Chapter 8

Unmanned Aerial Systems (UASs) for Environmental Monitoring: A Review with Applications in Coastal Habitats

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Additional information is available at the end of the chapter

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Abstract

Nowadays the proliferation of small unmanned aerial systems or vehicles (UAS/Vs), formerly known as drones, coupled with an increasing interest in tools for environmental monitoring, have led to an exponential use of these unmanned aerial platforms for many applications in the most diverse fields of science. In particular, ecologists require data collected at appropriate spatial and temporal resolutions to describe ecological processes. For these reasons, we are witnessing the proliferation of UAV-based remote sensing techniques because they provide new perspectives on ecological phenomena that would otherwise be difficult to study. Therefore, we propose a brief review regarding the emerging applications of low-cost aerial platforms in the field of environmental sciences such as assessment of vegetation dynamics and forests biodiversity, wildlife research and management, map changes in freshwater marshes, river habitat mapping, and conservation and monitoring programs. In addition, we describe two applications of habitat mapping from UAS-based imagery, along the Central Mediterranean coasts, as study cases: (1) The upper limit of a *Posidonia oceanica* meadow was mapped to detect impacted areas, (2) high-resolution orthomosaic was used for supporting underwater visual census data in order to visualize juvenile fish densities and microhabitat use in four shallow coastal nurseries.

Keywords: UAVs, UASs, drones, environmental monitoring, coastal habitats, mapping, aerial photography, photogrammetry, image classification, remote sensing, *Posidonia oceanica*, *Diplodus sargus*, juvenile sparid fish, Mediterranean Sea, Giglio Island

1. Introduction

Mankind has always been fascinated by the dream of flight, in fact in many ancient cultures, myths and legends depicted deities with the extraordinary ability to fly like birds. It should be sufficient to recall the Egyptian winged goddess Isis or the Greek myth of Icarus; even Christian iconography preserves and recovers the figures of winged beings as intermediaries between man and God, reinterpreting them as angels. From those ancient times, passing through the Renaissance intuitions of Leonardo Da Vinci, to the first balloon flights of the Montgolfier brothers in 1783, we came to the early twentieth century which witnessed the first sustained and controlled flight of a powered, heavier-than-air machine with a pilot aboard. Just over a hundred of years have passed since that fateful day—December 17, 1903, that is since the Wright Flyer took off near Kill Devil Hills, about four miles south of Kitty Hawk, North Carolina, USA. Nowadays the beauty of flying characterizes our daily lives, becoming an indispensable tool to move people and things in few hours in all parts of the world. We can state that the ability of flight has strongly changed the perspective on our vision of the world.

Long before this first powered flight of Wright brothers, one of the first recorded usages of unmanned aircraft systems (UAS) was by Austrians on August 22, 1849. They launched 200 pilotless balloons, carrying 33 pounds of explosives and armed with half-hour time fuses, against the city of Venice. On May 6, 1896, Samuel P. Langley's Aërodrome No. 5, a steam-powered pilotless model was flown successfully along the Potomac River near Washington. During World War I and World War II, radio-controlled aircrafts were used extensively for aerial surveillance, for training antiaircraft gunners, and they also served as aerial torpedoes (e.g. in 1917, the Hewitt Sperry Automated Airplane, developed by Elmer Sperry, was the early version of today's aerial torpedo). During Cold War, the drone was seen as a viable surveillance platform able to capture intelligence in denied areas. Reconnaissance UASs were first deployed on a large scale in the Vietnam War. By the dawn of the twenty-first century, unmanned aircraft systems were used more and more frequently for a variety of missions especially since the war on terror, becoming a lethal hunter-killer. Due to these historical aspects the public perception of most of the UAV applications is still mainly associated with military use, but nowadays the drone concept is refashioned as a new promise for citizen-led applications having several functions, ranging from monitoring climate change to carrying out search operations after natural disasters, photography, filming, and ecological research.

The interpretation of photos from airborne and satellite-based imagery has become one of the most popular tools for mapping vast surfaces, playing a pivotal role in habitat mapping, measuring, and counting performed in ecological research, as well as to perform environmental monitoring concerning land-use change [1]. However, both satellite and airborne imagery techniques have some disadvantages. For example, the limitations of piloted aircrafts must be considered in regard to their reliance on weather conditions, flight altitude, and speed that can affect the possibility to use such method [1]. In addition, satellite high-resolution data might not be accessible for many developing-country

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researchers due to financial constraints. Furthermore, some areas such as humid biotopes and tropic coasts are often obscured by a persistent cloud cover, mostly making cloud-free satellite images unavailable for a specific time period and location; moreover the temporal resolution is limited by the availability of aircraft platforms and orbit characteristics of satellites [2]. In addition, the highest spatial resolution data, available from satellites and manned aircraft, is typically in the range of 30–50 cm/pixel. Indeed, for the purpose of monitoring highly dynamic and heterogeneous environments, or for real-time monitoring of land-use change in sensitive habitats, satellite sensors are often limited due to unfavorable revisit times (e.g. 18 days for Landsat) and spatial resolution (e.g. Landsat and Modis ~30 m/pixel) [3]. To address these limitations, new satellite sensors (Quickbird, Pleiades-1A, IKONOS, GeoEye-1, WorldView-3) have become operational over the past decade, offering data at finer than 10-m spatial resolution. Such data can be used for ecological studies, but hurdles such as high cost per scene, temporal coverage, and cloud contamination remain [4].

Emerging from a military background, there is now a proliferation of small civilian unmanned aerial systems or vehicles (UAS/Vs), formerly known as drones. Modern technological advances such as long-range transmitters, increasingly miniaturized components for navigation and positioning, and enhanced imaging sensors have led to an upsurge in the availability of unmanned aerial platforms both for recreational and professional uses. These emerging technologies may provide unprecedented scientific application in the most diverse fields of science. In particular, UAVs offer ecologists a new way to responsive, timely, and cost-effective monitoring of environmental phenomena, allowing the study of individual organisms and their spatiotemporal dynamics at close range [4].

Two main categories of unmanned aerial vehicles (UAVs) exist: rotor-based copter systems and fixed-wing platforms. Rotor-wing units have hovering and VTOL (Vertical Take-Off and Landing) capabilities, while fixed-wing units tend to have longer flight durations and range. However, a more detailed classification can be made according to size, operating range, operational flight altitude, and duration (**Table 1**). For additional information regarding the classification of UAVs, please refer to Refs. [4–6].

