MONITORING OF INVASIVE AQUATIC PLANTS USING MULTITEMPORAL RAPIDEYE DATA

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ABSTRACT

Rising water temperatures due to climate change seem to favor thermopilic invasive aquatic plants. In Central Europe an increased spread of *Najas marina* and *Elodea nuttallii* can be observed. A monitoring system is required to estimate the effect of their expansion on the ecosystem. The observation of these spatiotemporal highly variable developments requires rapid on-demand information which can only be achieved by spaceborne multitemporal remote sensing data. The ability of RapidEye, which offers the desired temporal and spatial resolution, is tested. Two study sites in Bavaria (Lake Starnberg and Lake Tegernsee) were visited 2011 periodically to measure in-situ reflectance of *Elodea nuttallii* and *Najas marina* with submersible RAMSES spectroradiometers. Since measurements were performed directly above the vegetation patches, as well as beneath the water surface, information about water constituents is also available. The combination of two measurements of the downwelling irradiance in different depths allows the calculation of the vertical diffuse attenuation, which is as an apparent optical property (AOP) related to inherent optical properties (IOP) like Phytoplankton, colored dissolved organic matter (cDOM) and suspended particulate matter (SPM) content. Information about the water constituents is necessary to correct for the exponential radiation loss through the water column and to achieve bottom reflectances or water column corrected derivatives. The frequent reflectance measurements (14 days interval) allow building up a multiseasonal spectral library for both plants representing each phenological state. The in-situ derived attenuation measurements were used to calculate depth-invariant band ratios using a simple semi-empirical method based on logarithmic transformed and atmospherically corrected RapidEye data. These depth-invariant indices were also calculated for in-situ measurements. The transformed in-situ measurements were used as endmember in a subsequent linear spectral unmixing approach based on the matched filtering method. This was done to achieve sub pixel abundances of *Najas marina* and *Elodea nuttallii*.

INTRODUCTION

Some submersed macropyhtes, which can be used as longterm indicators for the trophic state of freshwater lakes [1], can now act as indicators for climate change profiting from increasing water temperatures [2]. In the freshwater lakes of Southern Bavaria a spread of *Najas marina* and *Elodea nuttallii* can be observed and it is assumed that both species profits from climate warming. *Najas marina* is indigenous to Europe while *Elodea nuttallii* is a neophyte, which is introduced from Northern America. However, the invasive growth of both plants causes severe ecological and economic problems. The species differ in their expansion speed with *E. nuttallii* expanding much faster. A regular monitoring of these plants will give important information about the ecologic development of these fragile ecosystems and would allow counter measures at an early stage.

A frequent observation of aquatic habitats is often limited to diving based mapping – a very cost and time intensive method. Only hyperspectral airborne data were used successfully to identify different species of submerged macrophytes [3, 4]. This is also a very expensive method and not suitable for observations on monthly to weekly intervals. This short revisit times are necessary since aquatic ecosystems are characterized by very fast developments and fluctuations during the growing season (either limited by temperature or incoming radiation).

Satellite imagery from the RapidEye AG offers very good preconditions for frequent observations consisting of five satellites allowing a revisit time of only one day. Together with a pixel size of 5 meters (scaled from 6.5 m) the images allows a detailed assessment of the spatiotemporal highly variable aquatic ecosystems. The information of substrate or vegetation coverage at the lake bottom is strongly influenced by the effects of the water column, which has to be corrected for further analysis. The results of a semi-analytical correction method and first results from 2011 are presented in this paper.

MATERIAL AND METHODS

Study sites

The study sites are Lake Starnberg (47°55’N, 11°N19’E) and Lake Tegernsee (47°43’N, 11°44’E) in Southern Bavaria (Fig. 1). Lake Starnberg is located 25 km southeast of Munich and is with an area of 56 km² Germany’s fifth largest lake. The lake was formed by the Isar-Loisach-Glacier during the last glacial period [5] and reaches depths up to 127.8 meters (53.2 meters on average). Extensive littoral terraces can be found on the western shore where a testsite was chosen near the municipality of Bernried. There high abundances of *Najas marina* occur over a larger area (50 meter length) at different water depths.

