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SUPPLEMENTARY MATERIAL

Remote sensing of macrophyte morphological traits: implications for the management of shallow lakes

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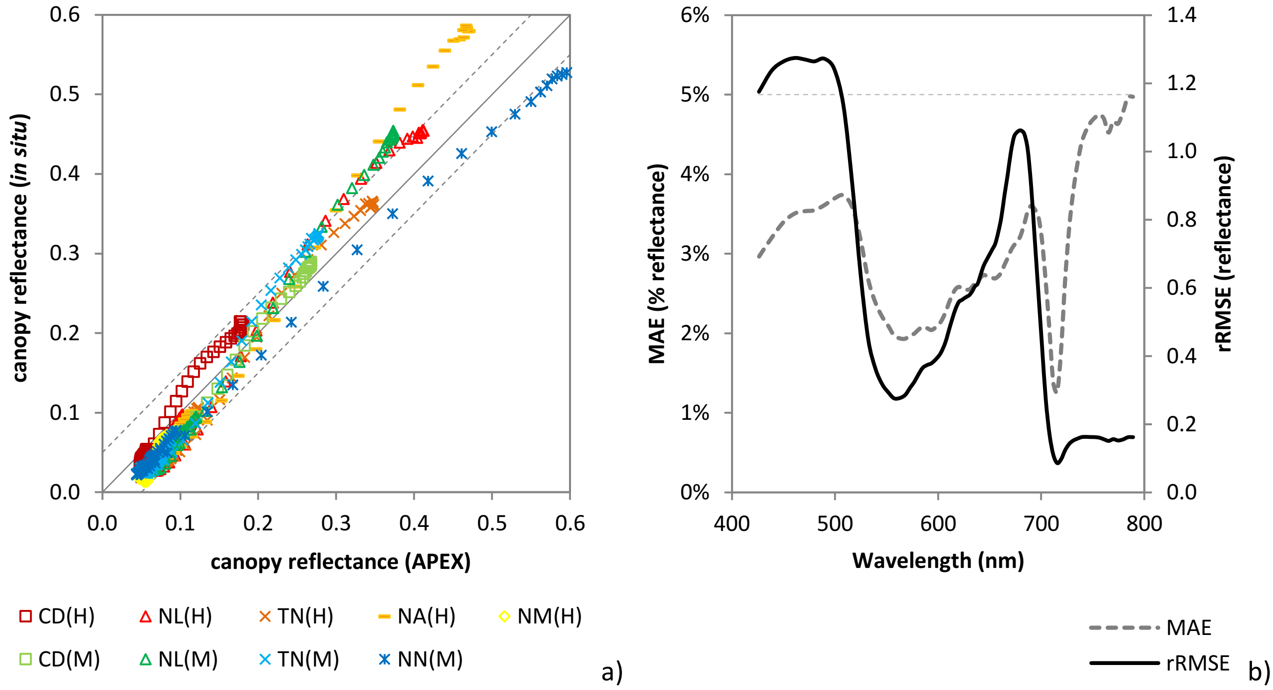
Atmospheric correction of APEX data

Radiometric quality of atmospherically corrected reflectance data for APEX data acquired during 2014 was assessed against macrophyte *in situ* canopy spectra and collected within 3 to 4 days (16-18 July 2014 for Lake Hídvégi, 23 September 2014 for Mantua lakes system) from sensor overflights (19 July 2014 and 27 September 2014, respectively). *In situ* canopy spectra of 9 plots in Lake Hídvégi (CD1, NA1, NA2, NL1, NM1, TN1, TN2, TN3, TN4) and 5 plots in Mantua lakes system (CD1, NL2, NN2, TN2, TN3), listed in Tab. 3, were resampled to match APEX bands in the range of interest of the Spectral Indices tested (420-800 nm), and a direct comparison was carried out with atmospherically corrected APEX reflectance spectra extracted from 3x3 pixels around each plot geolocation according to the maximum vegetated pixel approach (see "Estimation of macrophyte morphological traits" subsection). The comparison was done grouping *in situ* and APEX spectra per macrophyte species at each study site (Supplementary Fig. 1a), and Mean Absolute Error as well as rRMSE (expressed as reflectance) for each APEX spectral band were calculated (Supplementary Fig. 1b), with reference to *in situ* canopy reflectance.

