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THE MATRIX RELOADED: CARLIT ASSESSMENT TEN YEARS LATER IN THE SINIS COAST (SARDINIA, ITALY) COUPLED WITH DRONE TECHNOLOGY

Abstract
Mapping and monitoring of marine habitats are crucial tools for coastal management and the implementation of conservation measures. CARLIT index is based on the cartography of littoral assemblages and their sensitivity to changes of environmental conditions. It has been widely tested and applied in the Mediterranean Sea since its introduction in 2007, to assess the ecological status of water bodies within the Water Framework Directive (WFD). Sinis coast (Sardinia, Western Mediterranean) comprises Penisola del Sinis - Isola di Mal di Ventre MPA, being a poorly inhabited and almost devoid of man-made structures. The methodology was for the first time applied in 2008, representing the first application in Sardinia and among the first ever. In 2018, we re-monitored the same coastline coupling a drone technology integration of the classic methodology. The aim of the study was to compare the ecological status 10 years later and to develop a GIS database with more detailed information respect to previous data that will be available at high resolution for future monitoring and developments (e.g. coverage, DTM). Data were gathered by boat or by walking along the coast and high-resolution images were acquired by a commercial drone, elaborated using Structure from Motion (SfM) technique and georeferenced. CARLIT revealed an overall stability of ecological status of water bodies 10 years later, with some slight differences along restricted stretches of coast. The implementation of high resolution GIS based mapping of littoral habitats will allow to obtain more detailed data on the vertical zonation and extent of the most abundant assemblages. Furthermore, the drone technology will represent even more a historical baseline to follow temporal dynamics of marine vegetation, for both the early detection of native species regression and the spreading of non-indigenous one.

Key-words: CARLIT, *Cystoseira*, GIS, MPA, UAV

Introduction
The Mediterranean coastal seascape has sharply changed in the last decades, mainly due to the disappearance of species sensitive to local anthropogenic disturbances and global climate changes. Benthic communities associated with rocky littoral habitats are known to respond significantly to slight changes of environmental conditions, thus they are considered as good bioindicators of water quality for the implementation of Water Framework Directive (WFD) 2000/60/EC. Their occurrence is taken into account for the assessment of the ecological status of water bodies in the Mediterranean Sea, according to the Cartography of littoral and upper-sublittoral rocky-shore communities (CARLIT) method (Ballesteros *et al.* 2007). They include shallow species, such as *Cystoseira* spp., threatened (UNEP/MAP-SPA/RAC, 2018) because experiencing a huge decline in Mediterranean Sea (Thibaut *et al.* 2015). This is especially noticeable where an historical baseline of long phycological tradition is present, allowing to recognise an appropriate reference point and correctly interpret the possible decline. On the contrary, this is not

evident when proper dated historical records are lacking. Despite the CARLIT methodology is widespread all around the Mediterranean Sea (Badreddine *et al.* 2018 and reference therein), only a few examples of re-surveys after many years have been reported in literature, namely for France (Blanfuné *et al*. 2017) and Spain (Torras *et al*. 2015).
The method proposed by Ballesteros *et al.* (2007) has been modified, simplified (Blanfuné *et al*. 2017 and references therein) and empirically adjusted (Lasinio *et al.* 2017). Notwithstanding, to date, no technological improvements have been yet considered to increase the amount and resolution of collected information during the monitoring of rocky shore communities, especially for detailed shift detection. In recent years, Unmanned Aerial Vehicles (UAVs) or briefly 'drones' became a powerful tool for environmental applications including surveying and monitoring, that are essential for the implementation of habitat mapping and conservation measures (Lorah *et al*. 2018; Ventura *et al.* 2018).
In the Sinis Peninsula (Western Sardinia, Italy), apart from former punctual references, i.e. phycological lists (Cossu, 1992; Gueneau *et al.* 1992), the CARLIT assessment of Guala *et al.* (2010) performed during spring 2008 is the most significant oldest semi-quantitative baseline of macroalgal assemblages.
This paper aims to re-evaluate the CARLIT along the same strength of the coast, exactly 10 years later, in order to assess historical change of macroalgal communities and water quality along the Sinis Peninsula. Additionally, the potential of a commercial drone have been assessed i) to test the feasibility of data acquisition for the addition to the CARLIT protocol; ii) to explore new type of data available from this type of approach; iii) to built a detailed reference baseline for future comparisons in the study area.

