A DRONE'S EYE VIEW: A PRELIMINARY ASSESSMENT OF THE EFFICIENCY OF DRONES IN MAPPING SHALLOW-WATER BENTHIC ASSEMBLAGES

Andrea Francesca Bellia*, Julian Evans, Sandro Lanfranco
Department of Biology, University of Malta, Msida, MSD2080, Malta
*phone +356 9919 3606, e-mail: andrea-francesca.bellia.17@um.edu.mt

Abstract – This study represents a preliminary assessment of the efficiency of consumer-level drones to survey shallow-water benthic cover (0-5m depth). We hypothesised that the use of a drone to map benthic assemblages would reduce the duration, cost, and manpower requirements, while increasing accuracy, relative to manual survey techniques.

A DJI Mavic 2 Pro drone was used to survey four bays in Malta by obtaining a high-altitude photo for each bay. This was then processed via *k*-means clustering to generate a pseudocolour image (PCI). The value of k corresponded to the number of benthic cover classes (BCCs), which was determined upon inspection of the original aerial image. Since *k* was dependent on the respective benthic complexity of each bay, the *k* value varied from site to site.

Each site was also mapped using manual survey techniques to enable comparison of the relative representation of BCCs between manual and drone-based methods. Data from manual surveys were obtained from transects spaced *ca.*10 m apart, where the number of transects taken was dependent on the size of the respective site.

The correspondence between the two survey methods was determined using Principal Component Analysis (PCA) on the BCC relative cover of each site. Results obtained indicated a statistically significant positive correlation between the relative cover of BCCs in maps produced through drone and manual surveys ($r=0.845$, $p<0.0001$).

The relative efficiency of the two survey methods was assessed by comparing the area surveyed per man hour (m^2h^{-1}), where the automated drone survey method was significantly more efficient in all four sites. The drone survey was also more accurate than the manual survey, in that it mapped the entire area without the need for any interpolation between transects. This suggests that while manual surveys are a good approximation of the field situation, PCIs are capable of analysing benthic cover to give results of superior accuracy and coverage, but in a much shorter time, and without bias.

The only real limitation with regards to using drones for mapping purposes is the weather, since the drone cannot be flown in rainy conditions, and waves caused by strong winds obscure the benthos. The time of day at which the drone is flown is also a factor due to the sun's glare on the water's surface, which also obscures the benthos beneath. In addition, aerial imagery can only be used for mapping of benthic assemblages in very shallow waters and requires high water transparency.

Introduction

Rapid and accurate surveys to map benthic assemblages in shallow water are a fundamental requirement of several coastal monitoring programmes [4]. The combination

FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)
Andrea Francesca Bellia, Julian Evans, Sandro Lanfranco, *A Drone's Eye View: A Preliminary Assessment of the Efficiency of Drones in Mapping Shallow-Water Benthic Assemblages,* pp. 501-509, © 2020 Author(s), CC BY 4.0 International, DOI 10.36253/978-88-5518-147-1.50

of speed and accuracy would permit more frequent surveys, increasing the probability of early detection of any environmental change [2]. In most cases, such monitoring programmes have utilised ground-based field survey techniques, where observers map benthic assemblages by sampling along transect lines and interpolating data to characterise the intervening areas. This method is rather slow, labour-intensive, and relatively imprecise, as it makes assumptions about the intervening areas.

A possible solution to these constraints is the use of a small unmanned aerial vehicle (drone) to survey and image areas from an altitude of tens or hundreds of metres. This could make the process more rapid than a manual survey, with comparable or increased accuracy. The increased availability of low-cost consumer drones with imaging capability of sufficiently high quality has propelled the use of drones into the mainstream and brought with it a need for new survey protocols to take advantage of this technology. This study aims to assess consumer-level drone efficiency to survey shallow-water benthic cover (0÷5 m depth) in the coastal zone. We hypothesise that the use of a drone to map benthic assemblages would reduce the duration, cost, and manpower requirements, while increasing accuracy, relative to manual survey techniques.

