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A low-cost drone based application for identifying and mapping of coastal fish nursery grounds

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ABSTRACT

Acquiring seabed, landform or other topographic data in the field of marine ecology has a pivotal role in defining and mapping key marine habitats. However, accessibility for this kind of data with a high level of detail for very shallow and inaccessible marine habitats has been often challenging, time consuming. Spatial and temporal coverage often has to be compromised to make more cost effective the monitoring routine. Nowadays, emerging technologies, can overcome many of these constraints. Here we describe a recent development in remote sensing based on a small unmanned drone (UAVs) that produce very fine scale maps of fish nursery areas. This technology is simple to use, inexpensive, and timely in producing aerial photographs of marine areas. Both technical details regarding aerial photos acquisition (drone and camera settings) and post processing workflow (3D model generation with Structure From Motion algorithm and photo-stitching) are given. Finally by applying modern algorithm of semi-automatic image analysis and classification (Maximum Likelihood, ECHO and Object-based Image Analysis) we compared the results of three thematic maps of nursery area for juvenile sparid fishes, highlighting the potential of this method in mapping and monitoring coastal marine habitats.

1. Introduction

Over the past decade, there has been an increasing interest in tools for environmental monitoring aimed at a variety of purposes including the conservation of fish habitats. In this framework a key issue is the identification and characterization of fish nursery grounds (Beck et al., 2001; Stoner, 2003; Sheaves et al., 2006; Martinho et al., 2007). The presence of suitable habitats becomes essential during the settlement of juvenile stages, as these habitats are the key to success for the conclusion of early life phases, providing shelter from predators and abundance of trophic resources. As a result of this site-attachment, juveniles exhibit systematic patterns of distribution, influenced by the availability of microhabitats, from the onset of settlement to recruitment to the adult population. Habitats identification has been carried out focusing on their fine description, aiming at highlighting the association with specific substrata type (Harmelin-Vivien et al., 1995; Vigliola et al., 1998; Garcìa-Rubies and Macpherson, 1995; Macpherson, 1998; Adams et al., 2004; Ventura et al., 2015). This goal is generally achieved by human underwater visual censuses (UVC) (Harmelin-Vivien et al., 1985; Watson and Quinn, 1997; Samoilys and Carlos, 2000). The latter has been considerably improved in recent years with visual underwater video technologies. For instance baited remote underwater stereo-video (stereo-BRUV) stations (Watson et al., 2005; Cappo et al., 2006; Lowry et al., 2012), diver operated stereo-video (stereo-DOV) systems (Harvey et al., 2002; Langlois et al., 2010), and rotating video apparatus (Pelletier et al., 2012). However, these studies require a deep knowledge of the environment in addition to considerable efforts in terms of time and experienced staff. Any technique involving only the direct human intervention has several limitations. For instance the extent of coastline that SCUBA operators can explore each time is often limited, this may lead to a partial identification of habitats, especially in areas with a high morphological heterogeneity. Moreover it is not always easy to maneuver for a diver in very shallow rocky areas, and even more difficult for a boat with remote apparatus for seabed mapping (e.g. Multibeam, Side scan sonar) leading to incomplete monitoring of these zones. This becomes

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very important when the interest is in the identification and cartographic representation of juvenile nursery grounds of coastal species, such as sparid fishes. In fact, the latter inhabit very shallow rocky areas (<5 m in depth). In addition, it should be noted that modern UVC techniques still require high application costs and do not provide fully satisfactory data for the identification of nursery grounds on a large spatial scale especially when one considers the ever-increasing need for the integration of point monitoring data into geographic information systems (Franklin et al., 2003; Brown et al., 2011). Hence, it seems necessary to develop a semi-autonomous and low-cost method of remote acquisition, aimed to improve classical visual census techniques; at least with regard to identification and description of coastal inshore habitats where juvenile life-stages occur.

In recent years satellite-based remote sensing images are extensively used in terrestrial studies on environmental dynamics for mapping and monitoring land use changes (Yang and Lo, 2002; Muller and Zeller, 2002; Cardille and Foley, 2003), animal behavior (Fiedler and Bernard, 1987; Coyne and Godley, 2005; Kawamura et al., 2005), riparian and forest ecosystem (Johansen and Phinn, 2006; Johansen et al., 2007), invasive species (Laba et al., 2008), upwelling system (Cole, 1999) and oil spill events (Brekke and Solberg, 2005). Remote sensing technology has proved to be highly effective in acquiring data for coastal environment monitoring and management (Ramachandran et al., 1998, 2000; Dahdouh-Guebas, 2002). However, remote sensing imagery with high spatial resolution data (<4 m/pixel) can be prohibitively costly (e.g. QuickBird, IKONOS) and might not be easily accessible to the entire scientific community (i.e. in several developing-countries) due to financial constraints.

