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The Use of Drones for Cost-Effective Surveys in Natura 2000 Protected Areas: A Case Study on Monitoring Plant Diversity in Sicily (Italy)

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Abstract: Unmanned aerial vehicles (UAVs), commonly known as drones, present a cost-effective solution for the swift collection of data from vast and remote areas that are otherwise difficult to access. The Mediterranean Basin, known for being a hotspot for plant biodiversity, hosts several habitats and taxa of significant naturalistic value. However, many of these areas are often inaccessible to botanists, making exploration and research challenging. The aim of this paper is to involve the utilization of drone surveys and open-source software for botanical research. Our primary goal is to show the effectiveness of these tools in the field and demonstrate their practical application in Natura 2000 sites. The protected area chosen for this research is Rocca di Novara, situated in northeastern Sicily. Thanks to our drone investigations, we were able to capture images of a mountainside that is inaccessible to humans. This allowed us to observe the habitat of some species in detail. One of the most fascinating discoveries was the reappearance of *Saxifraga callosa* subsp. *australis*, which had not been confirmed in this area for over 140 years. Using drones for botanical research can boost field research, making monitoring easier and more cost-effective over time, especially in Natura 2000 sites.

Keywords: endemic species; landscape monitoring; Mediterranean flora; remote sensing; *Saxifraga*; vascular flora

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1. Introduction

The task of observing and charting both natural and semi-natural habitats is crucial in protecting ecological diversity and the environment. These procedures are guided by European standards and regulations [1,2], which ensure that conservation efforts are carried out in a methodical and scientific manner. In the Mediterranean basin, the task of habitat mapping and investigation presents a unique challenge due to the wide range of flora combined with varied environmental conditions [3]. This area is a biodiversity hotspot that hosts a variety of habitats, including forests, grasslands, wetlands, and coastal zones, each with its own distinct ecological characteristics [4]. Accurate monitoring and observation of these habitats are necessary to understand the dynamics of the ecosystem and develop effective conservation management strategies, especially for habitats of European interest [5,6]. In recent times, drone technology has significantly transformed habitat mapping and monitoring, especially when it comes to conserving plant biodiversity [7]. Drones, also known as Unmanned Aerial Vehicles (UAVs), provide an innovative perspective on environmental conservation [8,9]. Equipped with advanced imaging capabilities and sensors, drones can capture high-resolution aerial photographs and generate detailed 3D models of habitats, offering a more comprehensive and precise representation of the terrain and vegetation structure compared to traditional ground-based surveys [10,11]. Moreover, the recent advent of UAVs has introduced the prospect of low-cost vegetation mapping [12,13]. In the vast and varied landscapes of the Mediterranean region, drones are particularly useful because they can cover large areas quickly and efficiently [14]. Drones can access remote and challenging-to-reach areas with minimal disturbance to the ecosystem, making them a valuable tool for monitoring sensitive habitats and endangered species [15]. They can also track changes in vegetation over time, providing essential data for assessing the impact of environmental changes and the effectiveness of conservation strategies [16]. The use of UAV photogrammetry has significantly enhanced the efficiency of 3D modeling and vegetation monitoring [17]. Furthermore, drone use contributes to the democratization of science. As drone technology becomes more affordable and user-friendly, citizens can participate in conservation efforts by collecting and sharing data [18,19]. This not only expands the scope of habitat mapping and monitoring but also fosters a greater public understanding and appreciation of biodiversity. In conclusion, drone use in habitat mapping and monitoring represents a significant advancement in environmental conservation. As this technology continues to evolve, it promises to play an increasingly important role in preserving the rich biodiversity of the Mediterranean region and beyond. The study aims to use drones to monitor and evaluate rocky habitats in a Natura 2000 site in Sicily and assess the cost-effectiveness of plant monitoring in inaccessible areas using user-friendly and open-source software.

2. Materials and Methods

2.1. Study Area

Sicily is an island located in the central Mediterranean. It is the largest island in the Mediterranean, covering an area of 25,832.4 km^2 (including smaller islands), and has a coastline of 1637 km [20]. The Tyrrhenian Sea is situated to the north of the island, the Sicilian Channel to the southwest, and the Ionian Sea to the east. The Strait of Messina separates Sicily from the Italian peninsula to the northeast (Figure 1). The island has rich and diverse flora, with a total of 3569 accepted taxa [21]. Sicily and its islets are a significant biodiversity hotspot with a consistent history of discovering both native and alien species [22–25]. The island's unique natural environment has garnered considerable interest from botanists due to its rich and diverse ecosystem. Consequently, there has been a continuous flow of new floristic records and descriptions of new species [26–31].

