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MAPPING BENTHIC HABITATS AND COASTAL SEAGRASS ECOSYSTEM USING NEW GENERATION OF HR MULTISPECTRAL SENSORS

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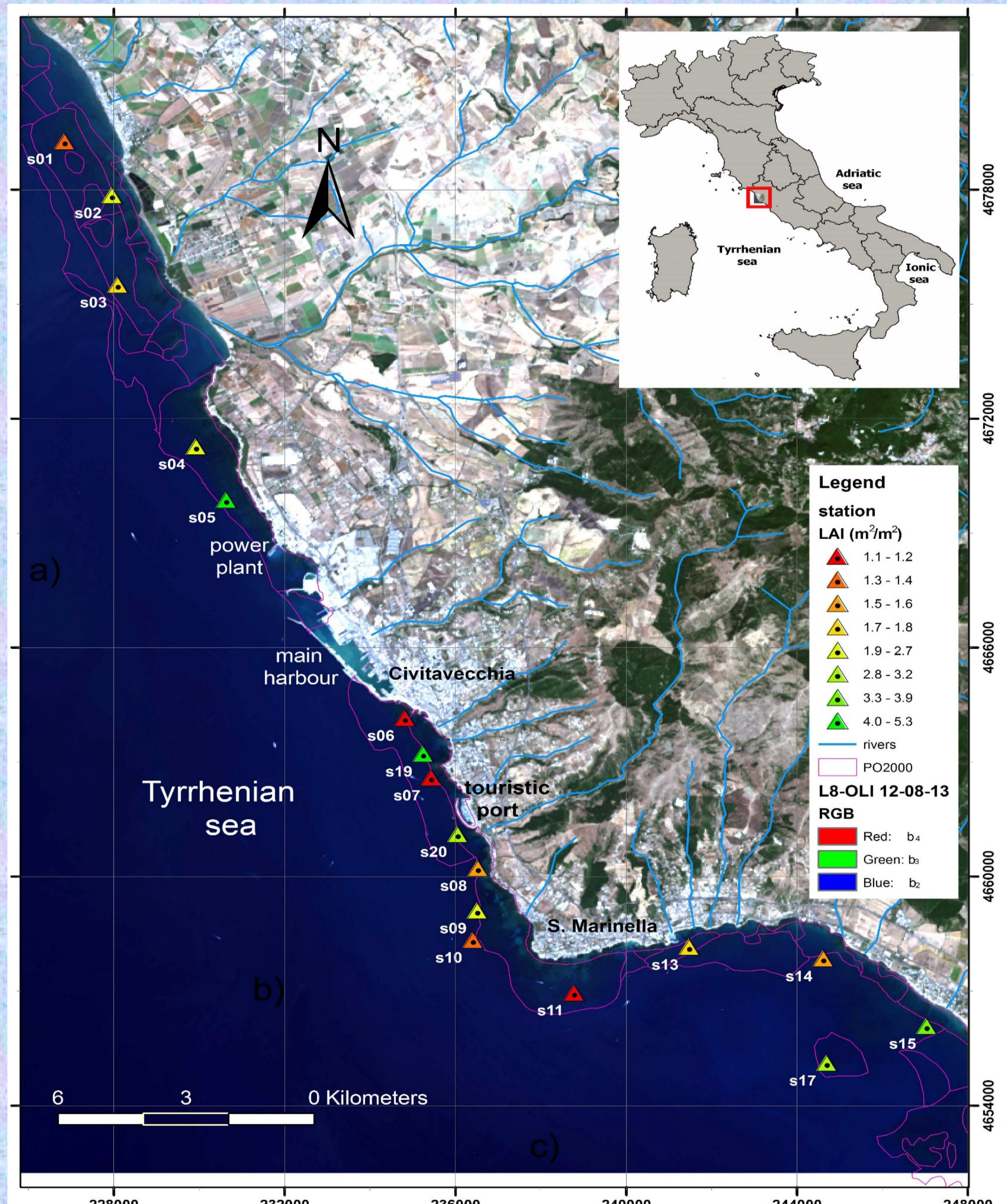
Mediterranean sea beds and benthic ecosystems, as the vulnerable *Posidonia oceanica* (PO) meadows, are increasingly being threatened, by various anthropogenic pressures and climate change effects; along the 8000 km of Italy coasts they are poorly mapped and the existing maps are not up to date and have often unsatisfying spatial resolution for properly evaluating their health status. Remote sensing (RS) has proved one of the most cost effective methods for coastal operative monitoring, to support the sustainable management of these shallow water areas. However in this context, the effective exploitation of the RS satellite techniques requires finer ground geometrical resolution, radiometry sensibility and capacity to properly account for the atmospheric noise (especially in term of the AOD – Aerosol Optical Depth, main contribution) increase of water turbidity and possible spectral contamination (adjacency effects) from near lands reflectance. Since the new families of polar satellite with HR (High Resolution) multispectral sensors, like Landsat 8 OLI (L8OLI) and Sentinel 2 MSI provide a useful opportunity in this sector previously unavailable, this work focused on preliminary test of L8OLI data for seagrass (PO) mapping in the middle Tyrrhenian optically complex shallow waters. In addition to near synchronous sea truth information, including the PO LAI (Leaf Area Index) used for calibration/validation purposes, different image based approaches for atmospheric preprocessing of these multispectral HR data were exploited.