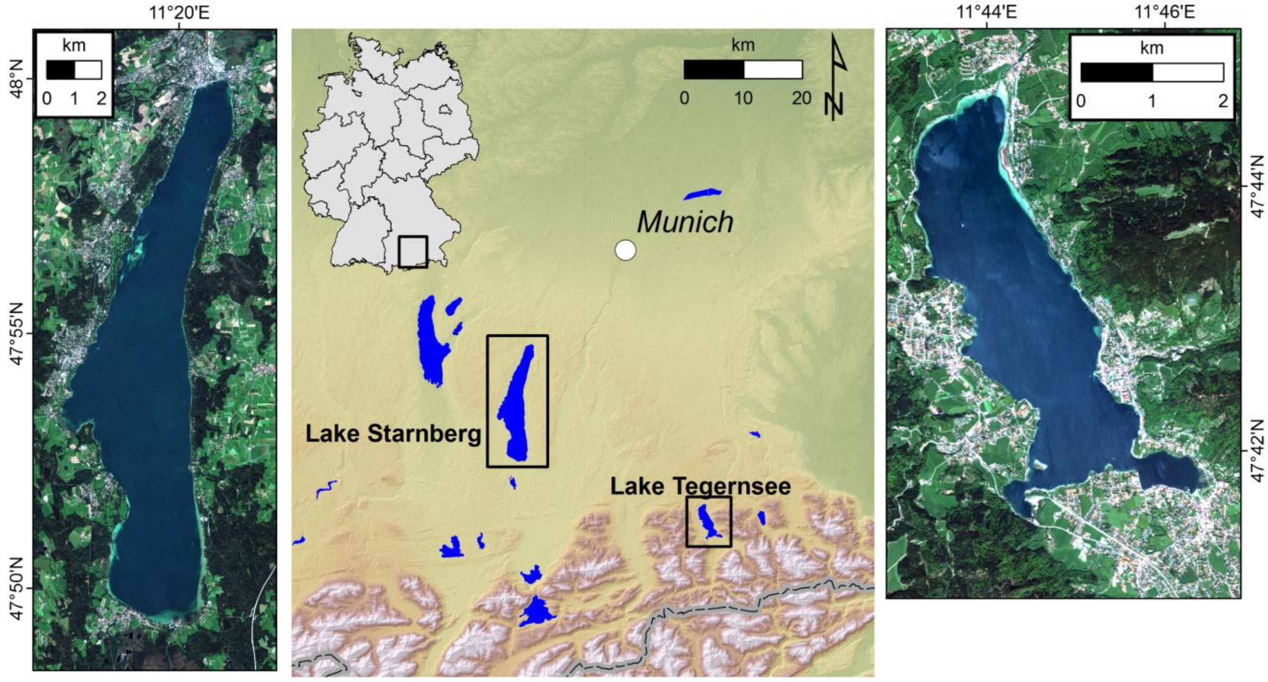

Figure 1: Location and RapidEye subsets of Lake Starnberg (left) and Lake Tegernsee (right)

Lake Tegernsee lies 50 km south of Munich in the Bavarian Alps and is also of glacial origin. A small bay (Ringsee bay) in the southwest of the lake was chosen as study site due to high abundances of *Elodea nuttallii*. Both lakes were visited several times during the growing season 2011 to collect spectral and biophysical parameters.

Material

Multispectral RapidEye data was acquired within the RapidEye Science archive (RESA) project No. 455. A tasking area was defined comprising lake Tegernsee, lake Starnberg and several other large and medium sized lakes in Upper Bavaria. For 2011, four scenes from Lake Starnberg (06/05/11, 28/06/11, 16/07/11 and 20/08/11) and three scenes from lake Tegernsee (23/08/11, 16/09/11 and 18/10/11) were chosen for analysis. Image selection was guided by data quality (clouds, sunglint, haze) and acquisition date (preferable close to in-situ observations). The images were delivered as level 3A product including standard radiometric and geometric correction.

Atmospheric correction was applied using ATCOR 2 [6] implemented in PCI Geomatics ™ (version 10.2.3).

In-situ measurements of reflectance behavior of *Elodea nuttallii* and *Najas marina* was performed during growing period 2011 at least every 14 days. Three submersible RAMSES irradiance and radiance spectrometers (TRIOS) were used to record simultaneously the upwelling radiance (L_u) and irradiance (E_u) and the downwelling irradiance (E_d), respectively. The sensors cover 320-950 nm with a spectral sampling interval of 3.3 nm. The measurements were made directly above the vegetation patches to minimize the influence of the water column as well as beneath the water surface to get information about water constituents and the radiative transfer in the water body.

