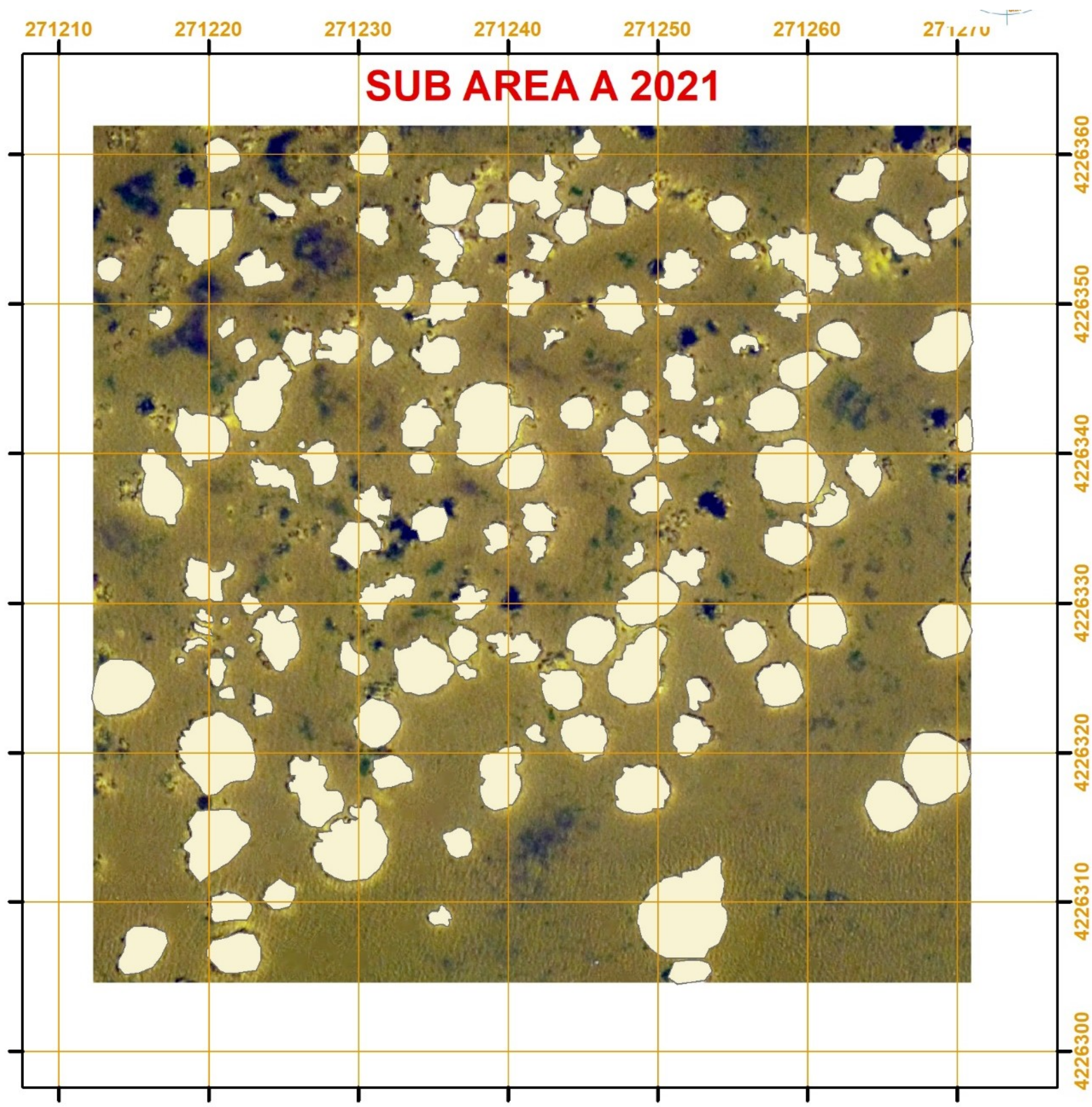

Figure 5. Each polychaete formation was digitzed and polygons were created in ArcMap environment at 1/500 scale.

As it can be observed in Figure 6, in subarea A, the extent of the polychaete formations was 731.3 sq.m. in March 2021 while a year later in March 2022 (Figure 7) the expansion of polychaete formations increased to 1476.6 sq.m. Thus, within a year, the polychaete formations extent was doubled.

As far as the sub-area B, the extent of the polychaete formations was 261.2 sq.m. in March 2021 (Figure 8) while a year later in March 2022 (Figure 9) the expansion of polychaete formations increased to 264,4 sq.m. Thus, within a year, the polychaete formations extent remained almost unchanged.

It should be noticed that the total extent of each subarea is 2500 sqm, so in March 2022 the polychaete formations have covered about 60% of the total surface, while in March 2021 they covered only 29.4%.