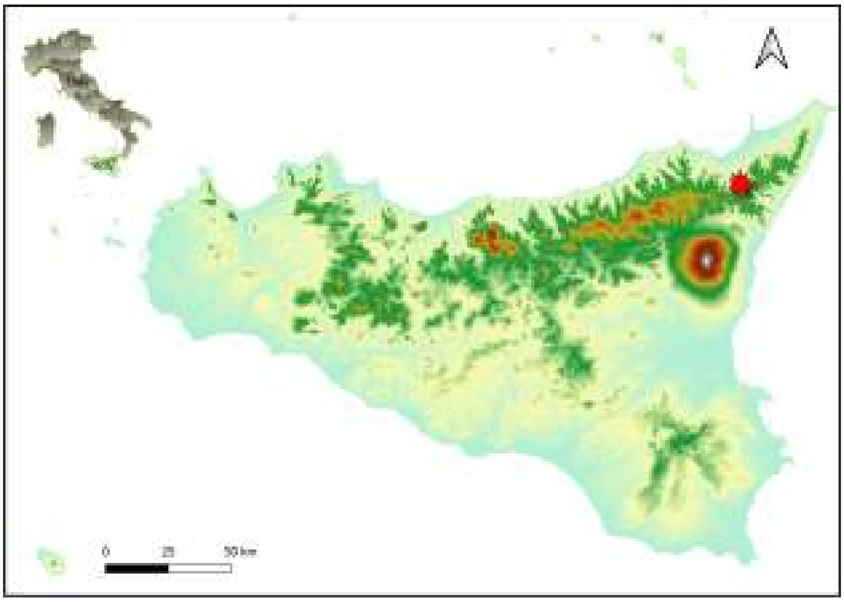

Figure 1. Map of Sicily (DEM used as base map [32]); Rocca di Novara (red star).

The main northern mountain range of the island, with the highest peak being Montagna Grande at 1374 m, is the Peloritani mountain range. In particular, for the goals of this study, the mountain Rocca di Novara (37°59′39.49″ N 15°08′49.08″ E, also known as Rocca Salvatesta) has been chosen as the study area. This peak is situated within the boundaries of Novara di Sicilia, located in the province of Messina [33]. Geologically, it is predominantly composed of limestone rocks, which makes it a peculiar feature in the Peloritani range, known for its metamorphic rock formations [34]. The Peloritani mountain range, including Rocca di Novara, makes it difficult for researchers to study its vegetation using traditional in-field techniques. This is why many regions within these mountains have not been thoroughly researched in terms of their vegetation and flora characteristics. The presence of limestone outcrops has resulted in a distinct and diverse floristic set, setting it apart from other peaks in the area. This area falls within the SAC "Rocca di Novara" (code ITA030006) due to its relevant naturalistic heritage (Figure 2). Moreover, Rocca di Novara belongs to the Important Plant Area (IPA) named "Monti Peloritani e Rupi di Taormina" [35].

Figure 2. Rocca di Novara, Sicily (Italy), photo by G. Tavilla.