Methods

A combination of in-situ derived parameters and image data is used to reduce the effect of the water column on the overall signal received by the sensor. Light intensity reduces exponentially with increasing depth [7] depending on the water constituents (inherent optical properties, IOPs) and illumination and viewing geometry. The anisotropy and the IOPs were summarized as apparent optical properties (AOPs) resulting in the water leaving radiance reflectance (R_L) and the vertical diffuse attenuation (K). The later can be achieved directly from in-situ measurements of downwelling irradiance in different depths [8].

A linearization of reflectance values for each band is performed using the natural logarithm [9]. Linear combinations of these log-transformed reflectances, incorporating the in-situ derived attenuation values (rescaled to the spectral resolution of RapidEye), leads to depth-insensitive indices which attain typical values for different bottom types. The depth-invariant bands (Y) were calculated using equation 1 [10].

$$Y_{i,j} = \frac{K_j \ln\left(R_i - R_{i\infty}\right) - K_i \ln\left(R_j - R_{j\infty}\right)}{\sqrt{\left(K_i^2 + K_j^2\right)}} \qquad (1)$$

Y is the calculated Index between bands i and j and R_∞ is the reflectance value over optical deep water (i.e. without the influence of the bottom). From the five spectral bands of RapidEye, the NIR channel was omitted in the analysis due to strong water absorption in this spectral region. Indices were calculated for six possible band combinations. Indices according to equation 1 were also calculated from in-situ reflectance measurements of the plants and a database of typical soil spectra collected at Lake Starnberg to get endmember for a subsequent linear spectral unmixing. The Matched Filtering method [11] was chosen since the derived endmembers are not assumed to represent all possible coverages of the littoral zone. To each pixel a score value is assigned indicating the possible endmember affiliation (values 0 to 1 and 1 to 2 indicate contribution of the endmember, a value 1 stands for 100%). Pixel values below 0 rule out an affiliation of this endmember.

For the image based index calculation some preprocessing steps were necessary. Land areas were masked using a normalized difference water index (NDWI) threshold [12], further deep water areas were masked with a deep-water corrected Red Index (RI) [13] and the signal reduction due to the refraction of the upwelling radiance at the water surface was corrected with the approximation from Lee et al. [14].

RESULTS AND DISCUSSION

In figure 2, reflectances of *Najas marina*, *Elodea nuttallii* and an exemplary soil spectrum are shown and the derived depth-invariant index values for all possible band combinations. It is obvious that some band combinations for depth-invariant indices are better suited to differ species and between bare soil and vegetated areas. As typical separability measure the Jeffries-Matusita Index [15] was calculated.

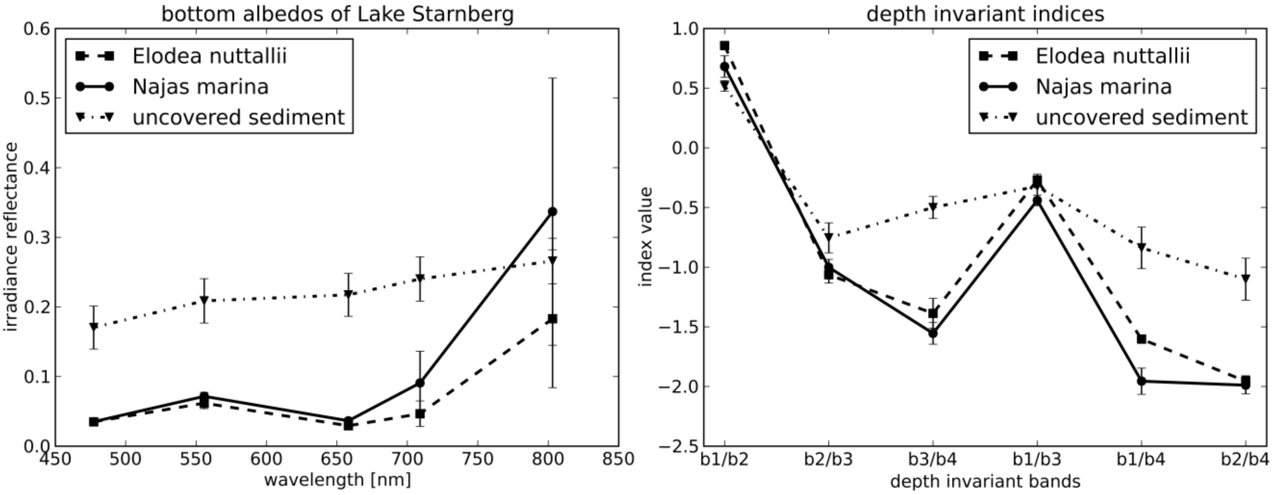

Figure 2: in-situ reflectances of different bottom types rescaled to RapidEye (left) and derived depth-invariant indices (right)