The principal questions addressed were the following:

(1) Are drone-based surveys faster and more accurate than manual field surveys over equivalent areas?
(2) Does benthic heterogeneity affect the relative efficiency of drone-based and manual surveys?

Figure 1 - Map of Malta, indicating locations of each Site of Study (SoS): Daħlet ix-Xmajjar (DX), Mistra Bay (MB), Daħlet il-Fekruna (DF) and Għajn Tuffieħa (GT). Scale bar bottom left, and North to the top of the image.

Materials and Methods

The study was based on photographic drone surveys of four sites of study (SoS) in Malta: Daħlet ix-Xmajjar (DX), Mistra Bay (MB), Daħlet il-Fekruna (DF) and Għajn Tuffieħa (GT) (Figure 1). Aerial photographs of each SoS acquired from the drone were processed into pseudocolour images (PCIs) showing benthic assemblages. These were subsequently verified through ground-truthing in the field.

All aerial imagery was captured using a DJI Mavic 2 Pro drone (Da-Jiang Innovations Science and Technology Co. Ltd., Shenzhen, China) equipped with a Hasselblad L1D-20c camera. The camera had a Field of View of approximately 77°, and a 20MP 1" sensor yielding images with a resolution of 5472 pixels x 3648 pixels. The drone was generally flown at around 08:00 h, as the low angle of incidence of sunlight at this time reduced the glare on the sea surface. Flying the drone at other times of day was also possible on windless and overcast days, due to the absence of glare or rippling of the sea surface. The drone was flown to an altitude which encompassed the whole SoS for imaging in DNG and JPEG formats. The altitude varied according to the size of the SoS.

The processing workflow carried out during this study was adapted from one described for terrestrial vegetation mapping [1]. The aerial images were visually inspected to estimate the number of different Benthic Cover Classes (BCCs) in each SoS. This value was assigned to the variable *k* that was then used during the image processing phase. Images were subsequently segmented via *k*-means clustering in ImageJ [5] to produce the respective PCIs for each SoS. In this type of cluster analysis, the user supplies a predetermined number of clusters (*k*) to be produced. The algorithm converges towards clusters in which the within-group variance is much smaller than the between-group variance.

In the context of the images being processed, the algorithm identifies areas with similar chromatic properties, and groups them into 'clusters', each approximating a BCC. This reductive procedure was iterative and continued until the requisite number of clusters had been reached [3]. This gave a PCI with *k* colours, in which each colour corresponded to a different BCC. PCIs were then inspected and compared with the original aerial photo. The *k* value which best reflected the benthic complexity was then used for the rest of the analysis. It was assumed that each colour on the map corresponded to a different BCC. Following image analysis, validation of the PCIs was carried out. This was done by reconciling BCCs in the PCIs of each SoS with direct field survey results, at depths of 5 m or less.

Each SoS comprised one or more BCCs. The BCCs were initially loosely based on those described for the Tyrrhenian Sea around the Tuscan Archipelago [7] and modified accordingly. Each BCC was identified on the basis of its dominant cover but was not exclusive of other cover classes. The BCCs identified were: Bare exposed rock (BER), Bare sand (BS), Bare submerged rock (BSR), Dead matte (DM), Juvenile *Posidonia* (JP), *Posidonia* meadow (PM) and Rock with photophilic algae (RPA). The percentage cover of each BCC in the PCI was calculated directly from the image analysis program. The percentage cover of the benthic assemblages in the aerial images was estimated by superimposing a virtual grid on the photograph in ImageJ and calculating the percentage coverage of each BCC.