Operative EO based monitoring of marine ecosystems and PO

- Sea truth calibration based spatial assessment of:
  - Geometrical features (distribution, extension, fragmentation,);
  - Biophysical parameters (species, density, biomass, shoots n., LAI, foliar constituents);
  - Changes detection, plant stress and health (mapping, phenology, biometry, genetics);
- EO HR ground/radiometric resolution: ~ 1-30 m., ~10-12 bit, multi/hyperspectral data;
- Periodicity dependent on site (constraint) and user needs (requirement), according to vegetation and seagrass dynamic (typically ~10 days);
- Atmospheric noise effects removal (Rayleigh and image based Aerosol distribution retrieval);
- Water column modelling (Lyzenga (1981) or bio-optical modelling);
- Geographic scale of thematic maps: ~1:30.000-1:5.000;

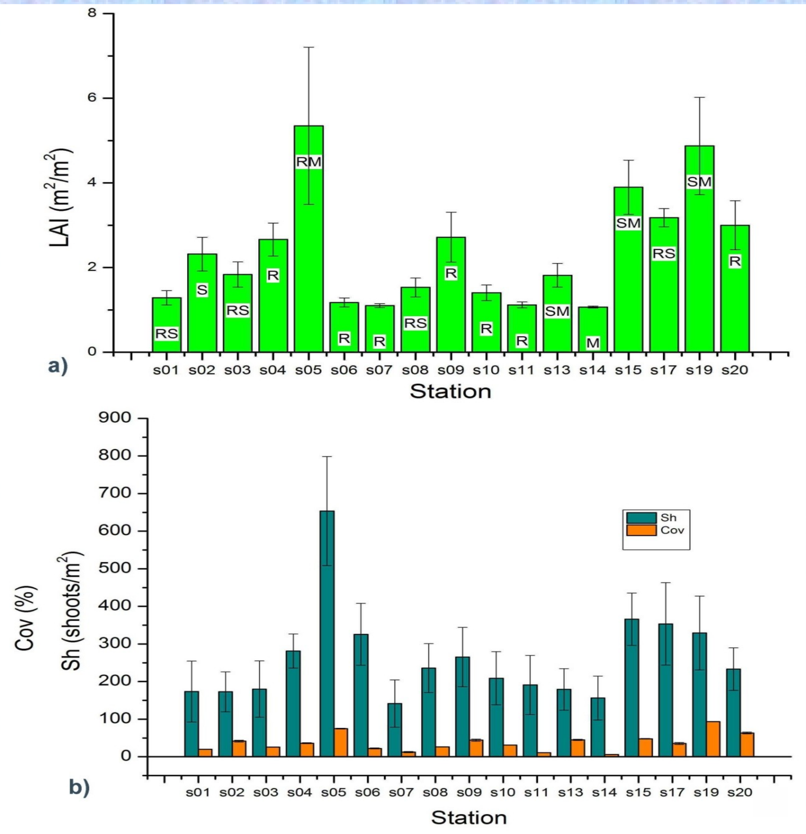
Study area and sea truth



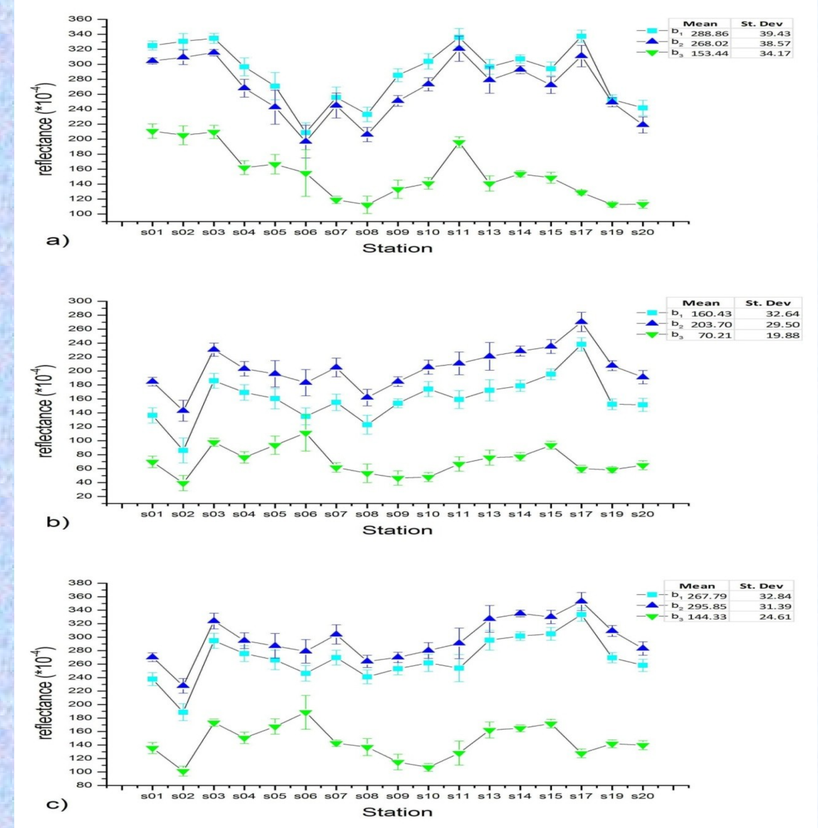
Coastal study area in the middle Tyrrhenian sea, including the sea truth measurements stations with point LAI distribution L8 OLI true colour acquired on 12-08-2013. The pre-existing PO limits (PO2000) surveys are reported in violet (according to E.U. 92/43/EEC Habitat Directive).

Substrate type have been also recorded in all sampling point and they have been classified into 6 classes: rock (R), sand (S), matte (M), rock-sand (RS), rock-matte (RM), sand-matte (SM).

PO measured biophysical parameters and atmospherically corrected spectral signatures



Sea truth data referring to PO biophysical parameters as Density [shoots/m²] *a)* and Cover (%) *b)*. The two measured parameters are represented by using the same y-axis and with related errors bars for each measurement station. LAI [m²/m²] estimates of PO meadows derived from sea truth data and laboratory biometric analyses for the measurement stations (Borfecchia et al.,2013 a and b).