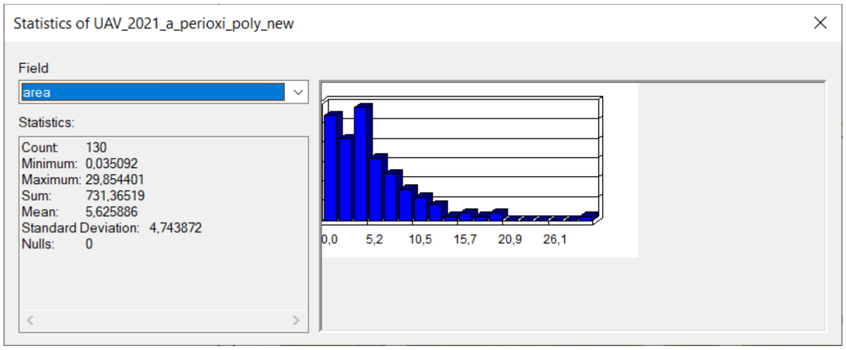

Figure 6. Statistics of the polychaete extent in March 2021 for subarea A.

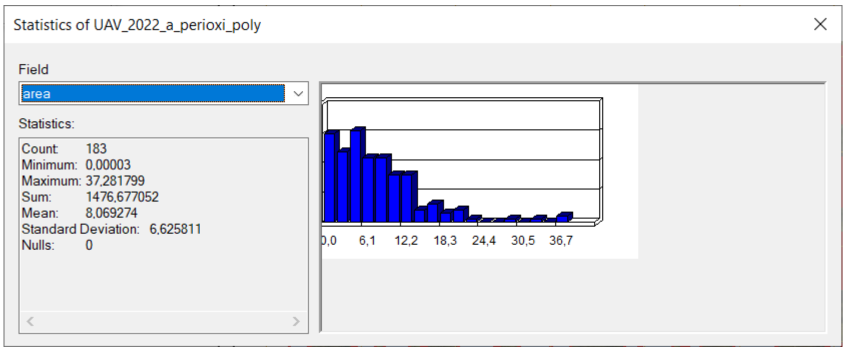

Figure 7. Statistics of the polychaete extent in March 2022 for subarea A.

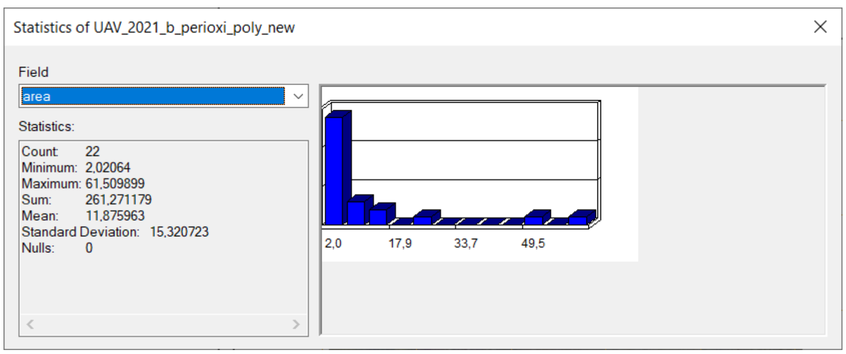

Figure 8. Statistics of the polychaete extent in March 2021 for subarea B.

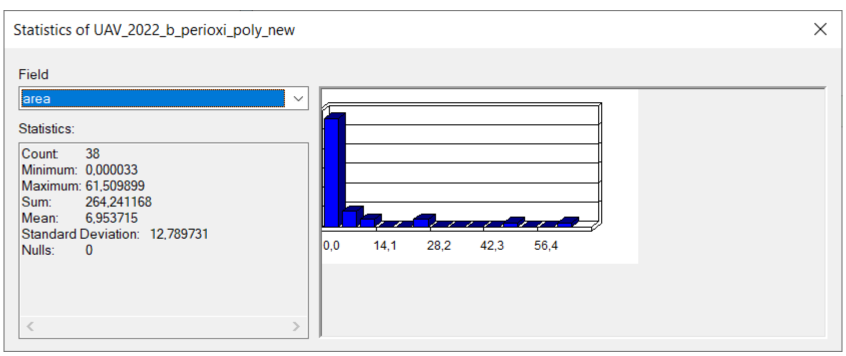

Figure 9. Statistics of the polychaete extent in March 2022 for subarea B.

3.2 Satellite data

As mentioned previously two orthorectified multispectral Pleides satellite images with a spatial resolution of 50 cm were also processed in order to:

- Compare the effectiveness of each data set in polychaete formations mapping
- Monitor the polychate evolution from 2019 to 2021

As it can be observed in Figure 10 the lower spatial resolution of Pleiades data (Figure 10 right part) compared to the ultrahigh spatial resolution of UAV imagery (Figure 10 right part) decreases the accuracy of polyxhaete formation mapping. Only the larger formations can be detected and mapped in Pleiades imagery. The smaller polychaete that was detected and mapped in Pleiades imagery has an extent of 1,03904 sq.m. In comparison, the smaller polychaete that was detected and mapped in UAV imagery (Figure 10 left part) has an extent of only 0,035091 sq. m.