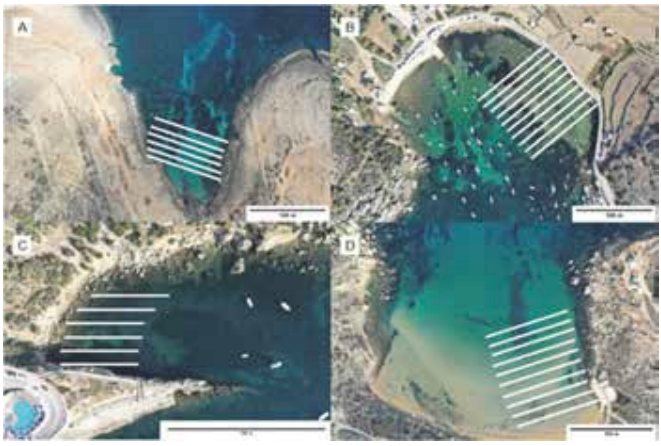

Figure 2 - Aerial images of the four sites of study (SoS), indicating the position of transects taken for the manual surveys. 100 m scale bars are at the bottom right corner of each image with North to the top of each image. A: Daħlet ix-Xmajjar (DX), B: Mistra Bay (MB), C: Daħlet il-Fekruna (DF) and D: Għajn Tuffieħa (GT).

Each SoS was also mapped using manual survey techniques (Figure 2) to enable comparison of the relative representation of BCCs between manual and drone-based methods. Data from manual surveys were obtained from transects spaced *ca*.10 m apart, where the number of transects taken was dependent on the size of the respective SoS. Data obtained were subsequently used to show approximate benthic assemblage distributions for each SoS. The correspondence between relative representation of BCCs in PCIs and in maps from manual surveys was compared using Principal Component Analysis (PCA).

The effect of benthic heterogeneity on the relative efficiency of both methods was tested using the Shannon-Wiener diversity index (H) as a measure of benthic complexity. This first-order diversity index has found very wide application in ecological studies where it is generally used to express the alpha diversity of a community. It was considered suitable for the purpose of expressing benthic heterogeneity since the fundamental principles that govern the use of this index have not been violated by taking BCCs in place of species [6]. The 'reference heterogeneity' for each SoS was calculated from the PCIs and expressed as H_{SoS}. This was subsequently compared against the 'discrepancy' between the relative representation of BCCs in the 'drone-based survey' and 'manual field survey' for each SoS.

The discrepancies for each SoS were estimated by measuring the Euclidean distance between the two data points for each SoS (one drone-based and one manual) on the PCA plot. The discrepancies were then correlated with the heterogeneity of each SoS by calculating the Pearson product-moment correlation coefficient.

The duration and manpower required to carry out each survey was recorded for both the drone and manual surveys and quantified in man-hours. This was subsequently used to compare the relative efficiencies, in area surveyed per man-hour, of the two methods.

Results

The original aerial images and the PCIs obtained after image segmentation are shown in Figure 2 to Figure 5.

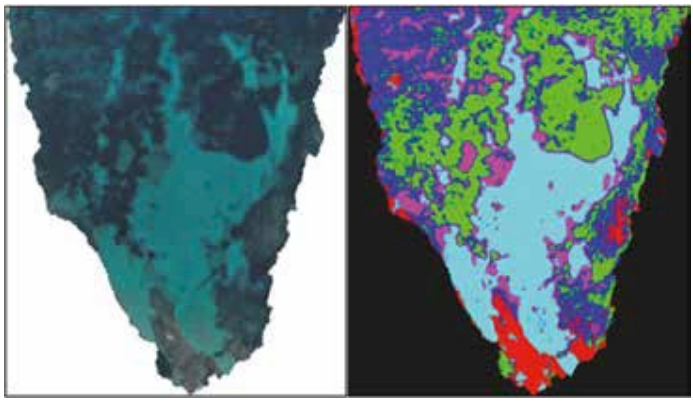

Figure 2 - Aerial image (left) and Pseudocolour image (PCI) (right) of benthic assemblages at Daħlet ix-Xmajjar (DX). PCI generated through *k*-means clustering (*k*=7). Two clusters corresponded to the same benthic cover class (BCC) and were merged into the Cyan BCC. BCCs: Blue=Rock with photophilic algae (RPA), Cyan=Bare sand (BS), Green=*Posidonia* meadow (PM), Magenta=Bare submerged rock (BSR) and Red=Bare exposed rock (BER).