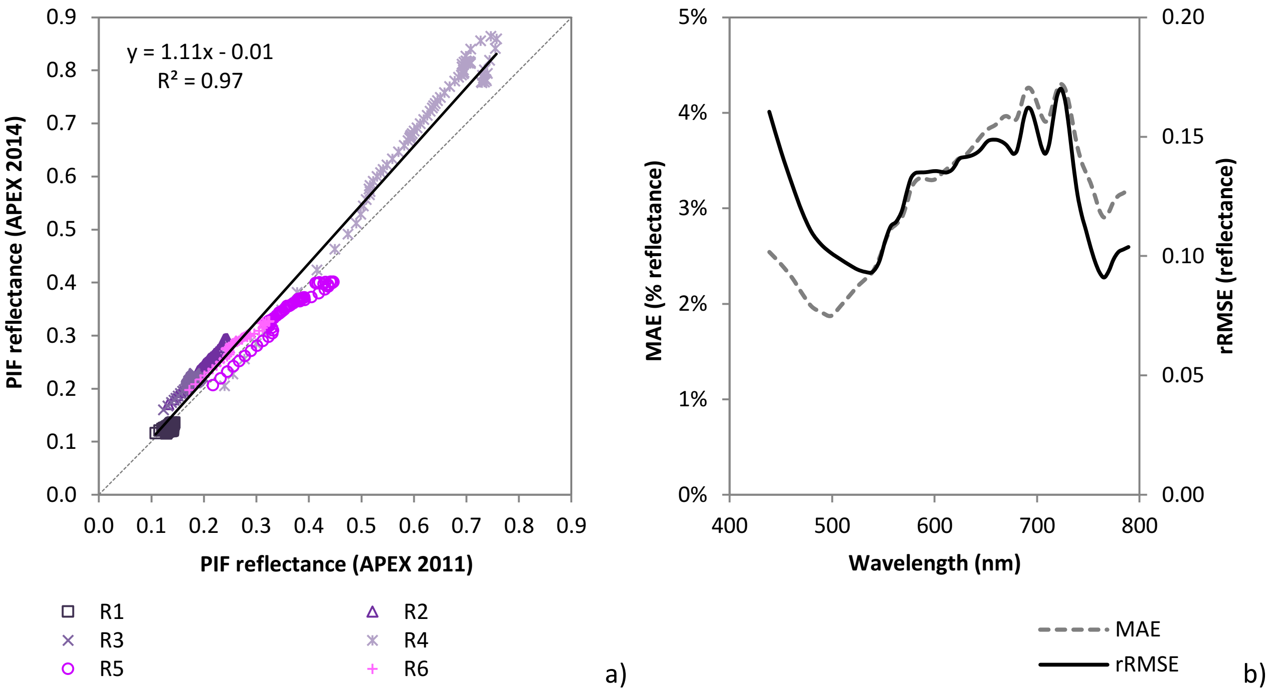
Apart from some point belonging to dense cover species at higher reflectance values within NIR region (*i.e.* NA and NN), the reflectance difference between APEX data and *in situ* reference spectra is below 0.05 (or 5%) across the spectral range considered, and the corresponding spectral angle difference vary from 0.06 (NN plot in Mantua lakes system) and 0.36 rad (NL plot in Lake Hídvégi). MAE of SIs used in morphological trait models (GSAVI, EVI, CIre) and derived from APEX corrected bands, with respect to indices derived using *in situ* canopy spectra in within 0.065 and 0.309 in SI unit, corresponding to percent errors in the range 13-24%. Such canopy reflectance error level, *i.e.*, lower than 5% for single spectral bands and lower than 25% for composite SIs, assessed for atmospherically corrected APEX data, is considered acceptable.



Supplementary Fig. 1. Comparison of atmospherically corrected APEX macrophyte canopy reflectance with corresponding *in situ* spectra collected within 4 days from APEX acquisitions over Lake Hídvégi (H) and Mantua lakes system (M). a) Scatter plot of canopy reflectance values for each spectral band grouped at plant species level (1:1 continuous line and ±5% error dashed lines are included). b) MAE and rRMSE calculated over all species for each spectral band (5% error level highlighted by grey dotted line). CD, *Ceratophyllum demersum;* NM, *Najas marina;* TN, *Trapa natans;* NA, *Nymphaea alba;* NL, *Nuphar lutea;* NN, *Nelumbo nucifera.*

Radiometric comparison of APEX 2011 and 2014 over Mantua lakes system

An assessment of the relative radiometric accuracy of APEX data acquired on 21 September 2011 was run by comparing homologous reflectance spectra extracted from Pseudo-Invariant Feature (PIF) objects from 2011 and 2014 data. A total of 6 PIF objects artificial, consisting of built-up targets of different brightness (from dark asphalt parking lot to very bright industrial building roof), unchanged from 2011 to 2014, were selected directly on the two APEX images (R1-R6 targets). PIF objects reflectance spectra derived from atmospherically corrected APEX images were compared (Supplementary Fig. 2a), and Mean Absolute Error as well as rRMSE (expressed as reflectance) for each APEX spectral band were calculated (Supplementary Fig. 2b), in terms of difference between APEX 2011 and APEX 2014 reflectance values per each band. Supplementary Fig. 2 shows the good match between 2011 and 2014 data (R^2=0.97), and the very low difference up to 0.5 reflectance magnitude, while for higher reflectance values we can notice a tendency toward 2011 data underestimation compared to 2014. As this could be done to some anomaly with the brightest PIF object (R4), which might not have been so stable across the three years passed between the two APEX flight, and taken into account that relative error between the two reflectance cubes is lower than the error assessed for 2014 data with respect to homologous *in situ* spectra (MAE<4%), we can consider 2011 and 2014 APEX data radiometrically consistent with each other.



Supplementary Fig. 2. Comparison of atmospherically corrected APEX data acquired on 21 September 2011 and on 27 September 2014 over Mantua lakes system. a) Scatter plot of PIF objects reflectance values (1:1 dotted line and continuous regression line are included). b) MAE and rRMSE calculated over all PIF objects for each spectral band.