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Optimising beached litter monitoring protocols through aerial imagery

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ABSTRACT

The monitoring of beached litter along the coast is an onerous obligation enshrined within a number of legislative frameworks (e.g. the MSFD) and which requires substantial human resources in the field. Through this study, we have optimised the protocol for the monitoring of the same litter along coastal stretches within an MPA in the Maltese Islands through aerial drones, with the aim of generating density maps for the beached litter, of assisting in the identification of the same litter and of mainstreaming this type of methodology within national and regional monitoring programmes for marine litter. Concurrent and concomitant in situ monitoring of beached litter enabled us to ground truth the aerial imagery results. Results were finally discussed within the context of current and future MSFD monitoring obligations, with considerations made on possible future policy implications.

1. Introduction

Marine litter is considered nowadays as one of the most insidious problems affecting the oceans, in particular since its accumulation has been identified in all the main oceanic gyres (Suaria and Aliani, 2014). Also, unfortunately, plastic pollution is globally distributed across all oceans due to its properties of buoyancy and durability (Eriksen et al., 2014). Since 1950, the global production of plastic has increased rapidly and this upward trend in production will continue in the coming decades (Cózar et al., 2014). The abundance of Marine Litter in the Mediterranean Sea is increasing: in fact, it has been estimated that in 30 years, the abundance of floating Marine Litter will increase by 6–8% when compared with the current situation (Lebreton et al., 2012). Therefore, it is essential to monitor the Mediterranean Sea on an operational basis in order to identify trends in marine litter accumulation. Operationality can only be achieved through the adoption of innovative monitoring means, and this study represents a preliminary attempt to apply to selected coastal sites in the Maltese Islands an innovative surface marine litter monitoring technique, involving drone flights.

Although no macroscale hydrodynamic phenomena leading to litter accumulation, such as gyres, operate in the Mediterranean Sea, marine litter is still considered of critical importance within the semi-enclosed Basin due to the basin's limited exchanges with other oceans, its densely populated coasts, highly developed tourism, 30% of the world's maritime traffic passing through and various additional inputs of litter from rivers and very urbanized areas (UNEP/MAP, 2015). Despite this, most information on litter quantities and distribution within the Mediterranean is still fragmented (Ioakeimidis et al., 2014).

The insidious nature of the marine occurrence of litter is acknowledged through the inclusion of Marine Litter as one of the Marine Strategy Framework Directive's (MSFD) 11 Descriptors. The list of indicators approved by the EU Commission for the first six-year MSFD cycle includes 'Trends in the amount of litter washed ashore and/or deposited on coastlines, including analysis of its composition, spatial distribution and, where possible, source' (Indicator 10.1.1). The MSFD Initial Assessment submitted by the Maltese Islands for Descriptor 10 specifies that information on litter from the archipelago's coast emerges mainly from one-off research initiatives or from clean-up efforts rather than from regular or even operational monitoring initiatives, revealing a glaring gap in the national monitoring capacity for this issue.

The approved MSFD monitoring programme for the Maltese Islands proposes that, every three months, visual surveys by human observers are conducted on two recreational beaches along two 100 m-long transects located on each beach and that SCUBA diving surveys are conducted along two transects within the nearshore area of two remote beaches so as to collect data for indicator 10.1.1. Additionally, surveys of floating litter ('litter in the water column'), conducted from the same beaches, are also envisaged. These monitoring obligations are onerous, especially for a small island state, and necessitate considerable human and infrastructure resources, also since the acquired data may not always be utilisable for additional marine litter reporting obligations that the Maltese Islands have under the Integrated Monitoring and

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Assessment Programme (ImAp) within the EcAp (Ecosystem Approach) of the Barcelona Convention, under the Bathing Water Directive, for Annex V of the International Convention for the Prevention of Pollution from Ships (MARPOL) and for the Blue Flag programme.

Despite their relatively recent emergence, drones are increasingly being deployed within research efforts. Research applications of drones include the monitoring of beach topography (e.g. Casella et al., 2016), the detection of oil spills, through integration with photogrammetry (e.g. Capolupo et al., 2014) and the long-term monitoring of forests (e.g. Zhang et al., 2016). Linchant et al. (2015) give an overview of the various applications of Unmanned Aircraft Systems (UASs) in wildlife monitoring. The drone deployment, however, only constitutes the initial stage within an integrated process which involves extensive post-processing of the raw data (e.g. aerial imagery, positioning data) provided by the drone. The regular acquisition of geo-referenced and high-resolution aerial imagery by drones is both cost-effective and rapid, assisting in the achievement of environmental monitoring obligations associated with marine litter, especially when coupled with machine learning protocols which increase the reliability of results by increasing replicability and decreasing human bias.

The main goal of this work was the definition of a protocol for the detection and monitoring of marine litter through the use of an off-the-shelf aerial drone. Thus, the study's two main aims were the following: (i) the formulation of an optimised protocol providing guidance on how to spot beached and floating marine litter through the use of a drone (unmanned aerial vehicle) and (ii) the application of machine learning techniques (specifically, those related to image analyses) to the qualitative and quantitative analyses of aerial imagery for coastal litter monitoring purposes. A set of recommendations on the integration of protocols presented in this study within the monitoring indicators being currently formulated for the second six-year MSFD cycle are also provided.