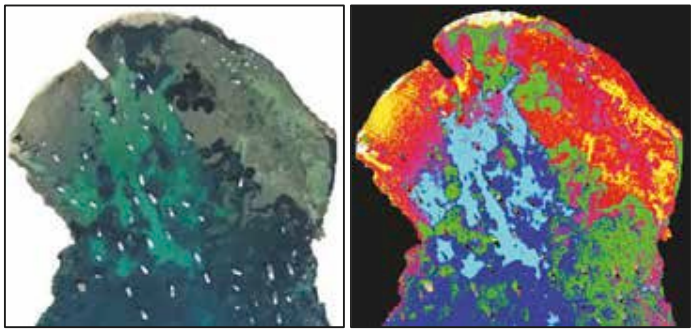

Figure 3 - Aerial image (left) and Pseudocolour image (PCI) (right) of benthic assemblages at Mistra Bay (MB). PCI generated through *k*-means clustering (*k*=8), where each colour corresponds to one benthic cover class (BCC). BCCs: Blue=*Posidonia* meadow (PM), Green=Juvenile *Posidonia* (JP), Magenta=Bare submerged rocks and pebbles (BSR), Red=Dead matte 'reef' (DM), Cyan=Bare sand (BS) (deep), Yellow=BS (shallow) and White=BS (exposed).

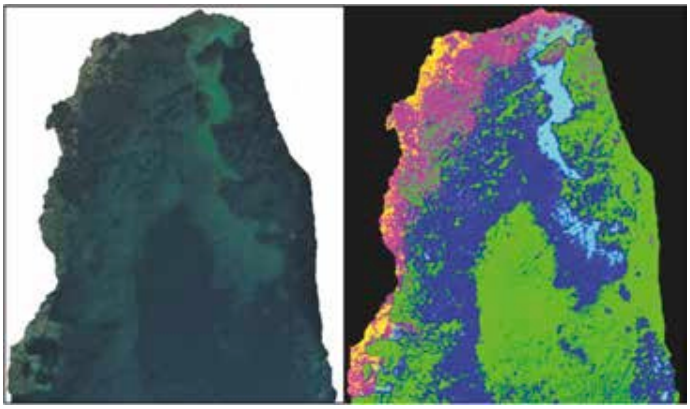

Figure 4 - Aerial image (left) and Pseudocolour image (PCI) (right) of benthic assemblages at Daħlet il-Fekruna (DF). PCI generated through *k*-means clustering (*k*=6), where each colour corresponds to one benthic cover class (BCC). BCCs: Blue=Juvenile *Posidonia* (JP), Cyan=Bare sand (BS), Green=*Posidonia* meadow (PM), Magenta=Rock with photophilic algae (RPA) and Yellow=Bare submerged rocks and pebbles (BSR).

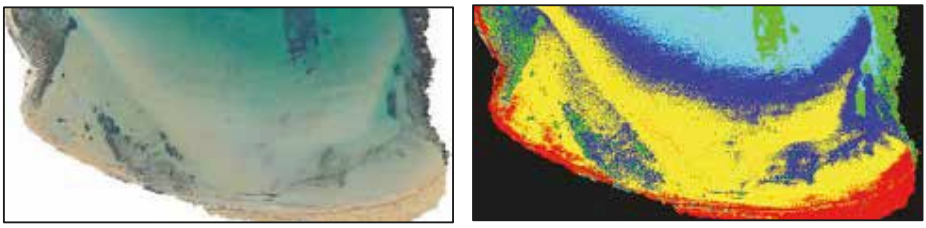

Figure 5 - Aerial image (left) and Pseudocolour image (PCI) (right) of benthic assemblages at Għajn Tuffieħa (GT). PCI generated through *k*-means clustering (*k*=6), where each colour corresponds to one benthic cover class (BCC). BCCs: Blue=Bare sand (BS) (with degraded *Posidonia* dust), Cyan=BS (deep), Yellow=BS (shallow), Red=BS (exposed) and Green=Rock with photophilic algae and *Posidonia* debris (RPA).