2.2. Drone Surveys and Data Collection

Based on the flowering period of the species in the study area, the field investigation took place in May 2022 and June 2022 to assess the area's floristic biodiversity. In this research, the drone model used to collect the images was DJI Mavic 3. It uses the WGS 84 Geodetic Reference System (SGR). The 20-megapixel RGB camera on the Mavic 3 captures images with a resolution of 5280 × 3956 pixels. During the flight, the camera was stabilized using a three-axis gimbal that was incorporated with the UAV's inertial navigation system. A Global Navigation Satellite System (GNSS) receiver provides the UAV's geolocation at the moment of image capture, which is stored in the image's EXIF (Exchangeable Image File Format) header. This UAV was chosen due to its cost-effectiveness and integration of a high-resolution camera and gimbal. To guarantee correct stitching, at least 80% of the front and 70% of the sides of each image were overlapped when acquired [36]. The flight was conducted manually and drone photographs were taken automatically every two seconds using a DJI smart controller. We carried out a total of 10 flights between May and June 2022, and each session had a maximum duration of 30 min. These flights led to the gathering of more than 1000 photographs from the study area. The field site analysis involved the utilization of aerial pictures processed through open-source software. The aerial photos of the cliff were transformed into a high-resolution 3D model using WebODM version 2.4.2 software, a free photogrammetric image processing program developed by OpenDroneMap [37]. This tool is specifically designed to process aerial photos captured by drones and is available for both Windows and Mac OS. WebODM is specifically designed to process aerial photos captured by drones. For each UAV picture uploaded, WebODM retrieves the EXIF header. The Ground Sampling Distance (GSD) refers to the amount of surface area covered by a single image in flight, and it was the parameter used to evaluate our project on WebODM. The GSD value of 1 cm/px is the one recommended for professional surveys to achieve higher accuracy in order to identify details in the field [38]. In fact, the GSD influences the quality and resolution of the final results. Additionally, the following options were selected: auto-boundary: true, mesh-octree-depth: 12, use-3dmesh: true, pc-quality: high, mesh-size: 300,000. The entire 3D model processing was entirely automatic (Figure 3).

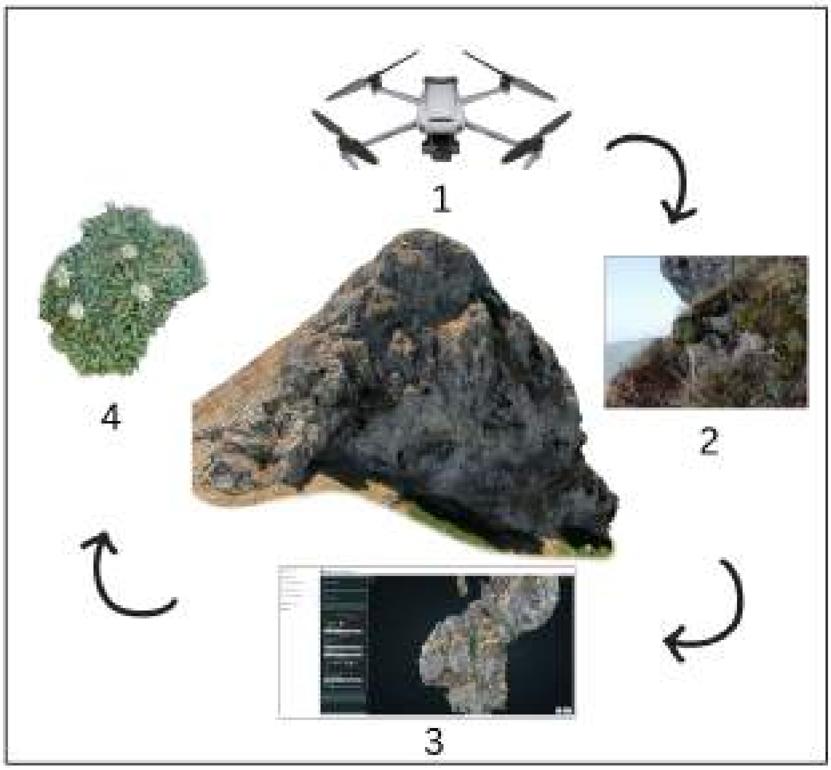

Figure 3. Workflow of this study. Step 1, prepare drones, including battery check. Step 2, capturing images using manual flight. Step 3, photo selection and processing. Step 4, plant identification.

2.3. Vegetation Sampling and Taxa Identification

The captured images were used to create virtual plots that enabled the evaluation of individual species coverage using a phytosociological method. The plot size was selected based on the most common plot size used to sample this type of vegetation [39]. This method, also known as the Braun-Blanquet approach [40], considers the relationships of plant communities with the environment and the interactions within communities. The phytosociological relevés take into account vegetation plot size, vegetation cover, and species occurrence. The Braun-Blanquet scale assigns each species a coverage value ranging from 1 (1–5% coverage) to 5 (75–100% coverage), while the symbol "+" is used for sporadic species with coverage less than 1%. As it concerns to the species observed in the pictures, the taxonomic identification was carried out using the "Flora of Italy" [41–44], and the life form follows the Raunkiaer system [45]. The nomenclature of taxa follows the "Portal to the Flora of Italy" [21], while the nomenclature of *Saxifraga callosa* subsp. *australis* (Moric.) Pignatti ex Tavilla & Del Guacchio is in accordance with Tavilla and Del Guacchio [46]. The habitat type code was used in accordance with Directive 92/43/EEC [47].