The best differentiation is possible with the depth invariant band 3 (red/red edge) also showing strong correlation to vitality of plants. Regarding the index development for different simulated soil/plant combinations (Fig. 3), the non-linear development of the depth-invariant band 3 index value can be assessed.

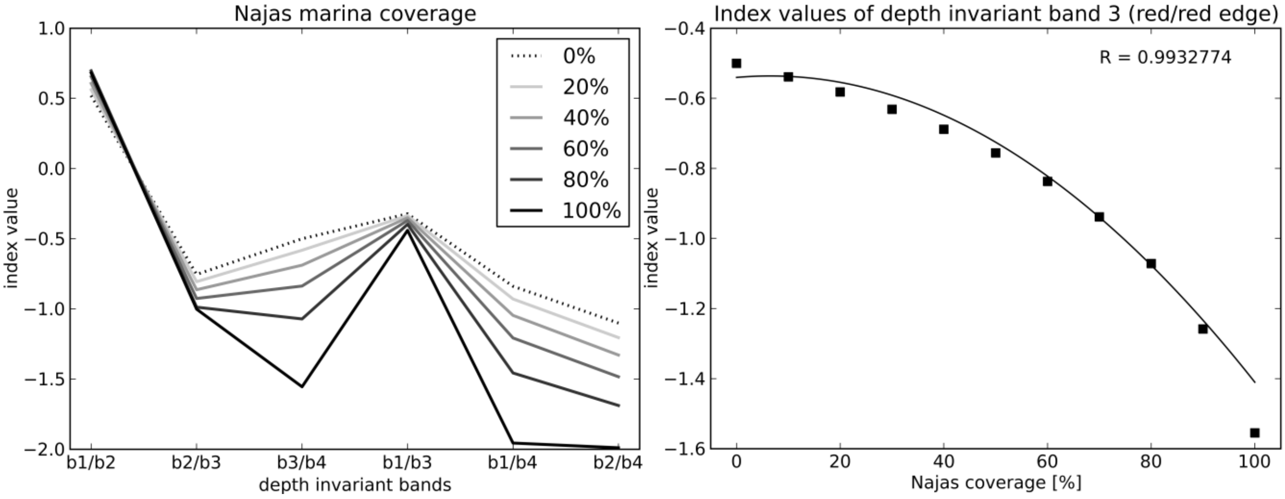

Figure 3: index development for different Najas coverages (left) and development of depth invariant band 3 depending on coverage (right)

Applying this relationship to multitemporal imagery, monitoring of aquatic vegetation dynamics is possible by using this index as vegetation indicator. For the identification of species on a subpixel scale, the matched filter unmixing approach is applied to all depth-invariant indices. In figure 4, the seasonal development of *Najas marina* at the testsite Bernried is presented, as well as the abundance of the endmember “bare soil”.

An increasing coverage can be observed in the august scene. The different amount of pixels where depth-invariant indices were calculated derives from comparatively low reflectance values of the bottom being equal or lower than the mean deep-water reflection in one spectral band (i.e. only pixel with valid pixel values were used for unmixing).