Material and methods
This study was carried out along the Marine Protected Area of Penisola del Sinis - Isola Mal di Ventre (thereafter, MPA) located in the Middle-West coast of Sardinia (Italy). The shoreline is characterized by different coast typology: low rocky shores and cliffs alternating with sandy beaches for about 27 km of coastline. Northwards the MPA is exposed to western winds, while southwards (inside the Gulf of Oristano) it is sheltered from dominant winds and waves. The study area is contiguous to a wide wetland system (Cabras and Mistras lagoons) and the Tirso mouth, the main river in Sardinia, both affecting the Gulf of Oristano, where they flow into. The area is scarcely urbanised with a demographic density of about 90 inhabitants/km^2 almost stable during the decade 2008-2017 (ISTAT, 2017). As a matter of fact, it can be considered very low compared to other Mediterranean sites where Fucales assemblages were assessed (Thibaut *et al*. 2015; Grech, 2017) such as Portici in the Gulf of Naples (Italy) with 12,000 inhabitants/km^2. In the entire Sinis coast, 12,000 is the mean number of touristic influx per season. A treatment plant system, devoted to civil and industrial wastewater, is located about 10 km apart from the MPA. It was settled in the 80s and was dedicated at the beginning to the industrial area and the Oristano city. Between the years 1990-2000, the plant system was extended to treat also neighbouring municipalities wastewater outputs. The treatment plant receives wastewater for a Population Equivalent or unit per capita loading (PE) of 79.423 (N. ab/eq) with a flow of 31.111 mc/g. (Provincia di Oristano, 2014). Discharge outlet flows into the industrial port channel and then into the Gulf of Oristano. The water circulation is mainly forced by the NW wind and is characterised by a short water-residence time (Cucco *et al.* 2006), with a fast and intense exchange of water masses with the open sea. Under the most common wind forcing, 1.5 days is required to renew the

70% of the gulf water.
The re-monitoring of CARLIT was carried out along the entire coastline of the MPA through the traditional method, by assigning the sensitivity level (SL) to benthic communities detected along the rocky coast and assessing the Ecological Quality Ratio (EQR) according to Ballesteros *et al*. (2007). The EQR values were calculated for each of the two water bodies (WB1 and WB2, respectively inside and outside the gulf) as defined by Guala *et al.* (2010) on the basis of the different geographic orientation and exposure to prevailing winds. In addition, we used a DJI Phantom4, a consumer grade drone, to collect macroalgal assemblage orthophotos. Take-off and landing were controlled manually from a small boat or by walking along the coastline. Different geomorphologic relevant features (*sensu* Ballesteros *et al.*, 2007) were selected to test the cruise feasibility and the cartographic rendering (i.e. accuracy, distortion, coverage) at different flying height (from 5 to 20 m a.s.l.). All the images were edited using the photogrammetric software Agisoft PhotoScan Professional and Structure from Motion (SfM) techniques to obtain a digital model of the coast and analysed through free and open source Geographic Information System (QGIS) to compute the surfaces covered by the most abundant assemblages.