Size	Nomenclature	Specifics	Operational requirements	Application areas	Examples
Very large (3–8 tons)	HALE (High Altitude, Long Endurance)	Fly at the highest altitude (> 20 Km) with huge operating range that extend thousands of km, long flight time (over 2 days), very heavy payload capacity (more than 900 kg in under-wing pods)	Prohibitively expensive for most users (high maintenance, sensors, crew training costs), long runway for takeoff and landing, ground-station support, and continuous air-traffic control issues, challenging deployment/recovery and transport	Assessments of climate variable impacts at global scales, remote sensing collection, and earth/ atmospheric science investigations	Global Hawk, Qinetiq Zephyr, NASA PathFinder

Size	Nomenclature	Specifics	Operational requirements	Application areas	Examples
Large (1–3 tons)	MALE (Medium Altitude, Long Endurance)	Medium altitude (3–9 Km), over 12 h flight time with broad operating range (> 500 km), heavy payload capacity (~100 kg internally, external loads of 45 up to 900 kg)	Similar requirements as for HALE but with reduced overall costs	Near-real-time wildfire mapping and surveillance, investigation of storm electrical activity and storm morphology, remote sensing and atmospheric sampling, arctic surveys, atmospheric composition and chemistry	NASA Altus II, NASA Altair, NASA Ikhana, MQ-9 Reaper (Predator B), Heron 2, NASA SIERRA
Medium (25–150 kg)	LALE (Low Altitude, Long Endurance), LASE (Low Altitude, Short Endurance)	Fly at moderate altitude (1–3 Km) with operating ranges that extend from 5 to 150 km), flight time (over 10 hours), moderate payload capacity (10–50 kg)	Reduced costs and requirements for takeoff and landing compared to MALE (hand-launched platforms and catapult-launch platforms), simplified ground-control stations	Remote sensing, mapping, surveillance and security, land cover characterization, agriculture and ecosystem assessment, disaster response and assessment	ScanEagle, Heron 1, RQ-11 Raven, RQ-2 Pionee, RQ-14 Dragon Eye, NASA J-FLiC, Arcturus T-20
Small, mini, and nano (Less than 25 kg for small AUVs, up to 5 Kg for mini and less than 5 Kg for nano)	MAV (Micro) or NAV (Nano) Air Vehicles	Fly at low altitude (< 300 m), with short duration of flight (5–30 min) and range (< 10 Km), small payload capacity (< 5 kg)	Low costs and minimal take off/ landing requirements (Hand-launched), often are accompanied by ground-control stations consisting of laptop computers, flown by flight planning software or by direct RC (Visual Line Of Sight or Beyond Visual Line Of Sight when allowed), usually fixed-wing (small AUVs) and copter-type (mini and nano AUVs)	Aerial photography and video, remote sensing, vegetation dynamics, disaster response and assessment, precision agriculture, forestry monitoring, geophysical surveying, photogrammetry, archeological research, environmental monitoring	AR-Parrot, BAT-3, SenseFly eBee, DJI Inspire 3, DJI Phantom 4, Draganflyer X6, Walkera Voyager 4

Table 1. Summary of f UAVs' classes with examples.

In this brief review and in our case studies, we only discuss and illustrate the use of small and mini UAVs because these portable and cost-effective platforms have shown a great potential to deliver high-quality spatial data to a range of science end users.

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2. Some recent ecological applications of lightweight UASs

Although lightweight UASs represent only a small fraction of the full list of unmanned systems capable of performing the so-called "three Ds" (i.e. dull, dirty, or dangerous missions), they have been used in a broad range of ecological studies.

2.1. Forest monitoring and vegetation dynamics

Tropical forests play a critical role in the global carbon cycle and harbor around two-thirds of all known species [7]. Tropical deforestation is a major contributor to biodiversity loss, so an urgent challenge for conservationists is to be able to accurately assess and monitor changes in forests, including near real-time mapping of land cover, monitoring of illegal forest activities, and surveying species distributions and population dynamics [2].

Koh and Wich [2] provided with a simple RC fixed-wing UAV (Hobbyking Bixler 2) helpful data for the monitoring of tropical forests of Gunung Leuser National Park in Sumatra, Indonesia. In fact, the acquired images allowed the detection of different land uses, including oil palm plantations, maize fields, logged areas, and forest trails.

UAVs have also been used for the successful monitoring of streams and riparian restoration projects in inaccessible areas on Chalk Creek near Coalville (Utah), as well as to perform nondestructive, nonobtrusive sampling of Dwarf bear claw poppy (*Arctomecon humilis*), a short-lived perennial herb of crust community which is very sensitive to off-road vehicle (ORV) traffic [8]. A fixed-wing (eBee, senseFly) and a quadcopter (Phantom 2 Vision+, DJI) were used [9] to acquire high-spatial resolution photos of an impounded freshwater marsh, demonstrating that UAVs can provide a time-sensitive, flexible, and affordable option to capture dynamic seasonal changes in wetlands, in order to collect effective data for determining percent cover of floating and emergent vegetation.

Dryland ecosystems provide ecosystem services (e.g. food, but also water and biofuel) that directly support 2.4 billion people, covering 40% of the terrestrial area, they characteristically have distinct vegetation structures that are strongly linked to their function [10, 11]. For these reasons, Cunliffe et al. [10] acquired aerial photographs using a 3D Robotics Y6 hexacopter equipped with a global navigation satellite system (GNSS) receiver and consumer-grade digital camera (Canon S100). Later, they processed these images using structure-from-motion (SfM) photogrammetry in order to produce three-dimensional models, describing the vegetation structure of these semi-arid ecosystems. This approach yielded ultrafine ($<1\ cm^2$) spatial resolution canopy height models over landscape-levels (10 ha). This study demonstrated how ecosystem biotic structures can be efficiently characterized at cm scales to process aerial photographs captured from inexpensive lightweight UAS, providing an appreciable advance in the tools available to ecologists. Getzin et al. [12] demonstrated how fine spatial resolution photography (7-cm pixel size) of canopy gaps, acquired with the fixed-wing UAV 'Carolo P200,' can be used to assess floristic biodiversity of the forest understory. Also in riparian contexts, UAS technology provides a useful tool to quantify riparian terrain, to characterize riparian vegetation, and to identify standing dead wood and canopy mortality, as demonstrated by Dunford et al. [13].