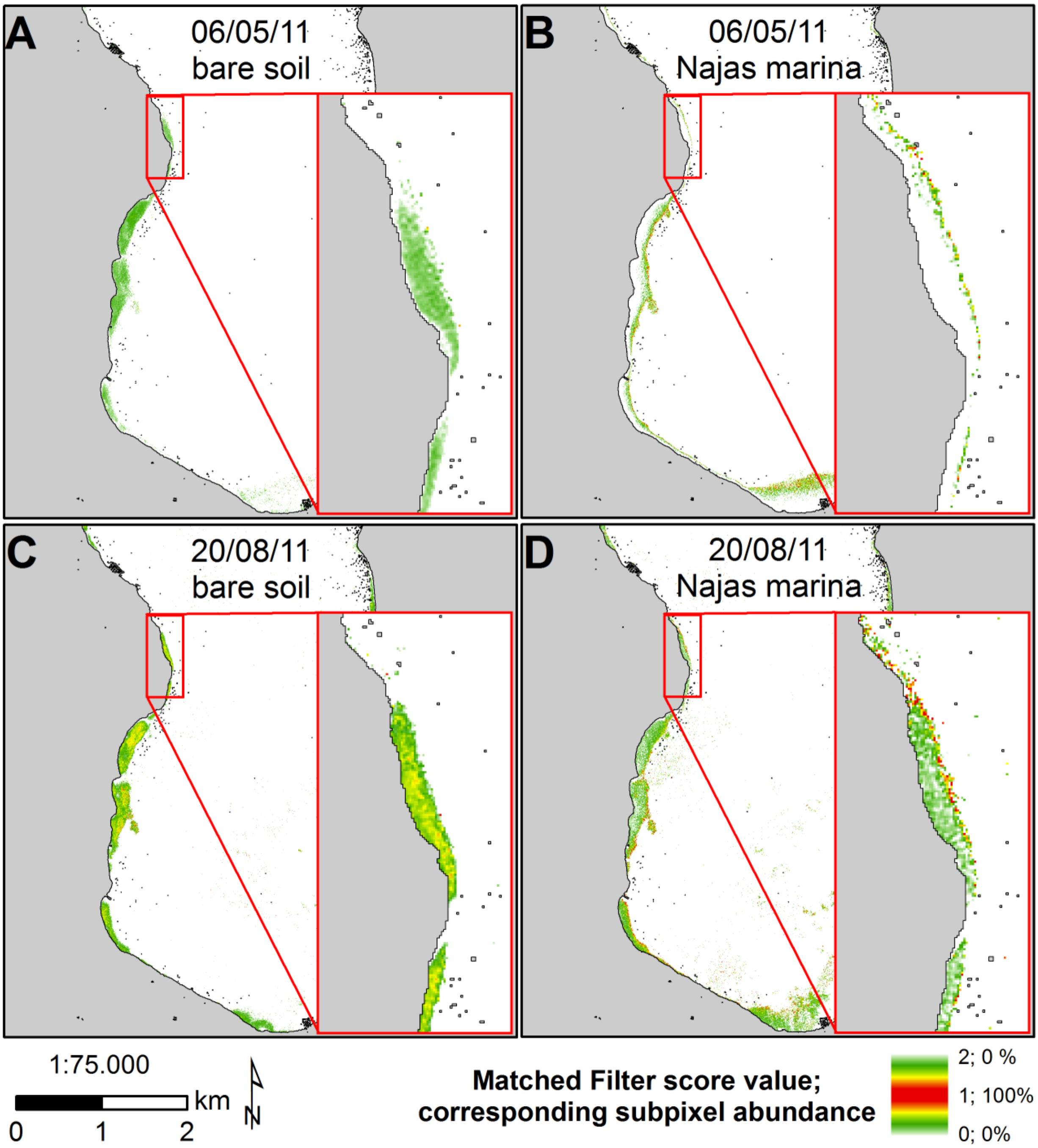

Figure 4: Unmixing result for the endmembers “bare soil” (A, C) and “Najas marina” (B, D) for two RapidEye scenes from 06/05/11 (A, B) and 20/08/11 (C, D)

At the testsite in Lake Tegernsee, the vegetation dynamic is not that distinct as at Lake Starnberg. The area opposite to the estuary in the Ringsee bay is completely covered by *Elodea nuttallii* during the entire year. Variations of the reflection curves are only due to alteration in pigment composition of *Elodea nuttallii*. However, those areas were not considered in the unmixing procedure. The reflectance signals of water depths greater than 2 meters are already nearly the same as over deep water (except of the green wavelength), resulting in invalid index values if equation 1 is applied.

CONCLUSIONS

The results show that a separation of substrate types is possible if the reflectance is sufficient separable and the water is not too deep (lower than 3 meters). The method requires a very good atmospheric correction considering the low radiances over water. This precondition has also to be fulfilled for another method which uses bio optical model inversion [16] which will also be applied.

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