The correspondence between percentage cover of BCCs for each SoS derived from both survey methods is shown in the PCA ordination plot in Figure 6. Considerable overlap of the convex hulls in the PCA plot indicates high correspondence between the relative coverage of the BCCs for both survey methods. The relative contribution of BCCs from PCIs and Manual surveys was significantly correlated across all SoSs ($r=0.845$, $p<0.0001$).

The hypothesis that benthic heterogeneity contributed significantly to the discrepancy between the two survey methods was tested by correlating the discrepancy between the two methods for each SoS with the value of H for that SoS. There was no significant correlation between discrepancy and H_{SoS} ($r=-0.0379$, $p=0.962$), showing that

the differences between automated and manual methods were not attributable to differences in benthic heterogeneity.

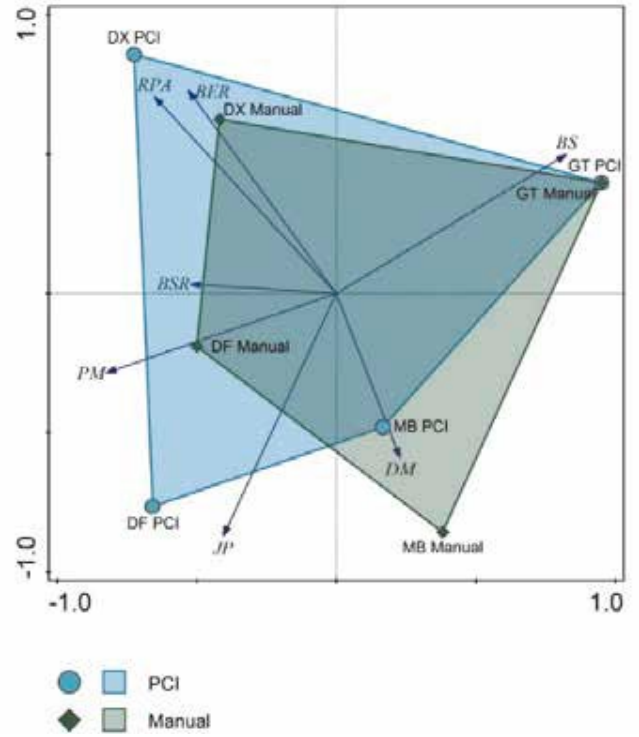

Figure 6 - Principal Component Analysis (PCA) ordination plot data of benthic cover class (BCC) percentage cover in maps produced via drone surveys (pseudocolour images; PCI) and through Manual surveys for the four sites of study (SoS): Daħlet ix-Xmajjar (DX), Mistra Bay (MB), Daħlet il-Fekruna (DF) and Għajn Tuffieħa (GT). BCC vectors: Bare exposed rock (BER), Bare Sand (BS), Bare submerged rock (BSR), Dead matte (DM), Juvenile *Posidonia* (JP), *Posidonia* meadow (PM), and Rock with photophilic algae (RPA). The first two ordination axes explain 71.7 % of the variation within the data.

The relative efficiency of the two survey methods was assessed by comparing the area surveyed per man hour (m^2h^{-1}). Figure 7 indicates that the automated drone survey method was significantly more efficient than the direct manual survey method in all four sites. The drone survey was also more accurate than the manual survey, in that it mapped the entire area without the need for any interpolation between transects.

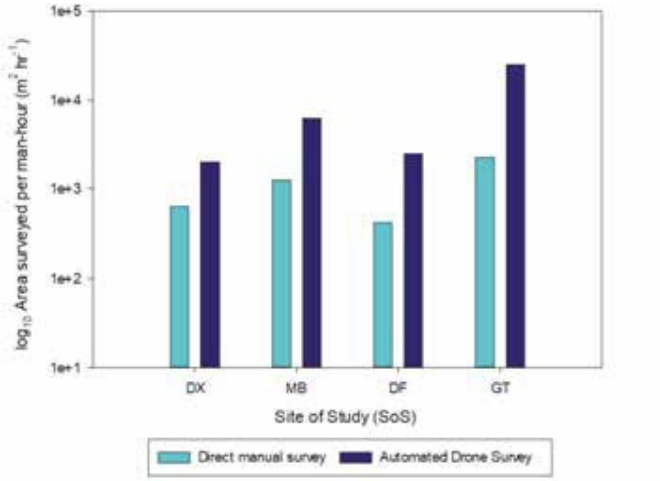

Figure 7 - Relative efficiency, expressed as Area surveyed per man-hour (m^2h^{-1}), for both survey methods at each site of study (SoS).

