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Marine litter and plastic detection on Black Sea beaches by using unmanned aerial vehicle (UAV)

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Abstract. Plastic and marine litter is one of the current growing issues worldwide, affecting the unique Black Sea ecosystem as well. Litter is yearly monitored for assessing ecological status across the Romanian beaches. We tested aerial drone-inspection or UAV method versus visual census for efficiency of litter monitoring on two Black Sea beaches, located in the Danube Delta area. The detection probability varied between size-category of items, with 71 – 100% accuracy of visual screening of drone images. Our pilot study showed the successful combination of the traditional visual census method with the new emerging UAV techniques for marine litter monitoring in the selected areas. To the best of our knowledge, this is the first study evaluating the UAV method for fast-screening of not-easily accessible sites at the Romanian coast of the Black Sea.

***Keywords*:** UAV; marine litter; macrolitter; plastic pollution; Black Sea.

1. Introduction

Marine litter (ML), defined as any persistent, manufactured or processed solid material intentionally discarded, or accidentally lost on shore or at sea [1] represents a major threat to marine ecosystems worldwide, requiring standardized approaches in order to develop improved waste management and efficient reduction measures [2].

Sources of marine litter can be sea- or land-based, with the latter comprising almost 80% of the total [3]. The densely populated coasts of the seas and oceans are particularly susceptible to ML pollution originating from anthropogenic activities and plastic litter of all sizes (micro-, meso-, macro- and megaplastics) is the most frequently encountered type of debris [4-6].

Currently, the EU Marine Strategy Framework Directive (MSFD) is one of the most important legislative instruments whose aim is the achievement of a Good Environmental Status (GES) for the water basins of the EU Member States by 2020 [7-9]. In this scope, marine litter is being assessed through Descriptor 10: "Properties and quantities of marine litter do not cause harm to the coastal and marine environment" and the GES is being evaluated based on the criteria D10C1: "The composition, amount and spatial distribution of litter on the coastline, in the surface layer of the water column, and on the seabed, are at levels that do not cause harm to the coastal and marine environment" and D10C2: "The composition, amount and spatial distribution of micro-litter on the coastline, in the surface layer of the water column, and in seabed sediment, are at levels that do not cause harm to the coastal and marine environment".

Quantitative assessments of coastal ML pollution on beaches are performed according to EU MSFD TG10 "Guidance on Monitoring of Marine Litter in European Seas – 2013 -JRC Scientific and Policy Reports" work protocols and methodologies [8]. The 100 m OSPAR protocol is widely used for the monitoring of beach litter and involves manual collection and identification of each litter item through visual census. Even if it has been proven to be a highly accurate method, manual collection of beach litter is a time-consuming laborious method, often limited by hard-to-reach areas [10, 11].

Started as an attempt to improve the application of the above-mentioned standardized methods, the OSPAR protocol has been readapted for beach-drone inspection of ML. The use of Unmanned Aerial Vehicles (UAVs), also known as drones, for marine litter and plastic detection, represent a complementary approach for researchers and by now, several survey studies have been conducted by using this novel approach to assess marine litter on the coast or in the ocean [12-14], but also marine mega-fauna [15]. Remote monitoring of marine litter by using UAVs, unlike satellite images that proved to have some limitations and difficulties regarding the low resolution of open-source data, high cost of commercial satellite images and time constraints [16-19], is a method that is increasingly used all over the world. Drones are widely used due to their accessibility, reduced cost and flexibility in the sensors that can be mounted on (RGB, multi-spectral and thermal cameras and even LIDAR). Also, UAV imaging can be combined with Machine Learning techniques for a faster analysis and to eliminate human errors [19].

The semi-enclosed basin of the Black Sea is being constantly exposed to litter pollution, many studies on

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this topic over time proving this growing issue and highlighting the need for better mitigating solutions [20-24].

The Danube River is the most international water basin (19 countries, 802.226 km^2) and the second longest river in Europe (2.857 km) [25] with an input of 6444 m^3/s at mean flow [26], contributing with about 40% of the freshwater input in the Black Sea [25], however, there is a major lack of data on river influenced beach litter, thus a study like this is necessary for the data completion.

Our study aimed to evaluate the abundance and composition of marine litter influenced by the Danube River using new emerging, advanced, and efficient technologies such as Unmanned Aerial Vehicles (UAV) for data collection. For this purpose, a pilot case study was performed in 2019 on two sandy beaches, with different levels of development, located in the vicinity of the Sulina branch of the Danube River, Romania.

2. Experimental

2.1. Study sites

The study was conducted on two different typologies of sandy beaches (touristic and wild) and used for beach macrolitter monitoring (Figure 1). Both selected beaches, Sulina and Câşla Vădanei, are part of the Danube Delta Biosphere Reserve.