Results
The EQR values after 10 years were maintained both in WB1 (from 0.64 to 0.60) and WB2 (from 0.97 to 0.95), with the same 'Good' and 'High' ecological status respectively. Superimposing the stretches of coastline with corresponding SL assigned to thriving communities in 2008 and 2018, some slight differences were detected and are represented in Fig. 1.
Through the drone survey, more than 2,500 high-resolution orthophotos of macroalgal assemblages were collected. The best compromise between sampled area and resolution was found at 15 m of flying height. Through the image processing, high-resolution ortho-mosaics (0,5 cm/px; Fig. 1) and digital terrain models (DTMs) were obtained. From the digital models and orthophotos of the coast, the coverages of the shallow subtidal communities and terrain attributes (slope, aspect, rugosity) were estimated with a decimetric accuracy and a sampling effort of 2.6 h/km. As additional result, here we defined the Index of Cystoseirety (IoC), namely the ratio between surface of the species and the coastal length (see example reported in Fig. 1).

Discussion and conclusions
The CARLIT index shows that the water quality did not changed from the first assessment in the MPA. The drone survey allowed to integrate the CARLIT data with more accurate information on the distribution and the surfaces covered by the most abundant communities.
This study demonstrated the high stability of the 10-years-later-CARLIT assessment (among the first in the Mediterranean Sea and the first reported in Italy). Despite this index could be performed every three years across all the water bodies without significant reduction in the confidence of EQR classification (Cavallo *et al*. 2016), it was no longer monitored in the study area after 2008 and this contribution updated the information to 2018.

