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Use of unmanned aerial vehicles for efficient beach litter monitoring

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A B S T R A C T

A global beach litter assessment is challenged by use of low-efficiency methodologies and incomparable protocols that impede data integration and acquisition at a national scale. The implementation of an objective, reproducible and efficient approach is therefore required. Here we show the application of a remote sensing based methodology using a test beach located on the Saudi Arabian Red Sea coastline. Litter was recorded via image acquisition from an Unmanned Aerial Vehicle, while an automatic processing of the high volume of imagery was developed through machine learning, employed for debris detection and classification in three categories. Application of the method resulted in an almost 40 times faster beach coverage when compared to a standard visual-census approach. While the machine learning tool faced some challenges in correctly detecting objects of interest, first classification results are promising and motivate efforts to further develop the technique and implement it at much larger scales.

1. Introduction

Marine litter is defined as any persistent, manufactured or processed solid material discarded, disposed of, abandoned or lost in the marine and coastal environment (UNEP, 2005). Estimates report that 60–80% of macro-marine litter and up to 100% of all buoyant debris are derived from plastic (Derraik, 2002; Galgani et al., 2015), although these represent only 16% of the worldwide municipal waste (Muenmee et al., 2015). The reason for its prevalence is its light weight, buoyancy and durability, which make it easily transported by winds and currents and persistent in the ocean.

Recent evidence that marine plastic pollution is a ubiquitous and everlasting threat impacting on marine life (Wang et al., 2016; Galloway et al., 2017) has raised public awareness mainly in the last decade. Consequently, research efforts have been catalyzed to quantify loads of plastic in the marine environment and help inform on possible mitigating measures (Cressey, 2016; Xanthos and Walker, 2017). The importance of resolving the mass balance and fate of marine plastic has also been highlighted by the finding that the global stocks of floating plastic represent only a minor proportion of all plastic ever discarded (Cozar et al., 2014; Eriksen et al., 2014; Jambeck et al., 2015; Van Sebille et al., 2015). The burning question is where the larger stock of plastic entering the ocean is to be found. Four major sinks of plastic debris have been identified worldwide: fragmentation (Cozar et al., 2014; Andrady et al., 2005; Andrady, 2011; Webb et al., 2013), ingestion by marine life (Ryan, 2016), sedimentation (Van Cauwenberghe et al., 2015) and shore deposition (Galgani et al., 2015; Wang et al., 2016; Barnes et al., 2009; Browne et al., 2011). Potentially, any coast or beach in the world could be reached by a floating item (Ebbesmeyer et al., 2007). Therefore, marine debris (mainly plastic (Thiel et al., 2013)), is found on shores regardless of their remoteness and proximity to human settlements (Derraik, 2002; UNEP, 2009; Haynes, 1997; Convey et al., 2002; Lavers and Bond, 2017). Moreover, beach litter is of particular concern because of the risk it represents for the environment, health, society and the economy (NOAA and UNEP, 2011).

Beach litter may represent a terminal phase of oceanic transport or may represent a transient storage, with some deposits washed again to sea following severe storms (Browne et al., 2011; Ramachandran et al., 2005; Shimizu et al., 2008). In any case, beach cast litter constitutes an important stock, which needs to be accounted for when attempting mass balances of plastic entering the marine environment. Whereas progress has been made in estimating both global input rates (Jambeck et al., 2015) and global stocks and distribution of floating plastic (Cozar et al., 2014; Eriksen et al., 2014; Van Sebille et al., 2015), estimates of the abundance and distribution of beach litter stocks, although numerous, are typically pursued on local or regional scales only (e.g.