The extent of the polychaete was digitized and mapped from the Pleiades imagery of March 2019 and June 2021 (Figure 11). A serious increase of polychaete extent can be detected in subarea A within the two years period. The number of poychaete has passed from 70 to 97. The total extent of polychaete has passed from 358 sq.m in 2019 (Figure 12) to 537 sq.m in 2021 (Figure 13). The polychaete present an increase of 50% between 2019 and 2021. Thus, it is obvious that the polychaete invasion in the lagoon has started many years ago and there is a serious increase to the rate of the poluchaete expansion.

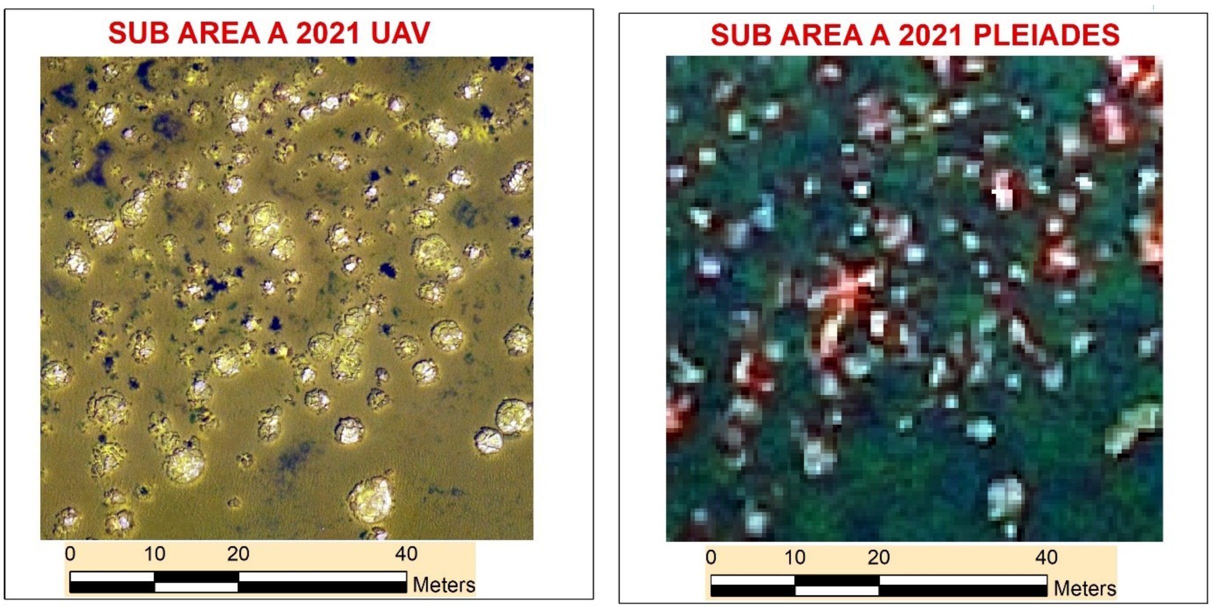

Figure 10. Comparison of the Pleiades imagery to the UAV imagery over subarea A.

