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Combining aerial and underwater photogrammetry for the monitoring of *Cystoseira* spp. habitats

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Introduction

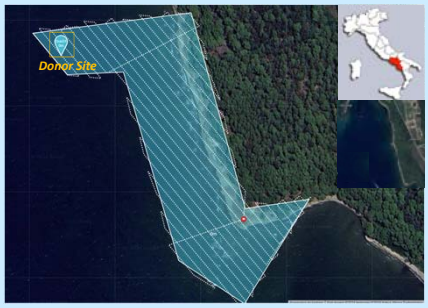
In recent decades, populations of the brown macroalgae *Cystoseira spp.* have significantly reduced their range, in relation with the increasing human threats, such as coastal development, habitat degradation, pollution, maritime traffic, aquaculture, and intensive fishing. Restoration actions have been taken recently to return to a pristine state and restore the "ecological status" of these ecosystems. In this contest, in 2022, EU funded the REEForest Project (101074309 - LIFE21-NAT-IT-REEForest) in the Nature and Biodiversity sub-programme for protection and restoration of the nature, with the aim to map, monitor and restore the *Cystoseira* spp. meadows in different Italian Marine Protected Areas (MPAs). High-resolution imagery acquired by autonomous vehicles across different seasons during 2023-2025, was used for mapping an area of approximately 51,000 m² within the Cilento National Park (Campania Region, Italy), near Licosa Island, known for its established presence of *Cystoseira* spp., in order to select a "*donor site*" of *Cystoseira* spp. for the subsequent restoration activities. This research evaluates the potential and limitations of integrating aerial and underwater Structure from Motion (SfM) photogrammetry using Unmanned Aerial Vehicles (UAV) and Autonomous Surface Vehicles (ASV).

Methodology

The **UAV platform** used was a DJI Mavic 2 Pro with a high-resolution camera (20 MP). Tests determined that flying at 40 meters altitude provided the best balance between image clarity and survey efficiency, achieving image resolutions around 1 cm. The UAV flew at 2 m/s, capturing overlapping images (about 80%) and completing the survey area in roughly 50 minutes. Ground Control Points (GCPs) were positioned using precise GNSS RTK technology to ensure accurate spatial referencing.

DJI Mavic 2 Pro

GCP



Flight plan

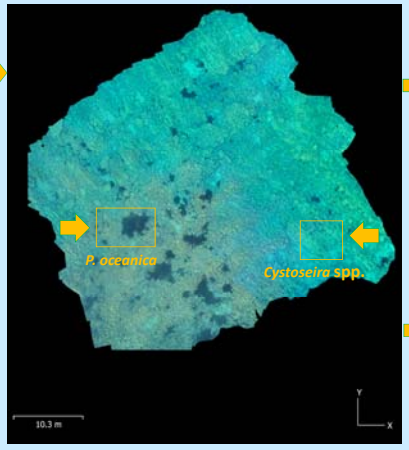
Orthomosaic of the investigated area

The **BASIC ASV**, developed by ISPRA, was equipped with a GoPro Hero 11 (27 MP sensor, ultra-HD 5.3K video), capturing underwater images at one-second intervals while traveling at 2 m/s during image acquisition. The images were georeferenced by matching the ASV's recorded coordinates with the image timestamps.

ASV Basic

These georeferenced underwater datasets can be combined with UAV surveys to collect ground-truth data points at sea, providing essential references for validating and enhancing UAV-derived habitat maps.

Additionally, the ASV can operate independently for mapping purposes. It primarily uses two modes: a wide transect mode without overlapping images to efficiently cover larger areas, and a dense transect or grid mode with partial image overlap, enabling detailed high-resolution orthomosaic reconstruction for smaller, targeted areas. In the first mode, BASIC ASV covered the survey area in approximately one hour and forty-five minutes, capturing slightly less than 7,000 images. In the grid coverage mode, it surveyed an area of 900 m² in about 20 minutes, collecting approximately 900 images.



Orthomosaic of the "*donor site*"

Posidonia oceanica

Cystoseira spp.

Photogrammetric Processing

Was performed by Agisoft Metashape Professional 2.2.1, generating high-quality dense point clouds and orthomosaics for both types of survey (UAV and Basic ASV). Although also DEMs were produced, the main goal of this study was not bathymetric mapping but habitat classification. The high image overlap (about 80%) allowed the use of the most nadir portions of the images, minimizing distortion effects and improving the reliability of orthomosaic-based habitat interpretation.

Results and Conclusion

The UAV demonstrates higher productivity compared to the ASV and represents an excellent solution for mapping *Cystoseira* spp. in intertidal and very shallow water areas, although its effectiveness decreases in deeper regions due to water transparency and penetration issues. In these conditions, the ASV becomes essential because it is less constrained by water depth and turbidity. Integrating ASV-based underwater imagery effectively addresses the UAV limitations, ensuring detailed habitat discrimination and enhancing the accuracy of habitat mapping through sea-truth data collection. Thus, the combined UAV-ASV approach emerges as an efficient, versatile, and cost-effective methodology for monitoring shallow marine habitats within coastal management programs.