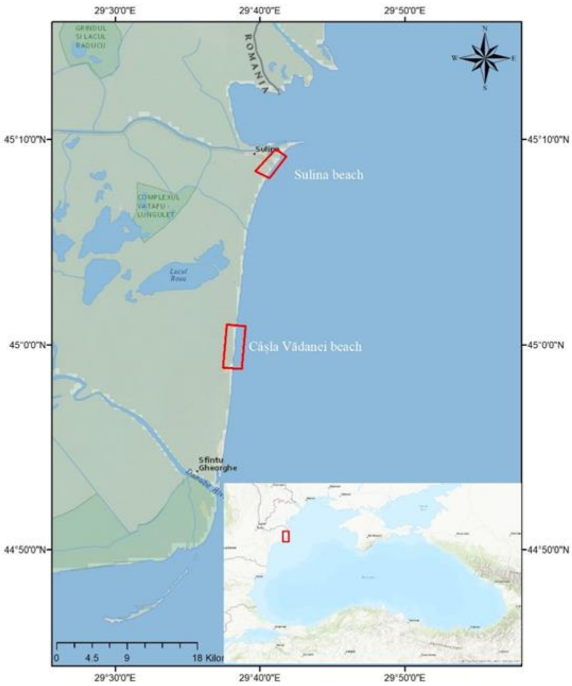

Figure 1. The map location of the two selected study beaches: Sulina and Câşla Vădanei

Sulina touristic beach (45.1438°N, 29.6845°E) localized in the Danube River's mouth (Sulina branch) at a distance of 2.5 kilometers from Sulina town is an isolated beach [27], with a mean number of just 7396 tourists per year [28], accessible only by water to Sulina [27]. Having a width of 150 m [29] and due to the Danube's River influence, it is the widest growing beach in Romania with fine sand, shallow water [27] and many protected species of flora [29].

The wild Câşla Vădanei beach (44.9945°N, 29.6369°E) is located in the midway between Sulina and Sfântu Gheorghe cities, and 7 km south of Lake Rosu. Its wild and non-touristic characteristics protect it from human direct pollution. Câşla Vădanei beach is narrower than Sulina beach [27] and its flora is represented by protected species of salt and dune vegetation [29].

2.2. Beach-visual inspection

The assessment of the litter accumulated on the selected beaches, Sulina and Câşla Vădanei, was performed in August 2019 [27] via the specially designed mobile application Marine LitterWatch (MLW) and according to the work protocol presented in the EU MSFD TG10 "*Guidance on Monitoring of Marine Litter in European Seas – 2013 -JRC Scientific and Policy Reports*" [8].

Litter items (> 2.5 cm) were visually identified on a 100 m long beach section (Figure 2) and were categorized using the mobile application according to TSG-ML codes provided in the Annex 8.1 of the protocol [27].

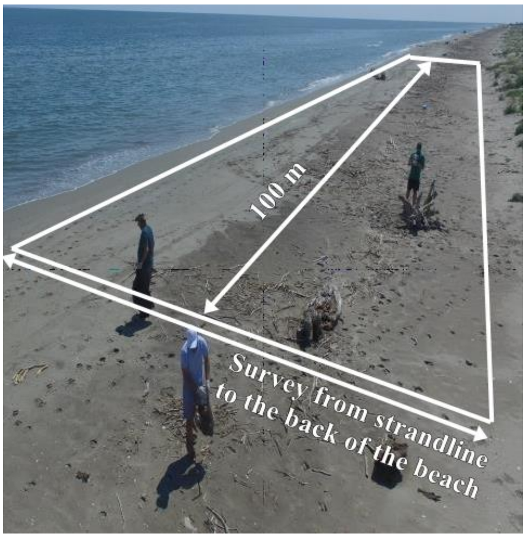

Figure 2. Visual inspection of beach litter on marine sites located in the river mouth survey area (*Original Photo: NIMRD Constanta, Romania*)