2.2. Wildlife research

Often population ecology requires time-series and accurate spatial information regarding habitats and species distribution. UASs can provide an effective means of obtaining such kind of information. Jones et al. [14] used a 1.5-m wingspan UAV equipped with autonomous control system to capture high-quality, progressive-scan video of a number of landscapes and wildlife species (e.g. *Eudocimus albus, Alligator mississippiensis, Trichechus manatus*). Israel [15] dealt with the problem of mortally injured roe deer fawns (*Capreolus capreolus*) by mowing machinery, and demonstrated a technical sophisticated 'detection and carry away' solution to avoid these accidents. In fact, he presented a UAV-based (octocopter Falcon-8 from Ascending Technologies) remote sensing system via thermal imaging for the detection of fawns in the meadows.

Considering that in butterflies, imagoes and their larvae often demand specific and diverging microhabitat structures and resources, Habel et al. [16] took high-resolution aerial images using a DJI Phantom 2 equipped with a H4-3D Zenmuse gimbal and a lightweight digital action camera (GoPro HERO 4). These aerial pictures, coupled with the information on the larvae′s habitat preference from field observations, were used to develop a habitat suitability model to identify preferential microhabitat of two butterfly larvae inhabiting calcareous grassland.

Moreover, UAVs may offer advantages to study marine mammals, in fact Koski et al. [17] used the Insight A-20 equipped with an Alticam 400 (a camera model developed for the ScanEagle UAV) to successfully detect simulated Whale-Like targets, demonstrating the values of such methodology for performing marine ecological surveys. In a similar manner, Hodgson et al. [18] captured 6243 aerial images in Shark Bay (western Australia) with a ScanEagle UVS, equipped with a digital SLR camera, in which 627 containing dugongs, underlying that UAS systems may not be limited by sea state conditions in the same manner as sightings from manned surveys. Whitehead et al. [19] described efforts to map the annual sockeye salmon run along the Adam's River in southern British Columbia, providing an overview of salmon locations through high-resolution images acquired with a lightweight fixed-wing UAV.

3. Case studies along temperate Mediterranean coasts

Although over the past decade there has been an increasing interest in tools for ecological applications such as ultrahigh-resolution imagery acquired by small UAVs, few have been used for environmental monitoring and classification of marine coastal habitats. Indeed, in this section we outline two case studies regarding the application of a small UAV for mapping coastal habitats. These applications represent a cross section of the types of applications for which small UAVs are well-suited, especially when one considers the ecological aspect related to marine species biology and habitat monitoring. Despite the fact that there are a number of advanced sensors that have been developed and many proposed applications for small UASs, here we carried out our studies using a commercially available and low-cost camera.

As such, it can be considered a simple, inexpensive, and replicable tool that can be easily implemented in future research which could also be carried out by nonexperts in the field of UASs technologies.

For each survey we used a modified rotary-wing Platform (Quanum Nova CX-20, **Figure 1**), which included an integrated autopilot system (APM v2.5) based on the 'ArduPilot Mega' (APM, http://www.ardupilot.co.uk/), which has been developed by an online community (diydrones.com). The APM includes a computer processor, geographic positioning system module (Ublox Neo-6 Gps), data logger with an inertial measurement unit (IMU), pressure and temperature sensor, airspeed sensor, triple-axis gyro, and accelerometer (**Figure 2**). This quadcopter is relatively inexpensive (<$500) and lightweight (~1.5 Kg). The cameras used to acquire the imagery was a consumer-grade RGB, FULL-HD action camera (Gopro Hero 3 Black Edition, sensor: Complementary Metal-Oxide-Semiconductor; sensor size: 1/2.3″ (6.17 × 4.55 mm), pixel size: 1.55 μm; focal length: 2.77 mm). In addition, a brushless 3-Axis Camera Gimbal (Quanum Q-3D) was installed, to ensure a good stabilization on acquired images, avoiding motion blur. Both drone and gimbal were powered by a ZIPPY 4000 mAh (14.8 V) 4S 25C Lipo battery which allowed a maximum flying time of about 13 min or less, depending on wind. In addition, by combining the APM with the open-source mission planner software (APM Planner), the drone can perform autonomous fly paths and survey grids.