3. Results and Discussion

The survey conducted in this Natura 2000 site utilized drone technology for comprehensive monitoring. We present the outcomes of our drone-based monitoring campaign in Rocca di Novara. Our study used advanced drone technology to gather high-resolution spatial data and imagery, providing unparalleled insight into the biodiversity of the site. A total area equal to 16,039.92 m^2 has been reconstructed with a Ground Sampling Distance (GSD) of 0.63 cm. Through our aerial surveys, image analysis, and interpretation, we have gained valuable insights into plant communities and flora growing on the sides of this mountain (Figure 4). Moreover, our results align with those of other studies using similar drone-based workflow for botanical research [48–51]. However, there are some limitations to using drones in the botanical field, which were also faced in our study. For instance, drones are limited to line-of-sight operations, which restricts survey sites. Additionally, geographic limitations arise due to short battery life, which ranges from 15 to 30 min. Drone operations are heavily influenced by weather. Good visibility and calm weather are ideal for flights. Severe weather can hinder data collection and pose risks to equipment [52]. The use of drones is subject to varying regulations, which can differ widely between regions. Researchers must obtain the necessary permissions and adhere to local and national regulations [53]. Drones offer a less intrusive way to survey plant ecology; however, using them comes with specific challenges that need careful consideration and planning [54].

Figure 4. Vegetation changes between (**A**) May and (**B**) June (Rocca di Novara, Sicily), photos by G. Tavilla.

Based on our findings, managing the 3D rocky face model was easy with WebODM's user-friendly interface (Figure 5). This interface allowed measurements of the basal leaves rosette diameter of the identified plants, and conducting population studies on rare species and vegetation sampling is now feasible (Table 1). Thanks to the phytosociological relevés carried out, it was possible to identify the habitat type in which this vegetation occurs. These rocky communities growing on the limestone side are included in habitat 8210 "Calcareous rocky slopes with chasmophytic vegetation", which is listed in Annex I of Directive 92/43/EEC. This is a vegetation of fissures of limestone cliffs, in the Mediterranean region belonging essentially to the *Saxifragion australis* Biondi & Balelli ex Brullo 1984 (*Asplenietea trichomanis* (Br.-Bl. in Meier & Br.-Bl. 1934) Oberdorfer 1977 class) [55].

Figure 5. WebODM 3D model interface.

Table 1. Phytosociological relevé from drone image.

Relevé n.	1
Date	28 May 2022
Locality	Rocca di Novara
Plot size (m^2)	15
Cover (%)	35
Species	
Saxifraga callosa subsp. *australis*	2
Sedum dasyphyllum	+
Hypochaeris laevigata	1
Edraianthus graminifolius subsp. *siculus*	+
Athamanta sicula	2
Saxifraga rotundifolia	1
Arabis alpina subsp. *caucasica*	+
Festuca circummediterranea	1
Aubrieta columnae subsp. *sicula*	+
Poa bivonae	1
Asplenium ceterach	+

3.1. *Taxa of Outstanding Interest*

The Rocca di Novara mountain is home to several plant species of high phytogeographic interest that were initially investigated by Nicotra [56]. The predominant life form found on the cliff is the chamaephyte, which is not surprising. However, hemicryptophytes, such as *Hypochaeris laevigata* (L.) Ces., Pass. & Gibelli and *Saxifraga rotundifolia* L. subsp. *rotundifolia*, also thrived on the side. In addition, some Sicilian endemic species grow on the cliffs of Rocca di Novara. The following paragraphs discuss the most noteworthy taxa.

3.1.1. *Lomelosia crenata* (Cirillo) Greuter & Burdet subsp. *crenata*

This species is a chamaephyte cespitose found in Albania, Algeria, Greece, Italy, Serbia, Sicily, Spain, and Tunisia [57]. According to Giardina et al. [58]. This taxon is rare across the rest of Sicily, but it is frequent on the rocky peaks of Northern Sicily, such as Rocca di Novara (Figure 6). Therefore, this species has important phytogeographical value in Sicily.