2.3. Beach-drone inspection

In parallel, an alternative innovative method based on Unmanned Aerial Vehicle (UAV) was tested for efficient beach litter monitoring in the Danube River mouth (Sulina branch) survey area. The assessment was made following the work protocol described by Martin et al. [10], to register the marine debris through image acquisition. A DJI Phantom 3 Professional drone equipped with a gimbal with a 12 Mega Pixel camera was used for the in situ survey. This specific drone, using the GPS/GLONASS satellite positioning system has a vertical accuracy of ±0.5m and horizontal accuracy of ±1.5m. A controller device is used, which combined with a smartphone or display can monitor the battery life, drone status and the flight parameters. A test was conducted to be able to identify the optimal altitude at which the items can be identified. The methodology for the UAV monitoring was set up using four steps: planning and preparation, data acquisition, image processing and data analysis. The drone was used for surveillance after checking the meteorological conditions and the No-Fly Zones according with local regulations (e.g. frontiers, crowded areas). The UAV flight covered the same beach surface inspected by visual observation at Sulina (100 m length, 20 m width) and Câșla Vădanei (100 m length, 14 m width) and was performed at 2 m/s speed and a 10 m altitude above ground level (AGL). The photos were taken from drone at 90 degrees from the ground and an approximate 30% overlap between images. Even though the selected drone model has a maximum range of 5 km, during this study the drone was kept within the eyesight during the whole procedure. A total of 413 images (each 4000x3000 resolution; *i.e.* 12 MP), 267 for Sulina beach and 146 for Câșla Vădanei beach, were acquired during the surveys and each was further processed using the Agisoft Metashape software, resulting in an orthophotoplan of the areas (Figure 3). Each aerial picture was then visually/manually screened to count the litter items and to categorize them according to TSG – ML code given in the Guidance on Monitoring of Marine Litter in European Seas – 2013 [8].

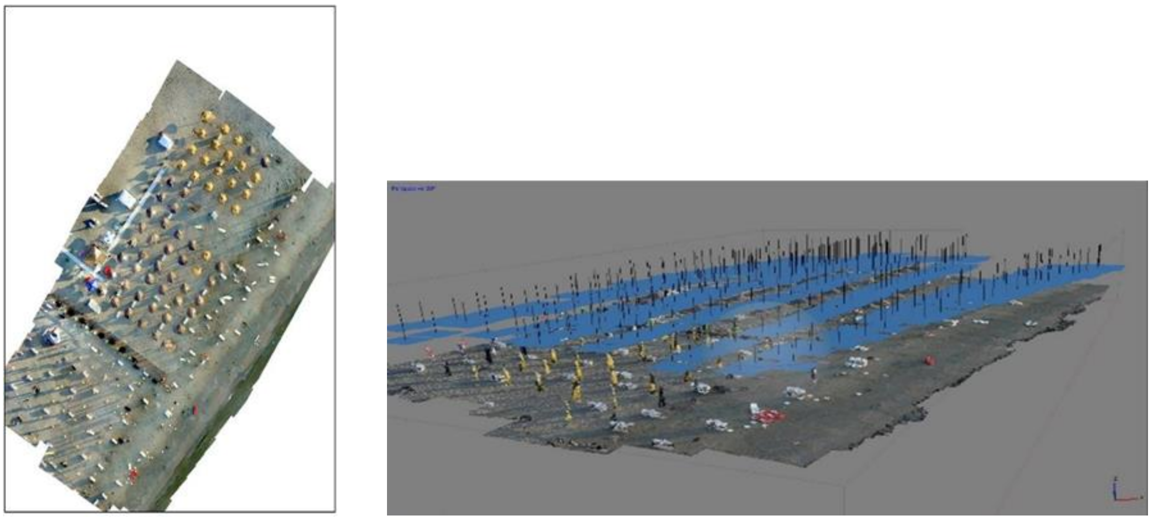

Figure 3. Example of orthophotoplan and aerial photos of Sulina touristic beach derived from the DJI Phantom 3 professional drone.

3. Results and discussion

At Sulina beach, a surface of approximately 2000 m^2 was inspected during a 50-min flight. The manual screening of the aerial pictures reported an amount of 234 litter items, with an average density of 0.12 items/m^2. Five main litter categories (plastic, cloth/textile, paper /cardboard, wood, and metal) were identified at surveyed area. The most abundant litter sub-categories were cigarette butts and filters (n = 136, 58.11% of total debris), followed by plastic pieces 2.5 > < 50 cm (n = 10, 4.27% of total debris), and other paper items, (n = 9, 3.84%). Only 12 items were not plastic litter and were represented by cloth/textile (n = 3), paper/ cardboard (n = 7), wood (n = 1), metal (n = 1). Unidentified items were also present (n = 25, 10.68%) (Table 1).

Table 1. Results from drone-survey at Sulina beach: abundance (number of items) and relative percentage (%) of the marine litter categories identified.