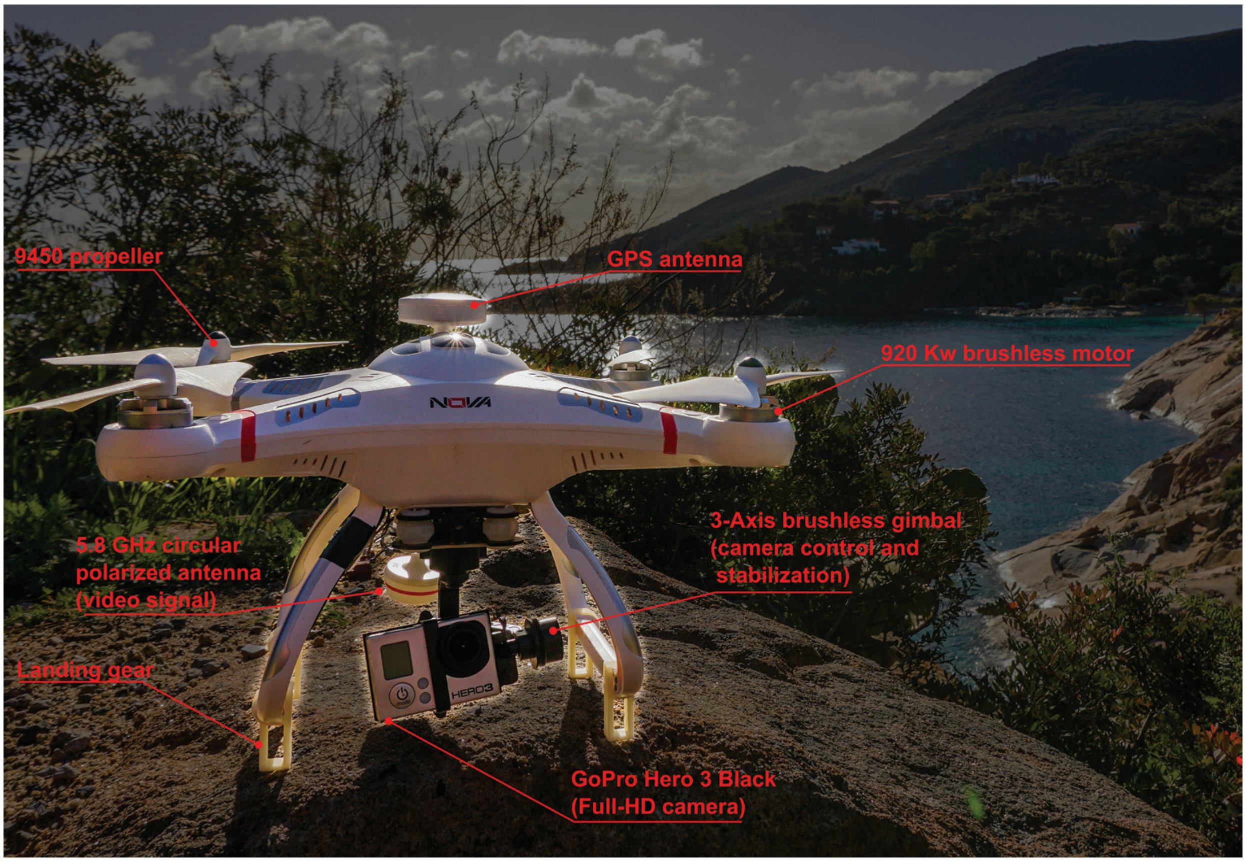

Figure 1. The Quanum Nova CX-20 Quadcopter ready to fly just before a coastal mapping mission.

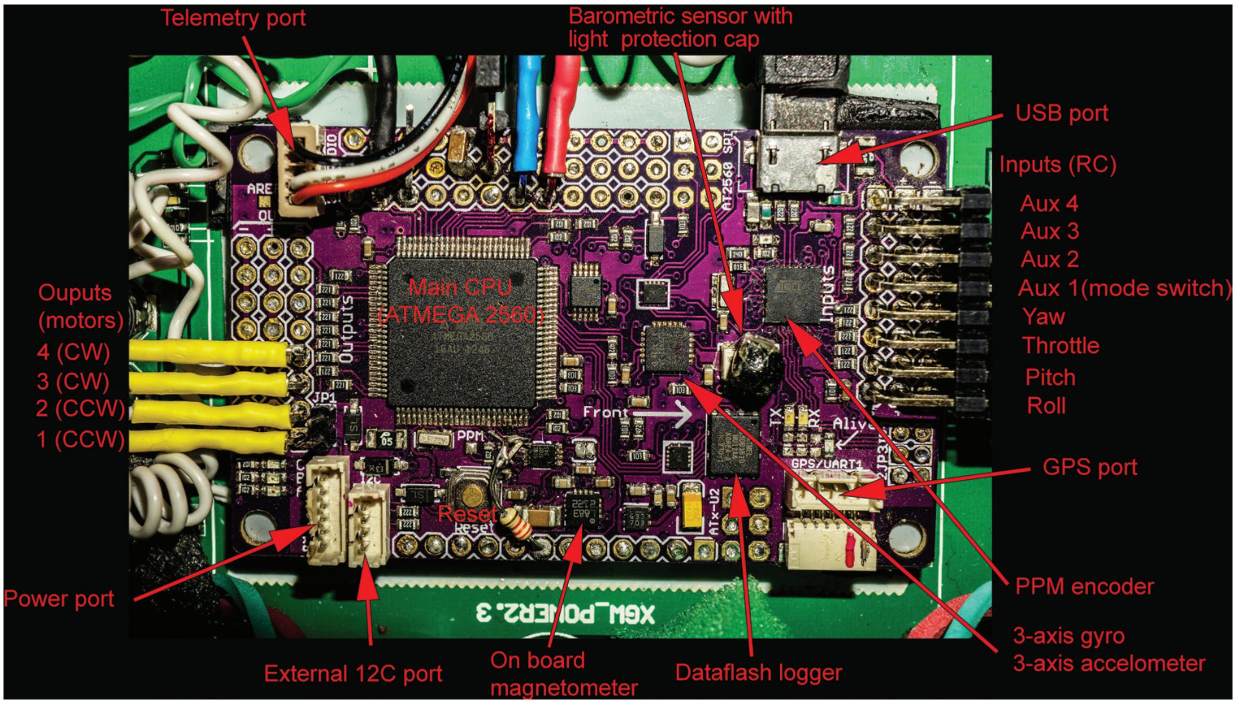

Figure 2. The integrated navigation and autopilot systems (APM 2.5).

3.1. Case study 1: mapping of the upper limit of a *Posidonia oceanica* meadow for the detection of impacted areas

The marine phanerogam *P. oceanica* (L.) Delile is the most widespread seagrass in the Mediterranean Sea [20]. It plays a pivotal role in the ecosystems of shallow coastal waters in several ways by (i) providing habitat for juvenile stages of commercially important species [21]; (ii) significantly reducing coastal erosion, promoting the deposition of particles with dense leaf canopy and thick root-rhizome ('matte') [22]; and (iii) offering a nursery area for many fish and invertebrate species [23, 24]. Although known to be a reef-building organism capable of long-term sediment retention, *P. oceanica* meadows are however experiencing a steep decline throughout the Mediterranean Sea [25, 26]. Along the Mediterranean coasts, the decline of seagrasses on a large spatial scale has been attributed to anthropogenic disturbances such as illegal trawling [27], fish farming [28], construction of marinas [29], and sewage discharge and pollution [30]. On contrast, on a smaller spatial scale, particularly in coastal areas subjected to intense recreational activity, seagrasses are impacted by mechanical damage caused by boat anchoring or moorings [20, 31]. Major damage to seagrasses seems to be caused by dragging anchors and scraping anchor chains along the bottom, as boats swing back and forth, generally resulting in dislodgement of plant rhizomes or leaves [20]. In most published works the mapping of *P. oceanica* meadows has been based on satellite, airborne imagery, multibeam bathymetry, and side-scan sonar mosaics [32]. Remote sensing data from satellites and piloted aircraft can be used to map large areas, but they either do not have adequate spatial resolution or are too expensive to map fine-scale features, otherwise small UAVs are particularly well-suited to mapping the upper limits of meadows at a smaller spatial scale (i.e. 1–5 Km).

The case study for this application was carried out along a sandy cove (Arenella bay) with a well-established *P. oceanica* meadow, approximately 2 km north of Giglio Porto (Giglio Island, Tuscany, IT), in late November 2016. Our goals were to show the high level of detail that can be reached with UAV-based imagery, to respect other free-available remote sensing techniques, and to detect impacted areas of the meadow. In fact, in this study site, there are two principal sources of disturbance: a direct adverse effect on meadow due to boat anchoring during summer seasons, and the presence of a granite quarry that in the past (no longer operational) may have caused an increase in sedimentation rates, resulting in a reduction of cover and shoot density.

