ASTER and WorldView-2 satellite data applications for recognition of salt water intrusion on forest vegetation

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ABSTRACT
The salinization of the coastal aquifers is a worldwide issue affecting many delta areas. The low-lying Ravenna plain (Italy) is strongly drained, highly subsident with the only topography present in dune and paleodune areas. In this context, the underlying phreatic aquifer is completely brackish and salty and the only fresh water lenses are located below the historical pinewoods (paleodune) and along the actual dune belt. Changes in the water salinity are able to induce variations in the leaves properties and vegetation cover, recognizable by surveys carried out in different spectral bands. Furthermore, a comparison between remote sensing satellite images with different resolution, ASTER and Worldview-2, was carried out using the Normalized Difference Vegetation Index (NDVI). Inside the San Vitale pinewood (Ravenna, Italy), different sample areas were selected within the Thermophilic Deciduous Vegetation because it covers more than 80% of the studied pine forest. The NDVI, calculated with traditional bands, identified the same stressed areas shown by both satellite data. Instead, using the new Red Edge band of the Worldview-2 image, a greater correlation between NDVI and groundwater salinity was detected.

INTRODUCTION
The salt water intrusion analysis is mainly carried out through generally time-consuming and relatively expensive ground monitoring campaign (Pu and Landry, 2012). In contrast, satellite data allow periodic monitoring of large areas, although some field work is still necessary for the image validation.
The aim of this work is to identify portions of pinewood affected by groundwater salinization through the multispectral satellite data analysis, with different spatial and spectral resolution. In order to quantify the benefits of both higher spatial and spectral resolution, ASTER and Worldview-2 results were compared.
The association between remote sensing techniques and vegetal biophysical indicators is exploited for the diagnosis and monitoring of threatened habitats (Barton 2012). In particular, several studies have used the NDVI to analyze indirect effects of environmental changes (Aguilar et al. 2012), including those due to processes of salinization (Zhang et al. 2011). Increased water salinity induces changes in chlorophyll concentration and therefore a photosynthesis slowdown (DeLaune et al. 1987). In detail, by measuring the relative difference between responses of chlorophyll and cellular structure in red and near-infrared bands (Peñuelas, 1998), the NDVI analyzes the greenness and productivity (Reed et al. 1994) of the plants.
The study area is San Vitale roman-time pinewoods that have suffered from groundwater salinization for the past several years. The main causes of the widespread salt water intrusion in phreatic aquifers are: natural and anthropogenic land subsidence, low topography, low natural hydraulic gradients and artificial drainage (Antonellini et al. 2008).
The Vegetation map defines two main vegetation type "Thermophilic Deciduous Forest" (below TDF) and "Thermophilic Evergreen Forest" (below TEF) (Regione Emilia Romagna, 1999). Because TDF cover more of the 80% of San Vitale, the study was performed within this vegetation type. The pinewood vegetation has been classified, excluding *Pinus pinea*

species from the classification because they are not able to reproduce inside these natural areas (Piccoli et al., 1991).

METHODS

In this study, satellite images with different spatial and spectral resolution and groundwater salinity data were used. ASTER sensor acquires invisible and infrared ranges with a spatial resolution of 15 m while Worldview-2 acquires data with spatial resolution of 2 m and has available in the same range four new bands. Both sets of data were acquired in the May 2011.

In the first step, the NDVI was implemented for both available remote sensed data using the same traditional bands: Red (0.630-0.690 μm) and NIR (0.780-0.860 μm) for ASTER image, Red (0.630-0.690 μm) and NIR1 (0.770-0.895 μm) for Worldview-2 image.

The NDVI was calculated for the same five Areas of Interest (AOIs) in both satellite data (CN1, CN2, CS1, CS2, S). For each AOI of every image, basic statistics of NDVI values were calculated. Consequently, the frequency histograms of AOIs were plotted to explain the data distributions and Skewness and Kurtosis (NIST/SEMATECH 2003) shape factors were obtained to evaluate deviation from the Gaussian trend.

In every image, the threshold of 5% for the AOI with higher NDVI was selected as criteria to compare the vegetation health status. Later, this value was used to quantify the percentages of pixel of the other AOIs corresponding to stressed vegetation that fall below this limit. This statistical analysis allowed for the identification of less green parts of the vegetation compared to the reference area. Therefore, in order to analyze possible advantages of high spatial resolution in respect to the medium resolution in this study, ASTER and Worldview-2 results were compared to verify if the same stressed areas were recognized.