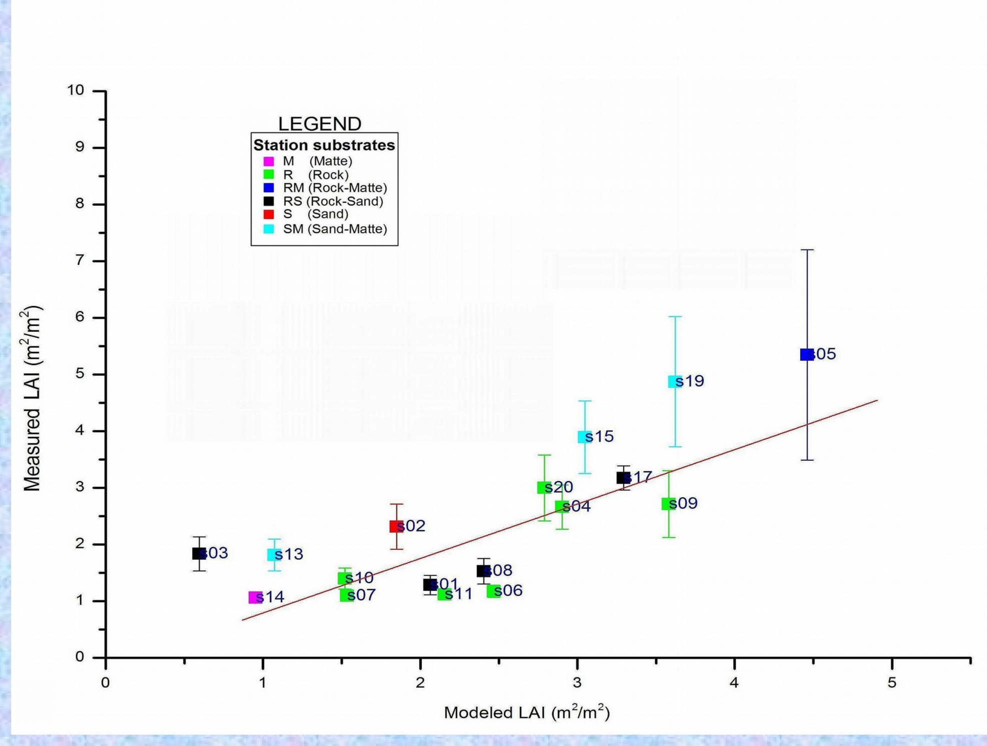


Spectral signatures (reflectance*10^{-4}) of the measurement stations in the short-waves bands (b_1 (coastal), b_2 (blue) and b_3 (green)) are obtained by means two software ATCOR (Richter, 2011) and ACOLITE (Vanhellemont and Ruddick, 2014) from three different atmospheric correction procedures, based on NIR and SWIR bands and so indicated:

a)ATCOR (not accurate AOD and with adjacency effects);

b)ACO-NIR (accurate AOD, but without adjacency effects);

c)ACO-SWIR (accurate AOD, but without adjacency effects).



The graph shows the comparison of measured (Y-axis) versus modelled (X-axis) LAI [m²/m²] using multivariate model including spectral indices and bathymetry at station levels. The error bars and different substrates were indicated according the legend.

Results

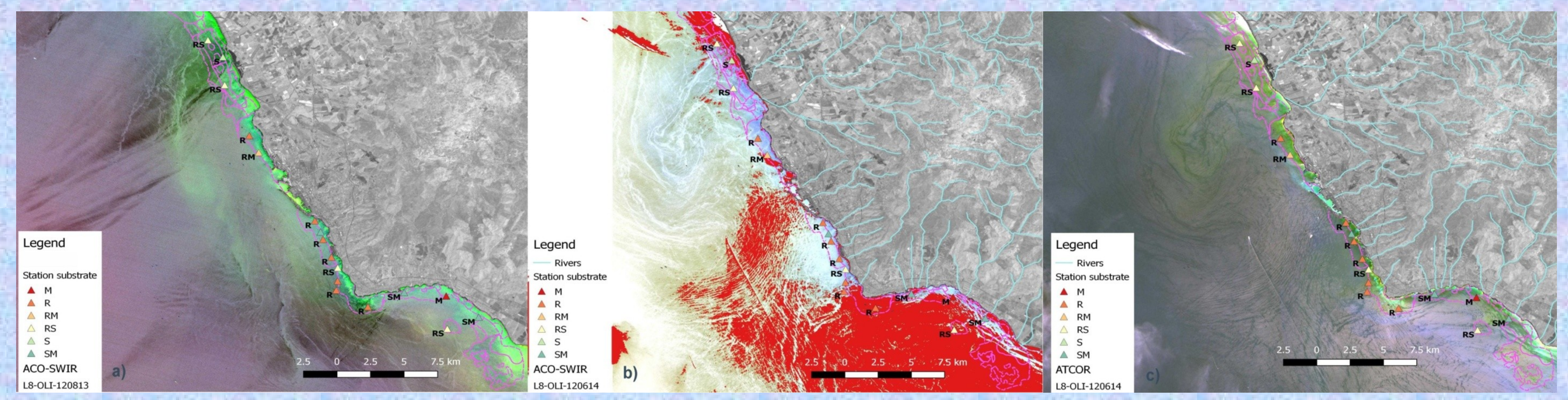
- In general, an overall agreement of the two modelled output layers of the sea bed substrates and PO LAI distributions with the pre-existing limits of PO meadow (PO2000) and the sea truth station data has been found.
- The best PO LAI [m²/m²] mapping results (correlation & RMSE) were obtained from the assessed weighted multivariate modelling based on ACO-SWIR atmospheric correction. The highest thematic accuracy was instead achieved for distribution of the sea bed substrates produced by means of ED classification of the atmospherically corrected (ATCOR) L8OLI frame acquired on 12-08-2013.
- The results achieved demonstrated the L8 OLI sensor effectiveness for seabed/PO/seagrass mapping and monitoring in the optically complex shallow water, evidencing the specific atmospheric correction relevance.
- Thanks to its acquisition channels, improved in terms of spectral and radiometric features and with the introduction of the new costal band, it was possible to produce suitable PO LAI and sea beds substrate distribution maps in a significant portion of the middle Tyrrhenian coast.