We set the GoPro Hero 3 camera to take photos every 2 s (time lapse mode) in Medium Field of View (M FOV: 7 Megapixel format, 3000 × 2250 pixels), and we set the camera pointing 90° downward with auto white balance. Flight speeds were maintained between 5 and 7 m/s to allow for 75% in-track overlap. The drone was programmed to fly at 30 m above mean sea level in order to get a Ground Sampling Distance (GSD) of ~2.5 cm per pixel, according to the formula :

$$GSD_{cm/pix} = \frac{SW_{mm} * FH_{m}}{FL_{mm} * IMW_{pix}} * 100 \quad (1)$$

where GSD is the ground sample distance (i.e. photo resolution on the ground), SW is the sensor width, FH is the flight height, FL is the focal length of the camera, and IMW is the image width. By multiplying the GSD by image size (width and height) the resulting photo footprint was 66 × 50 m.

The bay (1.96 ha) was flown in 16 strips with a total flight duration of 6.34 min. In total, the survey yielded 184 images, which were processed in Adobe Photoshop Lightroom 5.0 (Adobe Systems Incorporated, San Jose, California, USA) using the lens correction algorithm for the GoPro HERO 3 Black Edition camera, in order to remove lens distortion (fish-eye effect). Since for this application, high-spatial accuracy was not required, five ground-control points (GCPs) were placed at accessible locations along the coast (with easily recognizable natural features such as rocks), and they were surveyed with a handheld GPS + GLONASS receiver (Garmin Etrex 30), leading to horizontal errors of ±5 m. Successively, the images where used to produce a high-resolution orthoimage mosaic in Agisoft Photoscan 1.0 (www.Agisoft.com). This structure from motion (SfM) package allows a high degree of automation, and makes it possible for nonspecialists to produce accurate orthophoto mosaics in less time than what it would take using conventional photogrammetric software [19].

Figure 3 shows how high-spatial resolution of RGB imagery acquired from UAV has allowed us to detect the impacted areas of the meadow. In particular, we identified 1.437 m^2 of dead 'matte' by analyzing satellite imagery (Google Earth), 1.686 m^2 with Bing Aerial orthophotos and 1.711 m^2 with UAV-based orthomosaic. In fact, due to the higher spatial resolution of UAS imagery, we were able to detect even the smallest areas where dead 'matte' was exposed, due to meadow degradation (**Figure 3**).

The imagery acquired provides a new perspective on *P. oceanica* mapping and clearly shows how comparative measurements and low-cost monitoring can be made in shallow coastal

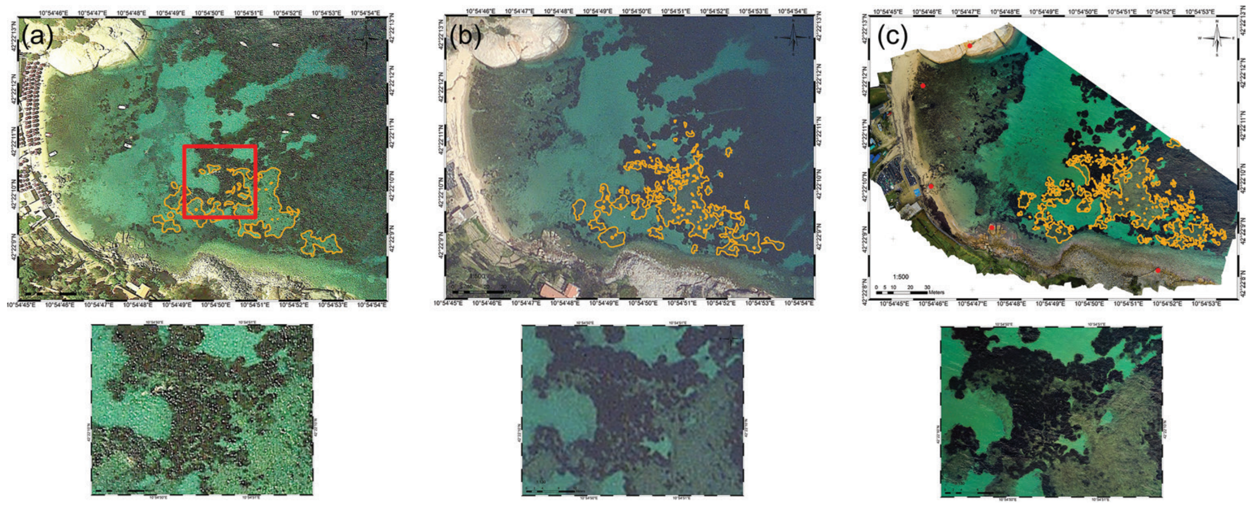

Figure 3. The bay of Arenella (Giglio Island, scale 1:500) with impacted *Posidonia oceanica* meadow (dead *P. oceanica* 'matte' is enclosed by orange polygons) mapped using three different free/low- cost remote sensing techniques: (a) Google Earth Satellite image; (b) Bing aerial orthoimage; and (c) UAV-based orthomosaic. The enclosed area highlighted by the red box is shown at greater scale (1:100) in order to visualize the increasing level of detail. In (c), red dots represent the position of GCPs.

areas. In fact, in this kind of environment, anthropogenic drivers such as boat mooring and creation of coastal dumping areas are significantly affecting ecosystem structure and function. In addition, considering that drone surveying is relatively not expensive, regular time-series monitoring can be adopted to assess the evolution of coastal meadows.

3.2. Case study 2: integration of underwater visual census (UVC) data with UAV-based aerial maps for the characterization of juvenile fish nursery habitats

Most demersal fishes have complex life cycles, in which the adult life-stage takes place in open deeper waters, while juvenile life-stages occur in benthic inshore habitats [33, 34]. The presence of suitable habitats becomes an essential requirement during the settlement of juvenile stages. In fact, 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 [33–35]. Habitat identification has been generally achieved by human underwater visual censuses (UVC) techniques [36]. The latter has been considerably improved in recent years with visual underwater video technologies [35]. However, these studies require a deep knowledge of the environment in addition to considerable efforts in terms of time and experienced staff [35]. Small UASs potentially offer a low-cost support to conventional UVC techniques, providing a time-saving tool aimed at improving data from underwater surveys. Indeed, our aim is to couple UVC data (e.g. number of juvenile fish) with remote sensing data (high-resolution UAV-based imagery), to extrapolate habitat features from image analysis, allowing a considerable saving of both time and efforts, especially for underwater operators.