Marine litter categories	Abundance (*n*)	Proportion (%)
PLASTIC		
Shopping Bags incl. pieces	8	3.41
Drink bottles $\leq$ 0.5 l	1	0.42
Plastic caps/lids drinks	5	2.13
Cigarette butts and filters	136	58.11
Crisps packets/sweets wrappers	8	3.41
Cups and cup lids	3	1.28
Straws and stirrers	8	3.413
Rope (diameter more> < than 1 cm)	4	1.70
Plastic pieces 2.5 > < 50 cm	10	4.27
Plastic pieces > 50 cm	5	2.13
CLOTH/TEXTILE		
Clothing / rags (clothing, hats, towels)	1	0.42
Rope, string and nets	1	0.42
Other textiles (incl. rags)	1	0.425
PAPER /CARDBOARD		
Cardboard (boxes & fragments)	1	0.42
Cigarette packets	1	0.42

Marine litter categories	Abundance (*n*)	Proportion (%)
Cups, food trays, food wrappers, drink containers	2	0.85
Paper fragments	3	1.28
Other paper items	9	3.84
WOOD (PROCESSED/WORKED)		
Ice-cream sticks, chip forks, chopsticks & toothpicks	1	0.42
METAL		
Other metal pieces > 50 cm	1	0.42
UNIDENTIFIED ITEMS	25	10.68

At Câșla Vădanei beach, a surface of approximately 1400 m^2 was inspected during a 50-min flight. The manual screening of the aerial pictures reported an amount of 104 litter items, with an average density of 0.07 items/m^2. Five main litter categories (plastic, cloth/textile, paper /cardboard, wood, and metal) were identified at surveyed area. The most abundant sub-categories were plastic pieces 2.5 > < 50 cm (*n* = 22, 21.15% of total debris), followed by drink bottles > 0.5 l (n = 17, 16.34% of total debris), and drink bottles < 0.5 l, (*n* = 14, 13.46%). Only 10 items were not of plastic material and were represented by paper/ cardboard (*n* = 3), wood (*n* = 1), metal (*n* = 4) and glass (*n* = 2). Unidentified items were also present (*n* = 22, 21.15%) (Table 2).

Table 2. Results from drone-survey at Câșla Vădanei beach: abundance (number of items) and relative percentage (%) of the marine litter categories identified.

Marine litter categories	Abundance (*n*)	Proportion (%)
PLASTIC		
Small plastic bags, e.g. freezer bags including pieces	4	3.84
Drink bottles < 0.5l	14	13.46
Drink bottles > 0.5l	17	16.34
Food containers incl. fast food containers	2	1.92
Plastic caps/lids drinks	6	5.76
Crisps packets/sweets wrappers	1	0.96
Cups and cup lids	1	0.96
Plastic pieces 2.5 > < 50 cm	22	21.15
Medical/Pharmaceuticals containers/tubes	2	1.92
Flip-flops	3	2.88
PAPER /CARDBOARD		
Cartons/Tetra pak (others)	1	0.96
Paper fragments	2	1.92
WOOD (PROCESSED/WORKED)		
Processed timber	1	0.96
METAL		
Aerosol/Spray cans industry	2	1.92
Cans (beverage)	1	0.96
Bottle caps, lids & pull tabs	1	0.96
GLASS		
Bottles including pieces	2	1.92
UNIDENTIFIED ITEMS	**22**	**21.15**

For a comparison with its time-efficiency, for each beach, the survey was initially conducted by drone-inspection followed by visual census on the same surface [27].

The items classification obtained from the two approaches is shown in Figure 4. At Sulina beach, 227 litter items were found through visual census, whereas manual screening of the UAV pictures identified 234 litter items for the same site. For Câșla Vădanei beach, the ground assessment allowed the detection of 148 litter items, while the litter identified from 10 m altitude pictures totaled only 104 items.

As seen in Figure 4, at Sulina beach, the identified plastic items have a greater number then the one from Câșla Vădanei. This is because, being touristic, on Sulina beach cigarette butts where more abundant. Even so, when comparing the UAV survey with the visual survey, the plastic item number is larger. This fact is due to the error occurred because of the similarities in shape and color with the shells, which makes it harder to identify one from the other.

Detection probability varied between size-category of items. Thus, the probability of detection was above 100% in case of Sulina survey possibly due to the high percent of unidentified items that were found by manual screening of the UAV pictures (Figure 5). At Câșla Vădanei beach, the detection of probability was 70.94% and this can be explained by the different capabilities of the two methods to detect smaller items (e.g. plastic pieces of 2.5 cm which were abundant in this survey area). Removal of these small items (< 4 cm) as well as of the unidentified items, led to detection probability of 100%.