Discussion

The results obtained during this preliminary study clearly indicated that automated drone surveys were faster and more accurate than manual survey methods. This result has important implications for the scientific and economic aspects of the process and would have a cumulative multiplicative effect in monitoring programmes that require regular surveys.

PCIs were found to be a better approximation of the distribution of benthic assemblages when compared to maps produced via manual surveys, whereby both approaches are based on simplification of the real field situation. PCIs reduce aerial images into a small number of chromatic dimensions, while manual surveys subsample at intervals. The differences in the results returned by the two methods is attributable to the simplification process employed in manual surveys and is independent of habitat heterogeneity.

Although the duration of the automated drone survey varied depending on the size of each study site, it amounted to less than 48 hours per bay. This value is inclusive of the drone survey, image analysis to construct the PCI, BCC identification and verification via ground truthing. This greatly reduces the time taken and manpower required when compared to manual survey methods, which may take days to cover similarly-sized areas, and require significantly higher manpower. The PCIs produced through a drone-assisted survey are therefore particularly useful in the context of a regular monitoring programme, where quantification of change in benthic assemblages is required. The speed and accuracy of the drone survey would permit more frequent monitoring, increasing the probability of early detection of any environmental change.

The only real limitation with regards to using drones for mapping purposes is the weather, since the drone cannot be flown in rainy conditions, and waves caused by strong winds obscure the benthos. The time of day at which the drone is flown is also a factor due to the sun's glare on the water's surface, which also obscures the benthos beneath. In

addition, aerial imagery can only be used for mapping of benthic assemblages in very shallow waters and requires high water transparency.

Conclusion

We may therefore conclude that while manual and automated surveys give results of comparable accuracy in terms of the BCCs present, drones are able to survey larger areas and produce maps with greater precision. This is because unlike in manual surveys, automated surveys using a drone allow for the acquisition and processing of larger areas in a shorter timeframe. This saves time and allows individuals to map larger areas per unit time.

References

[1] Bellia, A. F., & Lanfranco, S. (2019) - *A Preliminary Assessment of the Efficiency of Using Drones in Land Cover Mapping*, Xjenza, 7(1), 18-27.

[2] Blondeau-Patissier, D., Gower, J. F., Dekker, A. G., Phinn, S. R., & Brando, V. E. (2014) - *A review of ocean color remote sensing methods and statistical techniques for the detection, mapping and analysis of phytoplankton blooms in coastal and open oceans.* Progress in oceanography, 123, 123-144.

[3] Ng, H. P., Ong, S. H., Foong, K. W. C., Goh, P. S., & Nowinski, W. L. (2006) - *Medical image segmentation using k-means clustering and improved watershed algorithm*. In 2006 IEEE southwest symposium on image analysis and interpretation (pp. 61-65). IEEE.

[4] Orlando-Bonaca, M., Lipej, L., & Orfanidis, S. (2008) - *Benthic macrophytes as a tool for delineating, monitoring and assessing ecological status: the case of Slovenian coastal waters*. Marine pollution bulletin, 56(4), 666-676.

[5] Schneider, C. A., Rasband, W. S., & Eliceiri, K. W. (2012) - *NIH Image to ImageJ: 25 years of image analysis*. Nature methods, 9(7), 671-675.

[6] Spellerberg, I. F., & Fedor, P. J. (2003) - *A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the 'Shannon–Wiener' Index*. Global ecology and biogeography, 12(3), 177-179.

[7] Ventura, D., Bonifazi, A., Gravina, M. F., Belluscio, A., & Ardizzone, G. (2018) - *Mapping and classification of ecologically sensitive marine habitats using unmanned aerial vehicle (UAV) imagery and object-based image analysis (OBIA)*. Remote Sensing, 10 (9), 1331.