The case study for this application involved the same UAS used in the previous example, an underwater observer, and was focused on a common coastal fish species: the white seabream

(*Diplodus sargus*, L.). *D. sargus* is abundant in the Mediterranean and dominates fish assemblages in shallow rocky infralittoral habitats. It inhabits rocky bottoms and *P. oceanica* beds, from the surface to a depth of 50 m. In common with other sparid fishes, it is an economically important species of interest for fisheries and aquaculture.

Between early May and late June 2016, juvenile white seabream (*D. sargus*, L.) were censused from Cannelle Beach to Cape Marino, along a rocky shoreline (~1.5 km long) south of Giglio Porto (Giglio Island, IT). Counts of fish were obtained from two visual census surveys per month: the diver swam slowly along the shoreline (from 0 to 6 m depth) and recorded the numbers of individuals encountered while snorkeling. When juvenile fish or shoals of settlers (size range 10–55 mm) were observed, the abundance and size of each species were recorded on a plastic slate. In addition, the diver towed a rigid marker buoy with a handheld GPS unit with WAAS correction (GpsMap 62stc) in order to accurately record the position of each shoal of fish.

Two mapping missions were successfully carried out in late July 2016, along the same shoreline, in order to produce a high-resolution aerial map of the coast (**Figure 4**).

The quadcopter flew at 40 m, yielding a ground resolution of ~2.5 cm/pix. The two surveys covered 1446 m of shoreline and took approximately 16 min, resulting in 204 images. Since many stretches of the coast were inaccessible areas, where GCPs cannot be physically measured on

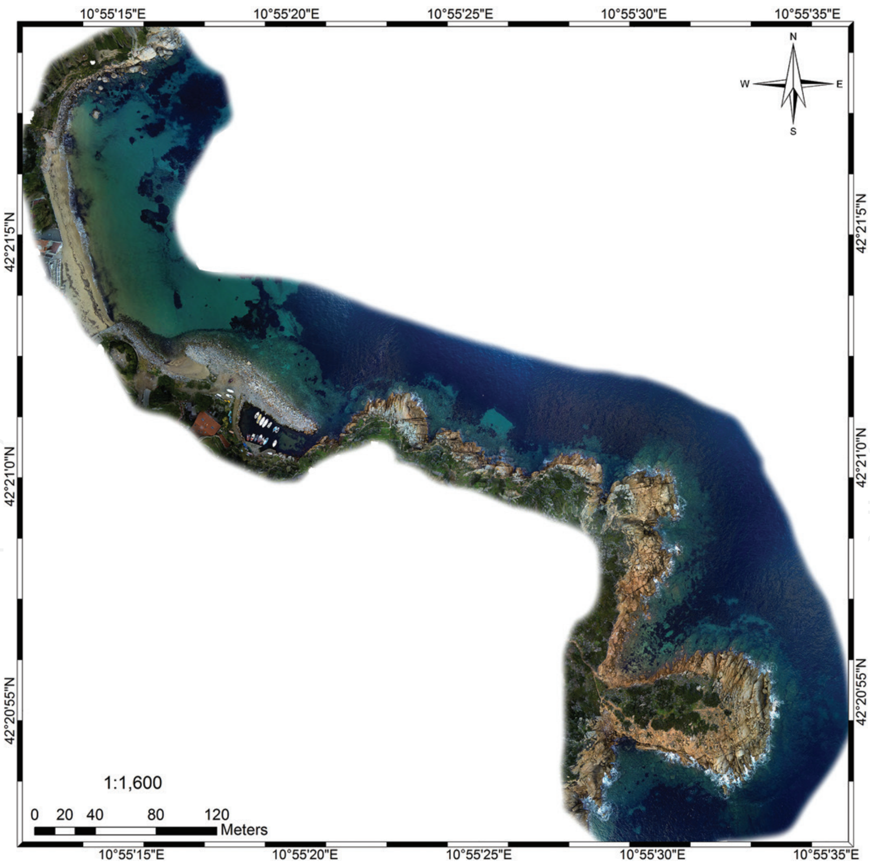

Figure 4. The high-resolution (2.5 cm/pix) mosaic representing the rocky coast (~1.5 Km) south of Cannelle Beach (Giglio Island, Italy), derived from two mapping mission (204 images) of Quanum Nova CX-20.

the ground, we used a direct georeferencing approach. The GPS coordinates of the cameras are determined using the UAV onboard GPS receiver, so that the GPS position at the moment of shot can be written to the EXIF header information for each image, after estimating time offset with Mission Planner (v.1.3.3 or higher) geotagging images tool (for better results preflight synchronization of the camera's internal clock with GPS time is recommended). In addition, these measured values (from onboard GPS) may be useful to estimate the camera's approximate external orientation parameters to speed up photogrammetric workflow (bundle adjustment) in Agisoft Photoscan. However, since they are typically captured at relatively low accuracy in the case of UAVs' consumer-grade GPS, we also registered the final orthomosaics, by importing it as raster image (TIFF format) into Arcmap 10.1 [37]. We aligned the raster with an already existing 1:5000 scale aerial orthophoto by 8 control points in order to perform a 2nd order polynomial transformation. Afterward, the control points were used to check the reliability of image transformations. The total error was computed by taking the root mean square sum of all the residuals to compute the RMS error (RMSE). This value described how consistent the transformation was between the different control points. The RMSE achieved was 0.15 pixels which was well under the conventional requirements of less than 1 pixel [38]. The successful geo-registration allowed a direct visualization on the map of UVC data (i.e. lat/long coordinates of fish shoals) after downloading GPS eXchange (.gpx) information from GPS unit. These GPS data were imported as point shapefile in ArcMap using DNRGPS 6.1.0.6 application [39].

As all juvenile fish positions, with their relative abundances (number of fish per shoal), are now available in a GIS environment, it is a straightforward process to model them with interpolation methods, which is, for example, available in ArcMap. The point data, measured from irregularly spaced locations, were converted into continuous surfaces using an inverse distance weighting (IDW) method and then rasterized into a grid format. We used local interpolators of inverse distance weighting because the concept of computation (i.e. it assumes that each point has a local influence that diminishes with distance [40]) is relevant for juvenile fish, where closer points are thought to be similar as a result of the habitat characteristics. **Figures 5** and **6** show the spatial distribution of *D. sargus* juvenile density collected through underwater visual census after IDW interpolation. GIS data integration allowed us to identify two important aspects: (1) four areas (a–d) with high densities of juveniles were clearly visible, suggesting that such zones serve as nursery grounds for juvenile white seabreams (**Figure 5**) and (2) as the juveniles grew larger in size (> 40 mm) a dispersal out of the nursery areas was evident and the preference for a given habitat type decreased leading to an increase in the number of shoals but with lower densities within shoals (**Figure 6**).