Conclusions

- The atmospheric correction of the synchronous L8 OLI frame was successfully carried out using the recent method of Vanhellemont et Ruddik (2015) implemented for HR multispectral data and optically complex shallow waters;
- From these preliminary results (to be improved through statistical/bio-optical modelling, Sentinel 2 data integration and further EO and sea truth data) the new L8 OLI system appears to be able to significantly contribute for operative HR monitoring of shallow waters and seagrass habitats, even if with limitations arising from cloud cover and sun glint conditions.
- A further preliminary indication, arising from the present work for the critical atmospheric pre-processing, is that in addition to per pixel AOD parameters effective retrieval, the adjacency effects removal capacity should be considered, especially in case of seagrass and PO meadows locations at land sea interface.

Atmospheric correction and preprocessing of the Landsat 8 OLI frames acquired on 2013-14

The suitable atmospheric correction of the remotely sensed HR data is mandatory for effectively monitoring and mapping the shallow waters and seabed. The original image was processed by removing the Rayleigh and aerosol effects (Vanhellemont et Ruddik, 2015). The first method provides a more effective per pixel AOD (Aerosol Optical depth) noise removing, also in case of optically complex shallow waters, but without a removal of adjacency effects, typical of land-sea interface areas. The second one, has less effective treatment of the AOD, but is able to correct for the adjacency effects.



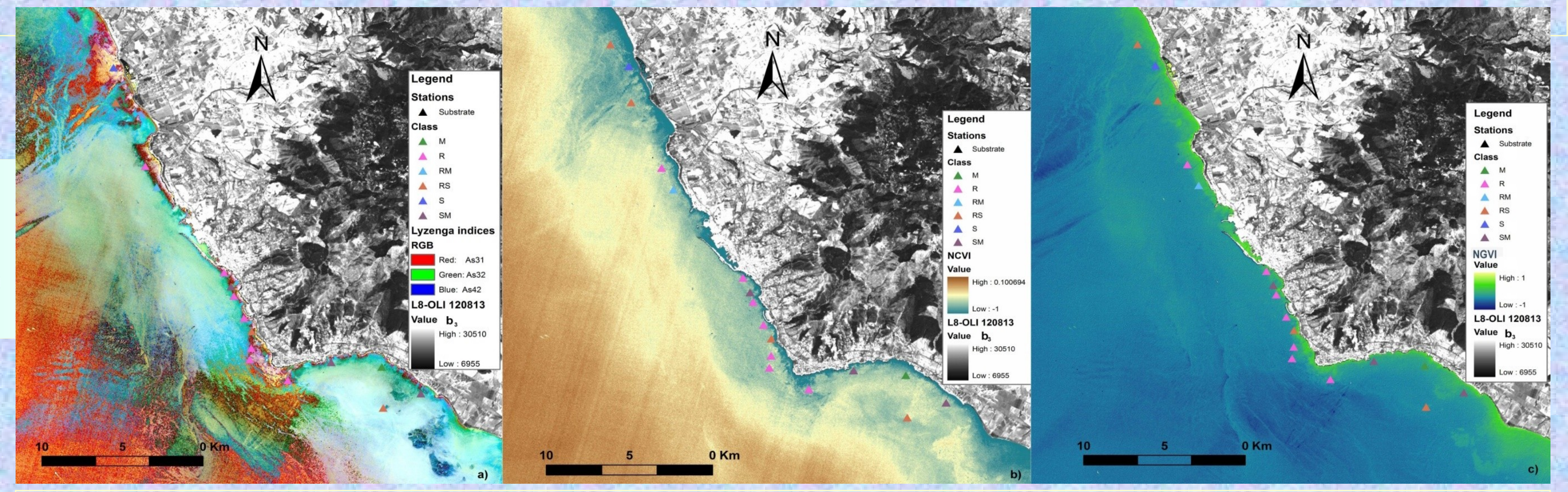
True color images of the 2013 **(a)** and 2014 **(b, c)** L8 OLI frames. The frames have been atmospherically corrected using the ACO-SWIR (**a, b**) and ATCOR (**c**) options. For the land background the red channel gray levels have been exploited.