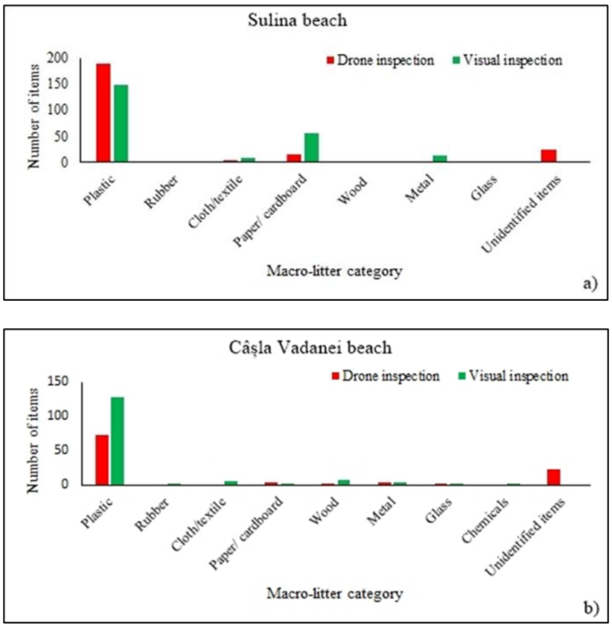

Figure 4. Comparison of data acquired through the two study methods on Sulina (a) and Câşla Vădanei (b) areas.

Figure 5. Example of aerial images of marine litter obtained by means of the DJI Phantom Professional quadcopter during the aerial survey of Sulina and Casla Vadanei beach (*Original Photo: NIMRD Constanta, Romania)*

UAV beach litter inspection limitations have been previously reported by Escobar- Sanches [14], when it was observed that bright unnatural colored and/or shaped litter items (> 2.5 cm) where easier to identify than (< 2.5 cm) white, black, brown, or transparent ones during visual screening of UAV captured images.

The opposite of this limitation, namely the overestimation of the number and type of the litter items, can also happen when there is a high variability of similar items within the same category, objects are partially covered by sand, due to a low contrast with the surroundings or the presence of shadows casted by the vegetation [10]. However, it is commonly believed that these current limitations will reduce over time with the rapid technological advances and the development of improved items recognition algorithms [30].

Besides the limitations of these methods, there are a couple of advantages that were observed in the field work. Using this method, the time that it would normally take for a team of researchers to carry out the sampling can be substantially reduced, and the survey can be completed by only one person. Large areas can be surveyed for the time normally needed for only one beach, but one of the most important advantage is, that in comparison with the traditional survey, through the UAV method, a litter distribution map can be generated [31], along with identifying accumulation areas and hotspots [32, 33].

On both surveyed beaches, the plastic items category was the majority, in compliance with other similar studies carried out in the coastal Black Sea region [34-37] and worldwide [38-40]. Rivers are major sources of plastic pollution in the ocean, accounting for almost 80% of global annual emissions [41] and an input of 1.15-2.41 million tons of plastic each year [42]. The Danube River is no exception, with an input estimated at 1533 t of plastic litter per day [26].

A study carried out on 10 rivers that flow into the Black Sea, including the Danube, revealed plastic items to be predominantly (83.7%), with cover/ packaging, plastic bottles, bags, and other plastic/ polystyrene items being in top 10 most encountered types of floating litter [43], as observed in our present study results, highlighting Danube's River influence as a major potential source of beach litter.

Plastics are the ideal manufacturing materials nowadays, but many of their advantages such as durability and lightness also make them one of the most challenging types of recalcitrant materials once they get into the marine environment [44]. Polyethylene (PE), polypropylene (PP) and polystyrene (PS), polyvinyl chloride (PVC), high-density polyethylene (HDPE), low-density polyethylene (LDPE) and polyethylene terephthalate (PET) are the most encountered types of polymers in the aquatic environment [45-47] having negative impact on both biota and the environment [48].

4. Conclusions

Our pilot study has provided first-hand evidence of the macro-litter presence in the beach sediments of the Romanian coast of the Black Sea area influenced by the Danube River.

The visual monitoring data on the beached litter at the Danube River mouth (Sulina branch) showed a clear predominance of plastic (up to 95% of the total items), thus confirming the previous findings concerning the major input of plastic into the Black Sea via the Danube.

During our study, we successfully tested a more efficient method to assess marine beach litter loads involving the use of an Unmanned Aerial Vehicle (UAV) to record marine litter through image acquisition. Comparison of the acquired data from the two monitoring methods (drone-inspection versus visual census) showed that that UAV marine monitoring could be a more suitable approach for marine litter monitoring in the selected Black Sea areas in term of time-efficiency. However, the variation of detection probability we found during our pilot survey requires improvement of the aerial photo resolution taken by drone, particularly for the small litter items such as cigarette butts and filters.

Conflict of interest

Authors declare no conflict of interest.

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