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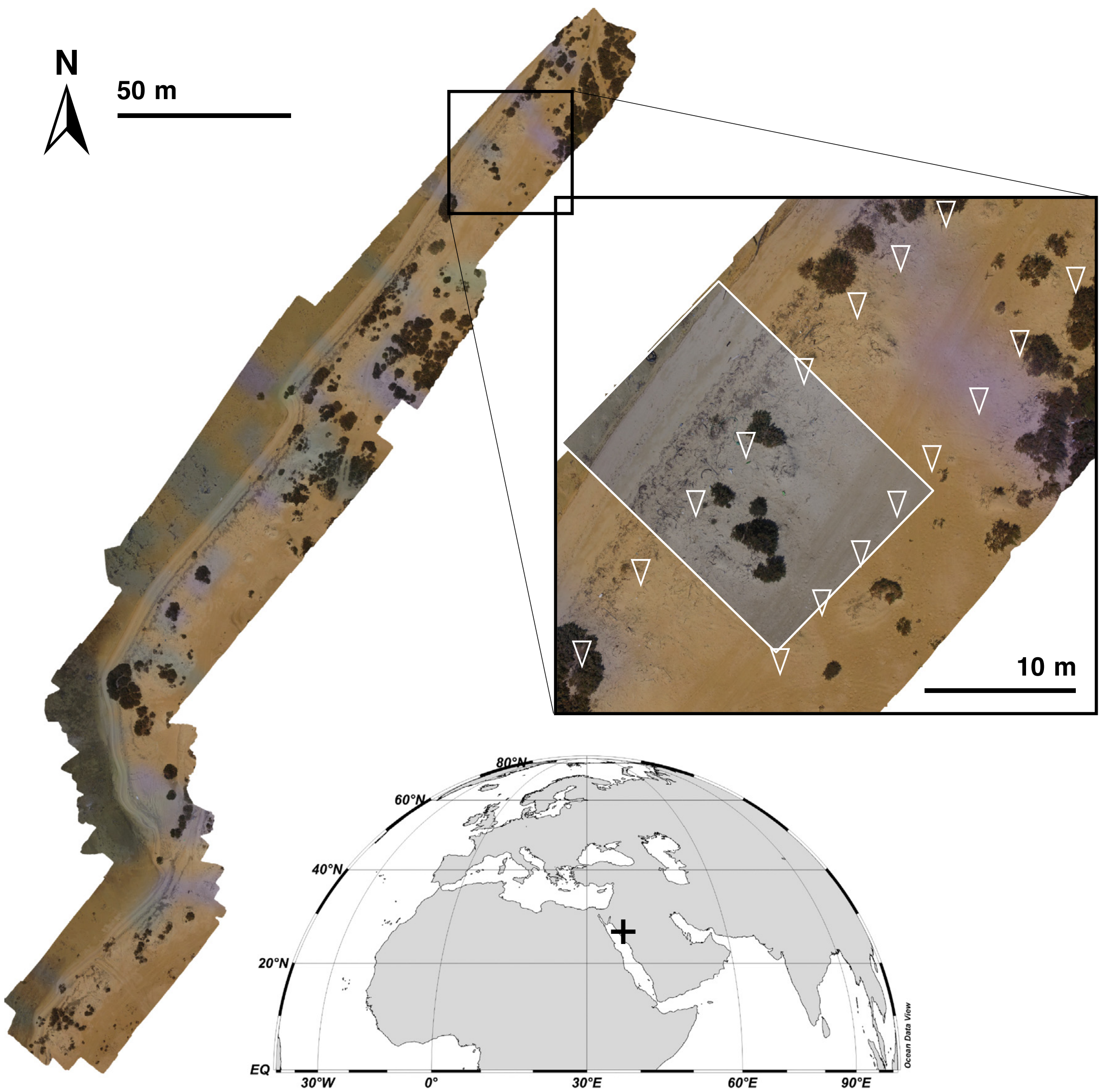

Fig. 1. Study site. Geographic location of the test beach (black cross on the world map) and area surveyed with the UAV, represented in this figure by the orthomosaic obtained merging 243 aerial pictures. The orthomosaic close-up shows (with white marks) the distribution of 16 aerial pictures, like the one framed in white. A .kmz file of the orthomosaic is also provided.

(Lavers and Bond, 2017; Moore et al., 2001; Claereboudt, 2004; Martinez-ribes et al., 2007; Bravo et al., 2009; Lee et al., 2013; Andrades et al., 2016; Hengstmann et al., 2017; Watts et al., 2017; Laglbauer et al., 2014) see also Table 2.1 in (Galgani et al., 2015)) and are therefore insufficient to attempt a global inventory. In addition, despite the availability of guidelines to monitor beach litter (e.g. AMDS, NMDMP, NOWPAP and OSPAR guidelines; (OSPAR, 2010; Cheshire et al., 2009; Ryan et al., 2009; Schulz et al., 2017)), protocols differ, making comparison and integration of data challenging (Galgani et al., 2015). Most importantly, assessment of beach litter is time consuming (Nelms et al., 2017). Traditional beach monitoring relies on visual census methods, where plastic items are recorded along transects. According to OSPAR, 2010 recommendations, plastic should be counted between the end of the beach and the water's edge along 100 m transects (1000 m for items larger than 50 cm). Litter items larger than 2.5 cm are collected, separated in classes and quantitatively measured. The whole process generally requires 2–5 trained persons and ideally should take < 3 h per assessment (Laglbauer et al., 2014; OSPAR, 2010). Detection ability varies depending on the observer's skills, adding discrepancies to surveys carried out by different people (Lavers et al., 2016). Hence, visual censuses are subjective, time and labor consuming, and the area covered is in most cases only a sub-sample of the targeted beach. The median area surveyed across a number of studies (Lavers and Bond, 2017; Martinez-ribes et al., 2007; Bravo et al., 2009; Hengstmann et al., 2017; Watts et al., 2017; Nelms et al., 2017; Abdo et al., 2011; Abu-hilal, 2004) was 1.162 ha, ranging from 0.131 to 15.915 ha. Therefore, efficient acquisition of estimates of beach litter remains a major bottle neck to produce the data necessary to assess global distribution patterns, stocks, and contribution to regional and global marine litter mass balances.

Here we develop 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. We also provide evidence that processing of the higher throughput of images delivered by the UAV's, which might also represent a bottle neck in terms of observer time, can be greatly reduced by developing machine learning tools aimed at quantifying and categorizing beach litter. Most importantly, this approach requires only one trained person and allows a total coverage of the beach in a few minutes.

UAVs, because of their high-resolution and their relatively low cost, are becoming useful and widespread tools supporting environmental and wildlife surveys (Bhardwaj et al., 2016; Cunliffe et al., 2016; Jones