Spectral indices

The application of on purpose developed blue-green spectral indices allowed to optimize spectral signal for PO and seabed retrieval from the atmospherically corrected reflectance data. The indices were implemented and tested using the spectral signatures of stations with homogeneous substrate. They have then exploited for LAI modelling over entire area of interest.

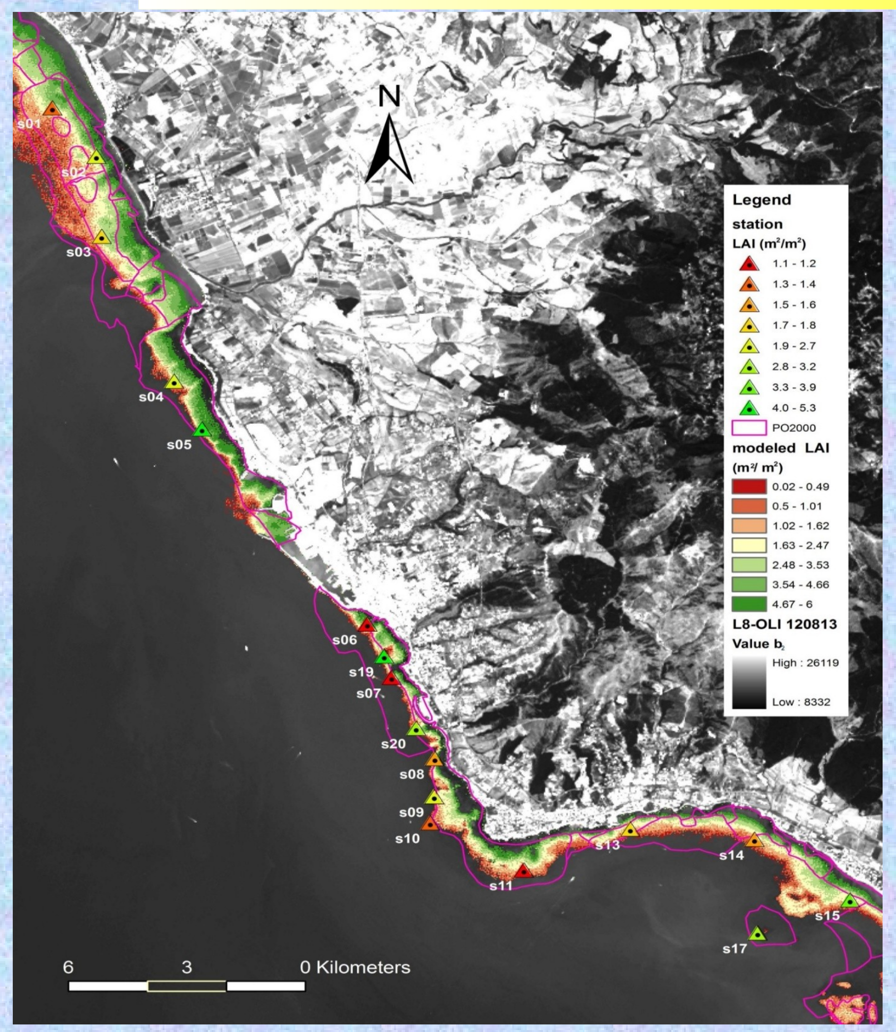
$$NCVI = (b_1 - b_2) / (b_1 + b_2)$$

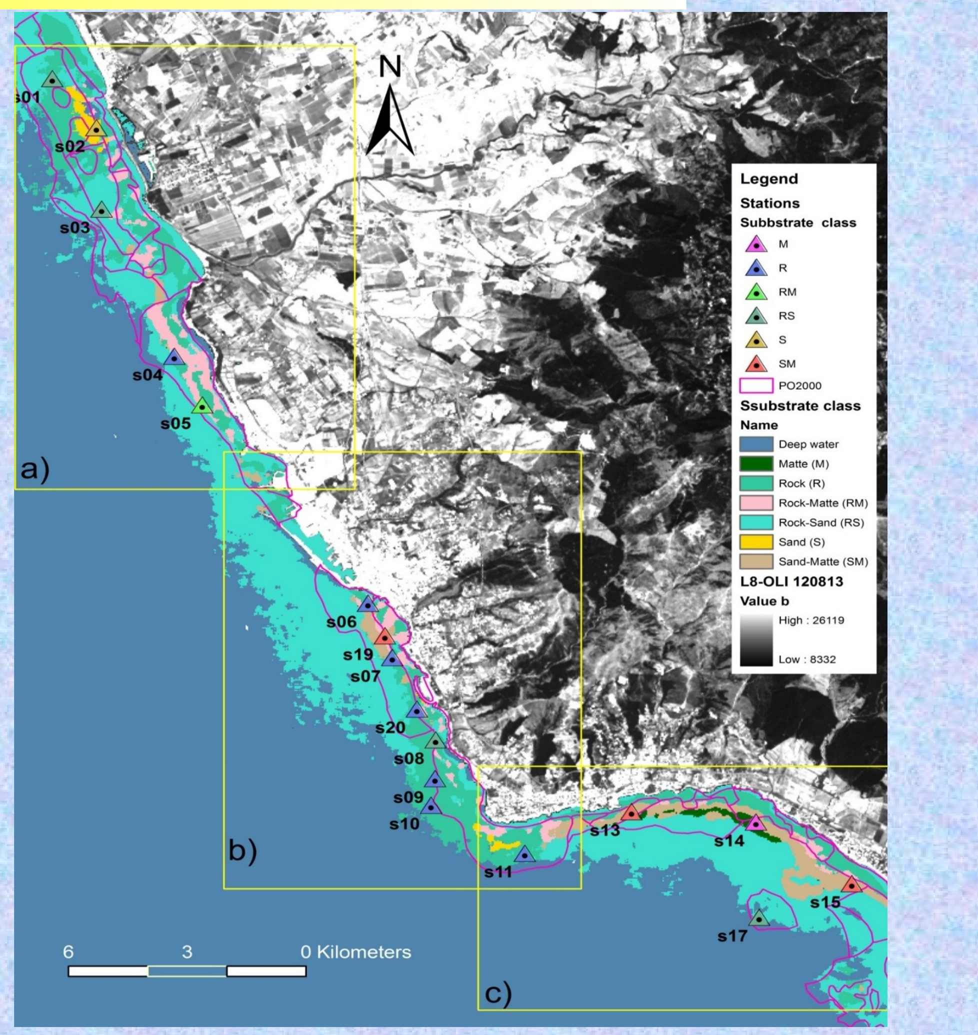
$$NGVI = (b_3 - b_2) / (b_3 + b_2)$$



a) True color image of the Lyzenga's indices obtained from the ACO-SWIR pre-processing for L8OLI 2013 image;
b) pseudo-color distribution maps of NCVI (Normalized Coastal Vegetation Index)
c) NGVI (Normalized Green Vegetation Index) indices.

Thematic maps of PO LAI distribution and substrate classification





Modelled LAI [m²/m²] of PO meadow (left) on different substrates using the ACO-SWIR spectral indices and bathymetry (R^2_{adj}=0.761, P-value(F)<0.0001,RMSE=0.175). Thematic map of different sea beds (right) was obtained from station spectral signatures corrected trough ATCOR method (Overall Accuracy =86.4%).

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