Here we describe for the first time a low-cost and partially human independent census technique that combines the use of an unmanned aerial vehicle platform (i.e. a small and low cost quadcopter) and specific human interventions to identify areas of interest in unexplored regions. We build the method to provide a way to acquire very fine spatial resolution imagery to map marine fish nursery areas. Small unmanned aerial platforms are increasingly used for very different applications: assessment and monitoring of biodiversity in tropical forests (Getzin et al., 2012; Koh and Wich, 2012; Vermeulen et al., 2013), gathering information on stream and riparian restoration projects (Quilter and Anderson, 2000), wildlife surveys against illegal activities such as timber extraction and poaching (Paneque-Gálvez et al., 2014), monitoring of crop health and mine surveys (Watts et al., 2012).

Considering that one of the most relevant reasons for aerial photo acquisition is the objective visual representation of the sampled area, we report the workflow adopted to produce the thematic map of the site of interest. The latter includes automatic classification algorithms of habitat patches. Manual digitization of patches is not only extremely time-consuming but can also lead to unreliable results being partially subjective (Ierodiaconou et al., 2007; Micallef et al., 2012). However it is challenging to achieve an accurate automatic classification (Rozenstein and Karnieli, 2011), then we discuss the use of several modern techniques applied to automated image classification in order to define a protocol for rapid and cost-effective analysis of coastal fish nursery areas.

2. Materials and methods

2.1. Study area

This study was conducted on about 2.6 km of coastline located in Giglio Island (42°20 N-11°540 E/42°20 N-11°540 E) in the Central Mediterranean Sea (Tyrrhenian Sea, Fig. 1). This stretch of coast was highly heterogeneous, with alternating rocky promontories and cliffs, pebbly coves, presence of man-made structures and beaches. This environmental variability with protected and unprotected areas (i.e. exposure to wave action and wind) was considered a good starting point to ensure the presence of juveniles according to results found in previous studies on *Diplodus* spp. (Harmelin-Vivien et al., 1995; Macpherson, 1998; Vigliola et al., 1998; Cheminee et al., 2011). Furthermore, the whole Island presented very clear water during most of the year that was a key feature to ensure a good result during aerial photo acquisition of seabed. A preliminary survey was carried out in October and November 2014, by one single observer snorkeling along the entire shoreline, highlighting the presence of suitable grounds for settlement (e.g. pebbly-sandy areas with the presence of photophilic algae). This first survey led us to define a cove (S1, Fig. 1), as a potential nursery site. This hypothesis was confirmed by a subsequent study on the recruitment of juvenile *Diplodus* species and shoal displacements (Ventura et al. *in progress*).

2.2. Aerial photo acquisition (aerial platform and camera)

Since S1 site showed the presence of four *Diplodus* species (*D. puntazzo, D. sargus, D. annularis and D. vulgaris*), we carried out an extensive-fine scale mapping. For this goal we used a home-made prototype quadcopter drone. This model was inexpensive (<$100), lightweight (~550 g) and equipped with an autopilot system based on the 'ArduPilot Mega' (APM). The APM includes a geographic positioning system (GPS), data logger, pressure and temperature sensor, airspeed sensor, triple-axis gyro, and accelerometer (Fig. 2a). The APM system in combination with an open-source software (APM Planner), developed by the same online community (diydrones.com) of APM, has allowed us to define an autonomous grid flight plan in order to map the whole nursery area (Fig. 2b), making the drones an effective AUS (Unmanned Aircraft system). In addition we equipped the drone with two low-cost action cameras: 1) an HD camera (Mobius) with a video signal transmitter that allowed us a direct visual monitoring (i.e. First Person View or FPV) during acquisition and 2) a full-HD camera (GoPro Hero 3 Black Edition) in order to perform the acquisition. The GoPro camera specifications were reported in Table 1a–b. The camera was attached to the underside of the drone pointing at 90° downwards; without protective case but with a shockproof support constituted by four pins made of rubber foam, to reduce vibration and motion blur effects. We tested two configuration of settings involving photo and video capture modes. First we used the time lapse mode that allowed to capture a series of photos at different time intervals (0.5, 1, 2, 5, 10, 30 and 60 s). Considering that GoPro Hero 3 Black produced in Medium FOV a 7 Megapixel format (3000 × 2250 pixels) images, the pixel size was 1.55 μm, the focal length was 2.77 mm and we flew at constant height of 18 m; we applied the following formula to get a resolution of 1.01 cm per pixel.

$$GSD = Px_s \times Fh/FL$$

Where GSD was the ground sample distance in meters (i.e. photo resolution on the ground), Px_s was the pixel size (in mm), Fh was the flight height (in m) and FL was the focal length (in mm) of the camera. The photo footprint on the ground was 30.3 m (3000 × 1.01) by 22.7 m (2250 × 1.01) then we oriented the camera so that the 22.7 m axis was parallel to in-track (i.e. overlap between each photos along the transects) and 30.3 m axis along the cross-track direction (i.e. the overlap between consecutive transects). We opted for 75% in-track overlap then we set the flying speed at 6 m/sec with the APM system so overlap in-track meant that we