In the second step, with the aim to study the greater spectral resolution contribution of Worldview-2 data, the same procedure with the new bands Red Edge (below RE, 0.705-0.745 μm) and NIR2 (0.860-1.040 μm) in NDVI index was applied.

The validation of these results was made by contemporaneous groundwater salinity measurements.

RESULTS

The main AOIs results are summarized in the Figure 1. The average groundwater salinity ranges between 1 and 7 g/l along an East-West gradient. The heterogeneous pine tree density goes from 6 to 25 individuals/hectare. The average NDVI values obtained by traditional bands (NDVI ASTER, NDVI WV-2) are coherent between the satellite data. For WV-2 image, the NDVI values computed as Red Edge-NIR1 and Red Edge-NIR2 combinations show a different discrimination between AOIs regardless of general different values due to the various bands used (Fig.1a). Considering the relative frequency histograms of the NDVI originated with traditional bands instead, the distribution values shows different behaviors for the two remote sensed data. In particular, for some WV-2 AOI the graph follows a bimodal trend (Fig.1b).

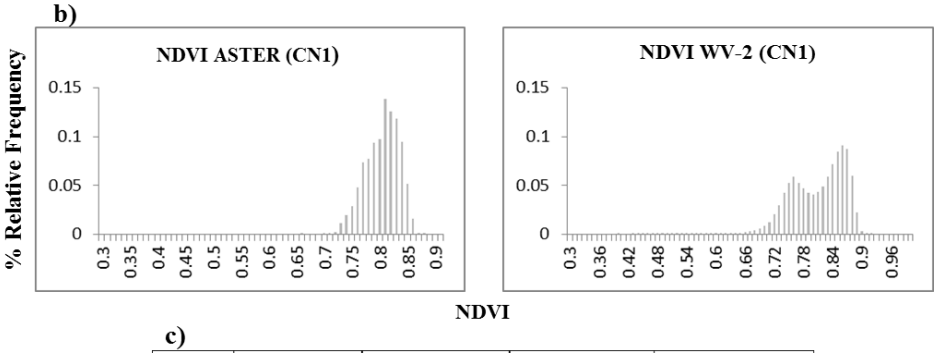
Finally, the AOIs ranking has been done in terms of salinity, pine tree density and both traditional (NDVI ASTER/WV-2) and new NDVI (NDVI WV-2 RE_NIR1/2), after the application of the whole procedure for all calculated NDVI (Fig.1c).

The overlays between groundwater salinity and NDVI results (Fig.2) show the different ability of traditional and new NDVI to recognize the areas stressed by groundwater salinity.

a)

AOI	Salinity g/l	Pine tree density N°/ha	NDVI ASTER	NDVI WV-2	NDVI WV-2 RE_NIR1	NDVI WV-2 RE_NIR2
CN1	3.903	19.8	0.799	0.805	0.298	0.316
CN2	2.191	25.2	0.813	0.826	0.304	0.318
CS1	7.124	7.6	0.823	0.837	0.297	0.312
CS2	1.766	5.8	0.841	0.850	0.313	0.327
S	3.425	14.1	0.821	0.829	0.299	0.317

b)



c)

AOI	Salinity g/l	NDVI WV-2 RE_NIR1/2	NDVI ASTER/WV-2	Pine tree density N°/ha
1	CS2	CS2	CS2	CS2
2	CN2	CN2	CS1	CS1
3	S	S	S	S
4	CN1	CN1	CN2	CN2
5	CS1	CS1	CN1	CN1

Figure 1.
a) NDVI analysis results. Light gray color represent healthiest AOIs while dark gray color indicates the more stressed AOIs.

b) Example of relative frequency histogram, related CN1 AOI, for traditional NDVI distribution values.

c) AOIs, ordered from the healthiest AOI (1) to the most stressed (5), for each considered parameter.