These four nurseries were investigated through image analysis (**Figure 7a–d**): we performed a Maximum Likelihood Classification algorithm followed by both postprocessing workflow [41] and manual polygons editing for edge refinement in order to highlight the most important habitat feature such as substrata type and extent (**Table 2**). In fact, due to high site-attachment of juvenile fish, the presence of specific habitats play a key role in the development of early life-stages, hence the fine characterization of these environments becomes an important aspect regarding ecological studies focused on juvenile fish. However, underwater data collection by SCUBA operators require a large effort to acquire such detailed information, therefore UASs-based remote sensing techniques become useful, reliable, and feasible tools for mapping coastal fish habitats and for supporting ecological investigations.

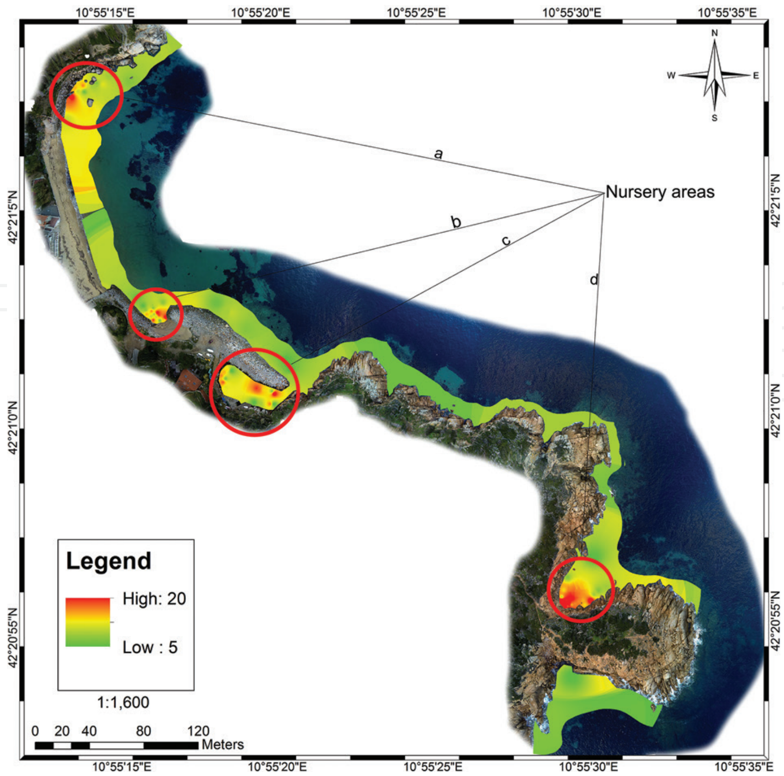

Figure 5. Spatial distribution of small-sized (10–40 mm) juvenile *D. sargus*. IDW-interpolated fish density after UVC data collection in May 2016. The four areas (a–d) with the highest densities of juvenile are highlighted by red circles.

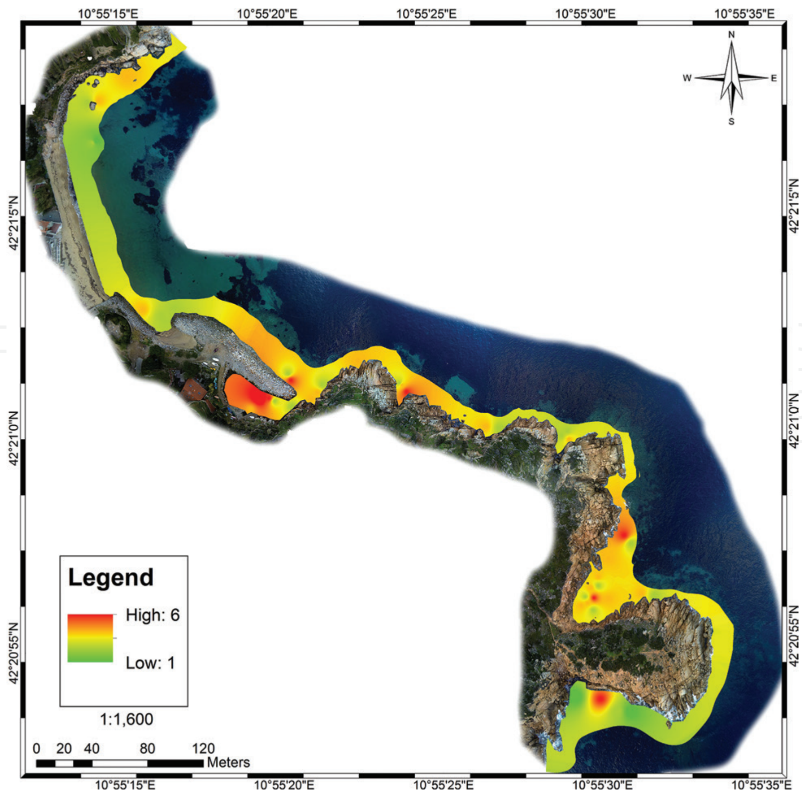

Figure 6. Spatial distribution of large-sized (41–55 mm) juvenile *D. sargus*. IDW-interpolated density after UVC data collection in late June 2016.