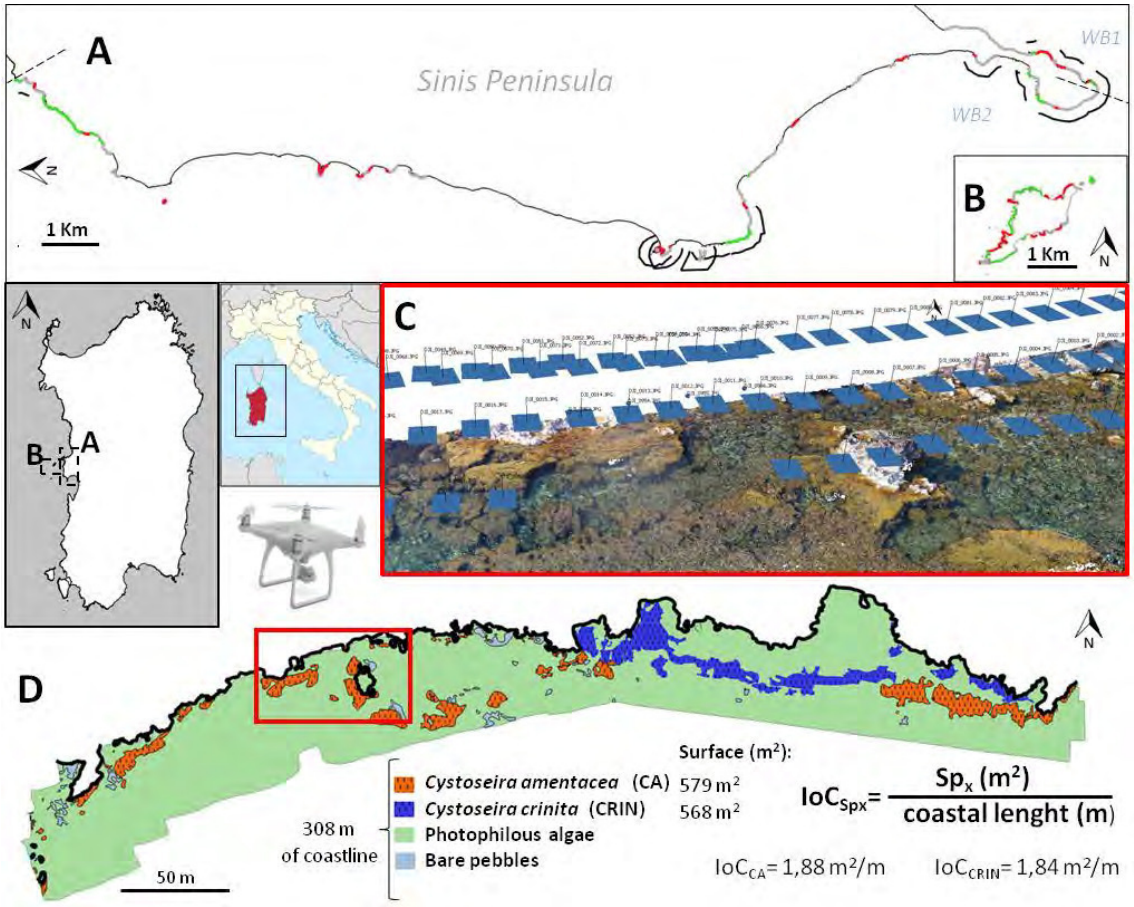

Fig. 1: SL variation after 10 year along the Sinis coastline (Red=decrease; Green=increase; Grey=stable). Black line below the coastline indicate the sectors where orthomosaic photos where acquired (A, B). Example of a 3D model coastline with the superimposed orthophotos (C). Final result of drone survey with delimited macroalgal assemblages (D).

Our results point out once more, as suggested by Guala *et al.* (2010), that Sinis coast (outside the gulf) is the ideal candidate to represent a proper reference site, at least for the biogeographic area that includes the coastline of Sardinia and the north Tyrrhenian sea (see Bianchi, 2004), with highly biodiverse stands along a very heterogeneous geomorphologic coastline. Considering the high level of EQR in WB2, with lushy forests of *Cystoseira amentacea* and *C. crinita*, the area is worth of conservation measures, detailed investigations and more frequent monitoring programmes. On the contrary, higher trophic conditions are evident inside the gulf, probably because of the influence of surrounding inland water systems. Although the assessment of the anthropic pressure was beyond the scope of this work, tourism activities in the Sinis area have shown a definitely slight increase in recent past. We felt confident that habitat destruction could be excluded at present, however human trampling should be monitored as some patterns may be significant and no data are currently available.
The slight difference of SLs recorded along a few stretches of coast (Fig.1), could be due to both natural temporal dynamics of algal communities and the influence of human pressure. Notwithstanding we cannot exclude the bias of the subjectivity of the CARLIT index assessors.

The innovative technique of post-processing images from drone allowed us to compute coastal surfaces covered by the most abundant community assemblages with a decimetric accuracy, through a relatively low sampling effort considering also the increased amount of information acquired. The current contribution is far to propose a further integration of CARLIT, that is complete for the purpose for which it was conceived. However, the information coming from ortho-mosaics and terrain attributes allow to detaily characterize the forests and open new scenarios of studies and analysis such as the IoC and the computation of spatial patterns through a seascape ecology approach.
This study suggests that new developments are available for the assessments of shallow rocky shores and that complementary data collected by drone could be coupled to raise the amount and the quality of data from standard monitoring. The use of drone technology, in conjunction with SfM algorithms, will offer a powerful contribution, that is additional to the EQR assessment, used until now. Furthermore the post processing workflow could be remarkably improved and the selection with mapping of the communities could be considerably simplified through algorithms (Adams, 2008), i.e. Object-based Image Analysis (OBIA; Ventura, 2018). Once implemented, such an analysis could automatically detect CARLIT categories on the ortho-mosaics to be furtherly validated by an expert and trained eye. Future habitat mapping, with improved sensors and longer battery life of drones, will easily advance the classic visual method, adding detailed and georeferenced data about assemblage coverage and terrain attributes (i.e. slope, aspect, bathymetry and DTM) with relatively low cost, sampling effort and high accuracy. These achievements will give a detailed baseline to follow temporal dynamics (e.g. the early detection of macroalgal community shifts and slight SL changes with high resolution models of coastline), and could allow to disentangle global changes to local one (punctual pollution or habitat destruction) in an area that is still far from to be properly studied from a phycological point of view.

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