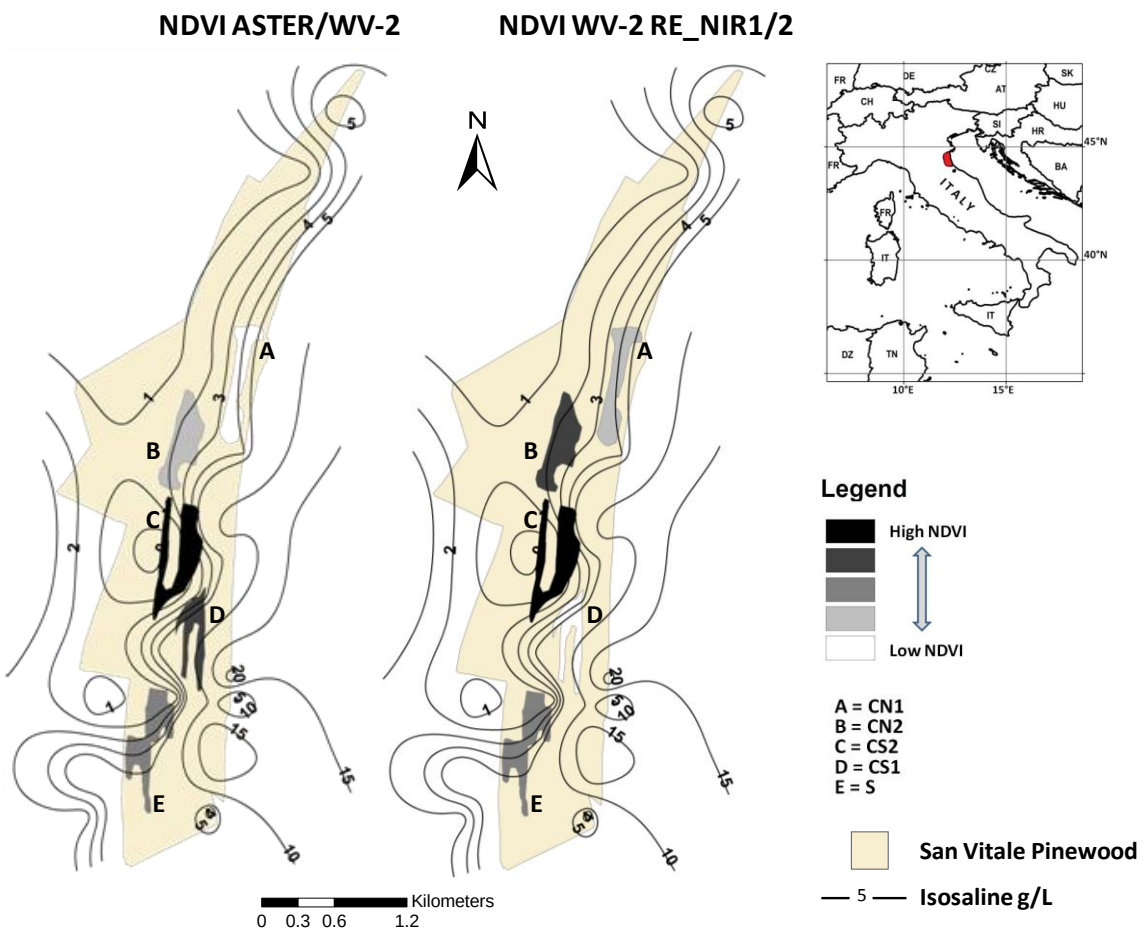


Figure 2. Overlay between groundwater salinity and NDVI results

DISCUSSION AND CONCLUSIONS

The NDVI results, calculated with same traditional red and infrared bands, are identical for ASTER and Worldview-2 data in term of AOIs discrimination.

Based on mean NDVI value, the south AOIs (CS2, CS1, S) were identified as less stressed areas compared to north samples (CN2, CN1). These results aren't agree with an increase in salinity along East-West gradient. The CN2 and CN1 areas are also the areas with the highest pine trees density and their low NDVI values confirm that the pine trees are a negative factor for the overall pine forest health.

In general, the response of the two satellite data seems to be influenced in the same way by pine trees density, but the contribution of the WV-2 higher spatial resolution is evident in the relative frequency histograms analysis. In fact, the CN1 and CN2 (partly S) NDVI values distribution have a bimodal trend, with the peak centered at lower NDVI values corresponding to pine species, as verified by further insights. The high spatial resolution, indeed, allows for the creation of sub-AOIs that exclude the pine trees.

Best results were obtained with the higher spectral resolution WV-2. New band Red Edge provides results less affected to pine trees density because it discriminates better evergreen and deciduous plants. The NDVI values obtained replacing the red band with Red Edge are perfectly consistent with the groundwater salinity of the considered AOIs.

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