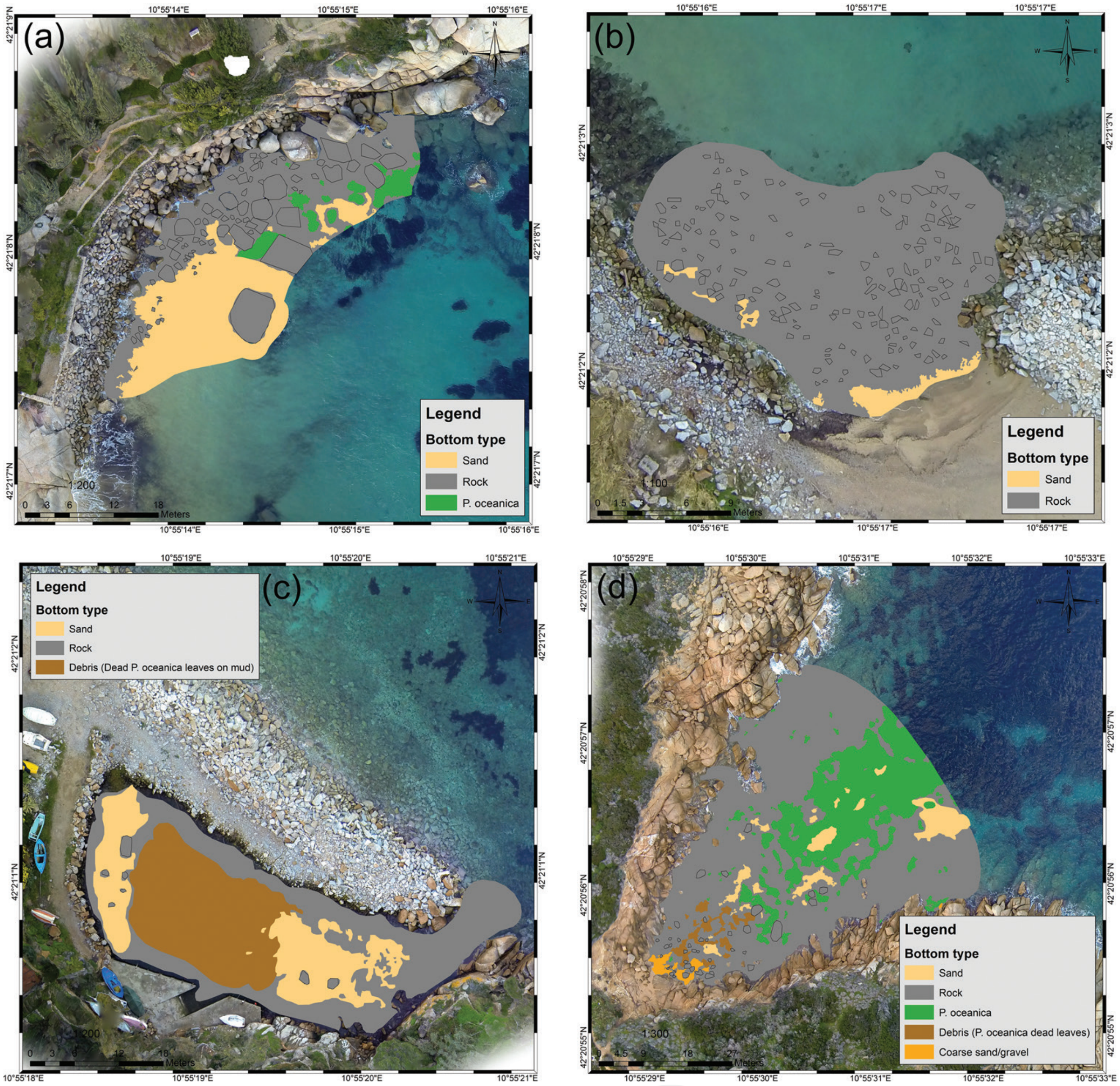

Figure 7. Thematic maps of the four nursery areas (a–d) derived from Maximum likelihood classification and manual editing. Different colors represent main habitat types.

Nursery	Substrata type	Habitat description	Habitat cover (m^2)	Percent cover (%)	Depth (m)	Total extent (m^2)
Sandy cove (a)	Sand	Granite coarse sand	243.9	36.2	0–3	674.4
	Rock	Large- (mean ± SD diameter: 3.4 ± 16) and medium-sized (mean ± SD diameter: 0.9 ± 0.3) boulders with photophilic algae biocenosis	382.5	56.7		
	Posidonia oceanica	Small patches on sand	48	7.1		

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Nursery	Substrata type	Habitat description	Habitat cover (m²)	Percent cover (%)	Depth (m)	Total extent (m²)
Rocky cove (b)	Sand	Granite coarse sand	11.6	3.7	0–3.5	317.8
	Rock	Small-sized (mean ± SD diameter: 0.6 ± 0.2) blocks and pebbles with photophilic algae biocenosis	306.2	96.3		
Small port (c)	Sand	Fine sand and mud	218.7	23.8	0–2.8	918.3
	Rock	Cranny rock semisciaphilic algae and isolated boulders on soft sediment	402.2	43.8		
	Debris	Dead *P. oceanica* leaves on mud	297.4	32.4		
Rocky/sandy cove (d)	Sand	Sandy patches	129.1	5.1	0–5.5	2521.2
	Gravel and pebbles	Small- and medium-sized pebbles on sand	25.2	1		
	Rock	Cranny rock with photophilic algae biocenosis and isolated boulders	1698.9	67.4		
	Posidonia oceanica	*Posidonia* meadow and 'matte'	621	24.6		
	Debris	Dead *P. oceanica* leaves on sand	47	1.9		

Measures are derived from high-resolution mosaics image analysis in Arcmap 10.1.

Table 2. Main habitat features characterizing the four nursery areas (a–d).

4. Conclusions

In this brief review we have provided an overview of ecological studies carried out with small drones. Through study cases we demonstrated how UAV-acquired imagery has a substantial potential to revolutionize the study of coastal ecosystem dynamics. The future of UASs applications looks very promising due to the relative low cost with respect to the benefits obtained [42]. In fact, the field of ecology is severely hindered by the difficulties of acquiring appropriate data, and particularly data at fine spatial and temporal resolutions, at reasonable costs [4]. As demonstrated in this study, unmanned aerial vehicles offer ecologists new opportunities for scale-appropriate measurements of ecological phenomena providing land cover information with a very high, user-specified resolution, allowing for fine mapping and characterization of coastal habitats. Although the camera equipment used herein only captures three color (RGB) channels with relatively low resolution (max 16 megapixel), it was possible to distinguish impacted areas in sensitive habitat types, as well as preferred sites for juvenile fish species. Moreover, high-spatial resolution data derived from UAVs combined with traditional underwater visual census techniques enable the direct visualization of field data into geographic space bringing spatial ecology toward new perspectives. High-resolution aerial mosaics allow rapid detection of key habitats, and thus can be used to identify areas of high relevance for species protection and areas where management action should be implemented to improve or maintain habitat quality [16]. UASs are potentially useful to investigate population trends and habitat use patterns, and to assess the effect of human activities (e.g. tourism, pollution) on abundance, particularly in coastal and shallow habitats, where visibility enables animal detection from the surface, as demonstrated for elasmobranch species in coral reef habitats [44]. Finally, although the flexibility of UASs will be able to revolutionize the way we address and solve ecological problems [9], we must consider government approval navigational stipulations and social implications that impose restrictions on the use of UASs before undertaking research projects involving the use of UASs [43–45].

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