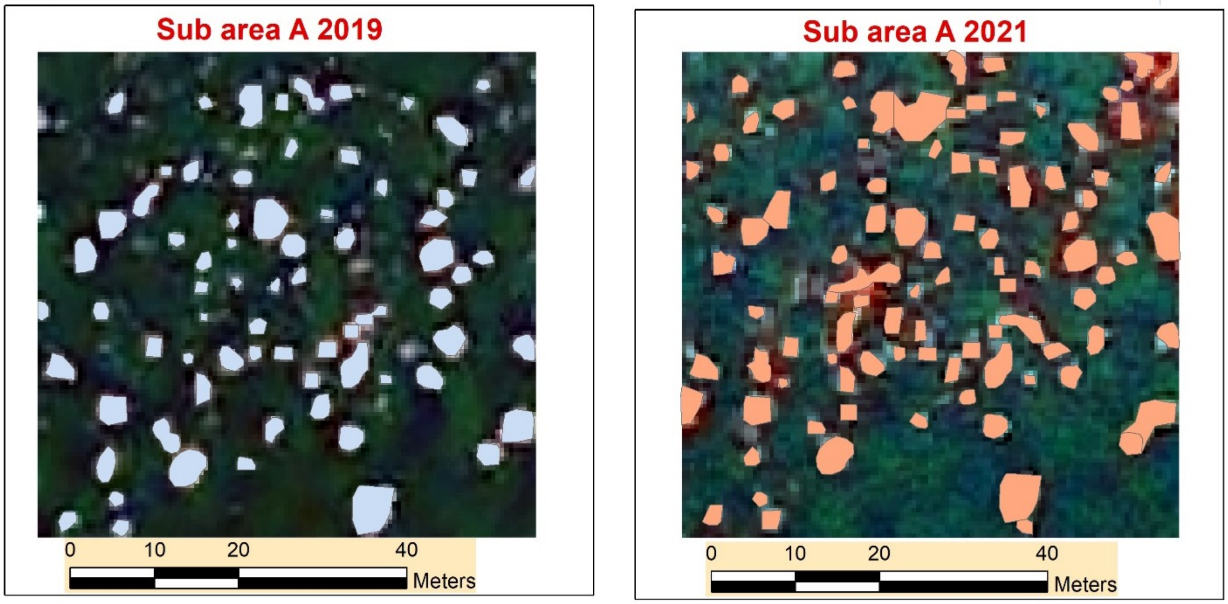

Figure 11. Polychaete formation digitization from Pleiades imagery on 2019 and 2021.

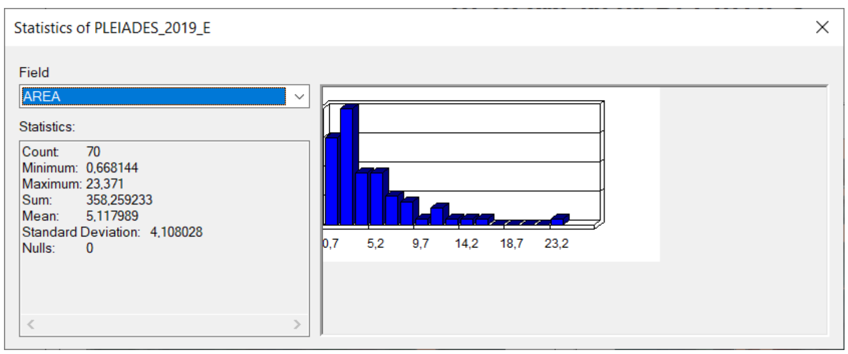

Figure 12. Statistics of the polychaete extent in March 2019 for subarea A.

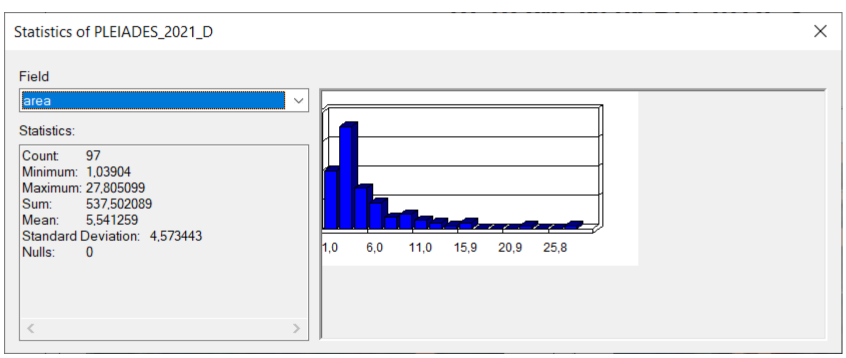

Figure 13. Statistics of the polychaete extent in June 2021 for subarea A.

4. CONCLUSIONS

In the current study, the use of UAV and satellite data for polychate formation mapping in a coastal lagoon in Western Greece is presented. Two sub areas, i.e. one at the north part of the lagoon and one at the south were used for the mapping of polychaete evolution. As discussed in details in [33] the expansion of the polychaete formations may related to changes in coastal ecosystems driven by increased agricultural activities, hydrological changes and rising temperatures.

It was proved that the two sub areas present a totally different rate of polychaete extent increase. At the north, in subarea A, the extent of the formations was doubled within a year from March 2021 to March 2022. At the same period, in subarea B (south part of the lagoon), polychaete seems to remain stable. At the same time, the use of UAV imagery is necessary due to the ultrahigh spatial resolution that allows the detection of very small polychaete and the precise mapping of their extent. Satellite data can be used for polychaete diachronic mapping, however the investigator should take into account that only polychaete larger than one square meter can be detected and mapped. Over the last years a serious increase to the rate of the poluchaete expansion in Prokopos Lagoon was observed.

5. FUTURE WORK

The monitoring of the polychaete expansion in Prokopos lagoon is still on-going. Two new UAV flight campaigns took place at the end of March 2024. The first campaign was perform with the high resolution RGB camera (SONY RX1RII) while a second campaign following the same photoframetric grid was performed using a multispectral camera (Micasense Rededge –P). In the near future the comparison between the RGB and the multispectral camera will be performed.

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