2. Materials and methods

2.1. Site description

Three coastal stretches situated along the coast of the North-East Marine Protected Area of the Maltese Islands (Malta, Comino, Gozo) were selected. These three low-lying rocky coastal stretches are located at Bahar Ic-Caghaq, where the western and eastern flanks of a rocky peninsula were monitored, and at Qawra Point, with the two locations being considered, at least a prima facie, as coastal hot spots for the beaching of litter. The domain was set such as to include marine as well as terrestrial facets of the coastal zone, with the study sites being chosen so as to represent (i) gently-/low-lying coasts congenial for the beaching of litter, (ii) stretches of the coast which are not sheltered from wind and wave exposure and (iii) easily-accessible sites which enable repeated visits. This approach permits the joint identification of anthropogenic litter on the coast, i.e. litter that has beached, as well as floating debris within nearshore waters.

As a proof of concept, the protocol was tested on four sites around the Maltese Islands, as shown in Fig. 1. Embayment regions within the North-East Marine Protected Area that are frequently exposed to strong winds and waves, were selected due to their ease of access and low-lying topography (and thus high potential for beaching of litter) and monitored over a period of three months. In particular, Qawra Point was selected as this consists of north and south facing coastal stretches that could be surveyed in parallel. On the other hand, Baħar iċ-Ċagħaq was considered due to the occurrence of two rocky coastal stretches that face the west and the east due to their position on opposing sides of a headland. Fig. 2 shows the flight transections in both locations.

2.2. Drone-mediated monitoring

The methodology followed specifically targeted the requirements of the Marine Strategy Framework Directive (MSFD) for the quantification of beached and floating litter. Apart from the accumulation of marine debris, the proposed technique allows an investigation of how this changes with time. High resolution overlapping aerial images were collected over fixed transects that cover coastal areas of about 200 m by 200 m (40 km^2).

All collected data was mosaiced into one georeferenced orthophoto map. Detected debris was then classified by position, material, and size. The litter size categories adopted in this study are consistent with those prescribed by the MSFD, namely the 2.5 cm to 5 cm, 5 cm to 10 cm, 10 cm to 20 cm, 20 cm to 30 cm and the 30 cm to 50 cm ones.

The aircraft used in this work was a DJI Phantom 4 Pro. The gimbal was set to $-90°$ to look at nadir. This allowed the capturing of photos perpendicular to the direction of flight. Images with a resolution of 5472×3078 pixels were recorded. The shutter speed and aperture were set to 1/320 s and f/2.8 respectively. The ISO setting was kept fixed at 1000 so as to avoid changes in the intensity levels between images. The drone was set to fly at an altitude of 30 m. Such a value was empirically established as a compensation between image and spatial resolution after carrying out tests at different altitudes ranging between 20 m and 50 m. While aerial imagery data collected from low altitudes had a very good resolution, this only covered a very small area. Such a scheme also required a very slow flight speed and a high photo capture rate. Moreover, flights at low altitude attracted more attention from beach users due to the propeller's operating noise. Images recorded from a high altitude covered a larger area but suffered from a poor resolution. As a result, the optimum altitude for data collection was found to be 30 m. From this altitude, each frame covered an estimated ground area of 45 m by 25 m. Automatically capturing images every 3 s while the drone is flying at a speed of 3.5 m/s resulted in the frames overlapping by 58% along the wider side and by 44% along the shorter side. Data collection during the summer months was always planned before 10:00 and after 18:00 so as to minimise sun glint. A polarised lens Z neutral density (ND16) filter was also used. Wind speed and gust measurements were recorded before and after each flight, through the use of an AMES RVM 96B-1 handheld anemometer from Belfort Instruments, as supplementary field data (mainly to test the drone under different wind conditions and to respect maximum wind speed thresholds [5 m/s] set by the insurance company).

Following data collection, the image sets were processed by the OpenDroneMap software for the generation of a point cloud and texture map (Open Drone Map, 2017). GPS information extracted from the EXIF information of each image file was used for the creation of a georeferenced orthophoto map having a resolution of 1 cm/pixel. This was imported in Google Earth© and tiled for visualisation. Placemarks were then manually added to all recorded litter items. In particular, plastics were marked through a blue marker. Rope, wood and rubber items were marked through green, red and black markers, respectively. White was used for all other non-natural items. Different marker icon polygons were used to represent different litter size categories. KML files were also generated and imported in ArcGIS for the computation of density maps. This made possible the identification of accumulated litter hotspots.

To ensure the correct categorisation of debris, blind tests were carried out by comparing the digitised data with field measurements taken after each drone flight. Some objects that were manually identified (such as plastic bottles) were compared to the markers on Google Earth to make sure that these were correctly marked and classified.

3. Results

Datasets from each survey at Qawra Point and Baħar iċ-Ċagħaq generated 115 and 358 images, respectively. Fig. 3 visualises the digitised database of the detected marine litter.

The total number of litter items recorded at the two monitored sites (Bahar Ic-Caghaq and Qwara) was considerably different (30 items vs