Figure 6. *Lomelosia crenata* (Cirillo) Greuter & Burdet subsp. *crenata* (Rocca di Novara, Sicily), photograph by G. Tavilla.

3.1.2. *Saxifraga callosa* subsp. *australis* (Moric.) Pignatti ex Tavilla & Del Guacchio

This chamaephyte grows in shady, mountain environments on the limestone of central and southern Apennines and Western Sicily [46]. The only population known in the eastern part of Sicily is in the Rocca di Novara area [58]. In the only floristic work ever made for Rocca di Novara by Nicotra, *S. callosa* subsp. *australis* was reported [56]. According to the author, he did not see the plant himself, but it was first noted by G. Seguenza. For over 140 years, there has been no confirmation of this species' presence. Thanks to our drone monitoring, we were able to photograph the plant on an inaccessible side of the rocky cliff not accessible by humans (Figure 7). This is another excellent example of how drones can be useful in botanical research, especially in cliff ecosystems [59], by avoiding hazards for botanists in rupicolous habitats and unnecessary spending (Figure 8). It should be noted that this is the only plant reported in this paper that can only be identified and reported through drone surveys.

3.1.3. *Aubrieta columnae* Guss. subsp. *sicula* (Strobl) M. A. Koch, D. A. German & R. Karl

This chamaephyte is endemic to Sicily and is classified as an endangered species according to the IUCN criteria [60,61]. It grows on the limestone cliffs of the Madonie massif (northwest Sicily), and only one population exists in northeast Sicily, i.e., Rocca di Novara (Figure 9). Nicotra [56] reported this taxa for the first time in the Peloritani mountains. Based on our recent field investigations, the majority of individuals bloomed in May. However, in the past, blooming peaks were seen in late June. This observation suggests that individual fertility may be at risk in the future since the Mediterranean mountain regions are very vulnerable to climate change [62].

3.1.4. *Odontites bocconei* (Guss.) Walp. subsp. *bocconei*

This species is an endemic Sicilian chamaephyte (Figure 10) with a rare distribution on the island [58]. Currently, it is classified at the national level as least concern [63].

Furthermore, it should be noted that *O. bocconei* is not currently reported in the section "Other important species of flora and fauna" of the Rocca di Novara SAC data form [64].

Figure 7. *Saxifraga callosa* subsp. *australis* (Moric.) Pignatti ex Tavilla & Del Guacchio (Rocca di Novara, Sicily), photograph by G. Tavilla.

Figure 8. Inaccessible side of Rocca di Novara, photograph by G. Tavilla.

Figure 9. *Aubrieta columnae* Guss. subsp. *sicula* (Strobl) M. A. Koch, D. A. German & R. Karl (Rocca di Novara, Sicily), photograph by G. Tavilla.

Figure 10. *Odontites bocconei* (Guss.) Walp. subsp. *bocconei* (Rocca di Novara, Sicily), photograph by G. Tavilla.

4. Conclusions

This study has enabled us to gain insights into various aspects of floristic biodiversity, habitat structure, and plant communities within the Natura 2000 site. In particular, thanks to our findings, we were able to rediscover the presence of *Saxifraga callosa* subsp. *australis* in the Peloritani mountains, which had not been confirmed for over 140 years. Additionally, photos taken with a drone allowed us to observe the flora and vegetation on an inaccessible side of Rocca di Novara mount. Drones have distinct advantages, including rapid and cost-effective data acquisition over expansive and often inaccessible terrain. However, using drones for botanical studies has limitations and challenges, especially in areas with high floristic diversity and similar species that are difficult to identify through images. Our workflow shows an easily applicable way to monitor and assess floristic diversity in protected areas. The use of this tool ensures the safety of botanists by preventing them from exploring inaccessible and dangerous habitats. Additionally, the use of drones can be combined with traditional fieldwork to conduct comprehensive floristic studies using integrative approaches. Finally, the aerial view provided by drones has enabled us to comprehensively assess landscape features and ecological processes at various spatial scales, facilitating a more nuanced understanding of ecosystem functioning.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflicts of interest.

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