REMOTE SENSING REFLECTANCE OF SUBMERSE MACROPHYTES – SEARCHING FOR TRUE SPECTRA

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ABSTRACT

Increasing temperatures of Bavarian freshwater lakes due to climate change exhibit a massive expansion of invasive macrophytes like *Elodea nuttallii* and *Najas marina* with unknown consequences for the lake ecosystems. For monitoring these plants with methods of remote sensing, a coupled reflection-/growth-model shall be generated. Therefore spectral reflectances were recorded and pigment compositions were determined. The spectral informations were collected during growing season from August to October 2010 using RAMSES submersible underwater spectroradiometers (TriOS ltd.). Pure stands of *Elodea nuttallii*, *Najas marina* and other common macrophytes were gathered. The hemispherically down- and upwelling irradiance and the upwelling radiance with a FOV of 7° were assimilated in a 2 to 4 weeks period, depending on light conditions. The test sites were three locations at Lake Starnberg (southwest of Munich). Affected by different influences, like the water column or the sun-object-sensor geometry, the reflectance spectra are subject to high fluctuations. A derivative analysis indicated that none of them can be entitled as wrong and thus have to be outlined as possible reflectance spectra to represent a certain population. Furthermore, in case of *Elodea nuttallii* and *Najas marina* plant material was sampled by scientific divers and analysed in the laboratory by high-performance liquid-chromatography (HPLC). Relating the pigment composition to the reflectance spectra was achieved by using simple correlation analysis and different spectral indices, which were calculated from the spectra and the derivatives.

INRODUCTION

Submerse aquatic macrophytes are suitable indicators for water quality of freshwater lakes [1]. To map submerse macrophytes and thus water quality by methods of remote sensing, the collection of in situ hyperspectral reflection data is needed to detect feasible bands for species discrimination. For *Elodea nuttallii* and *Najas marina* – two invasive macrophytes – coupled reflection-/growth-models shall be generated, by correlating high resolution reflectance spectra to the pigment composition of the plants. The spectral information was recorded with RAMSES submersible spectroradiometers (TriOS ltd.)

RAMSES sensors have already been used for similar investigations [2-6]. However, the reflectance spectra are subject to high variability, as downwelling irradiance is highly influenced by waves, the water column and sensor pitch [7].

Hence, this proceeding shows the deviations of remote sensing reflectance due to different external influences and different ways of data processing. Finally, a way how to deal with those deviations is given.

MATERIALS AND METHODS

Study Area

The study area is Lake Starnberg (47°55’ N, 11°19’ E) in the southwest of Munich. According to the abundance of the macrophytes *Elodea nuttallii, Najas marina, Potamogeton perfoliatus* and *Chara* spec., the test sites were selected at pier Starnberg in the north and close to the municipalities of Feldafing and Bernried on the west coast.

In situ measurements

The in situ data was collected during the vegetation period from August to October 2010. Three RAMSES submersible spectroradiometers (TriOS ltd.) recorded the hemispherically down- and upwelling irradiance (E_d & E_u) and the upwelling radiance (L_u) with a FOV of 7°. The data collection took place over pure stands of the mentioned species, in a 2 to 4 week period, depending on clear sky conditions. In general, spectra above water surface (R(0+)), just beneath water surface (R(0-)) and just above vegetation surface (R(b)) were gathered in a range from 320nm to 950nm with a 3.3nm interval. For each measuring level a series of at least 20 repetitions was taken up to 6 times per day. The calibration was carried out with MSDA_XE software (www.trios.com).

Data analysis

For this work, the amount of data was reduced to the downwelling irradiances E_d (Figure 1, left) and the upwelling radiances L_u (Figure 1, centre) of the *Elodea nuttallii* patch on September 20th, ranging from 400nm to 700nm. All calculations were performed with Python(x,y).

At the beginning, per cast, the remote sensing reflectance R_{rs} (Figure 1, right) for each repetition was calculated using Equation 1.

$$R_{rs} = \frac{\sum_{1}^{i} \left(\frac{L_{u_i}}{E_{d_i}} \right)}{i} \qquad (1)$$

where: R_{rs} = remote sensing reflectance

L_u = upwelling radiance

E_d = downwelling irradiance

i = number of repetitions per cast

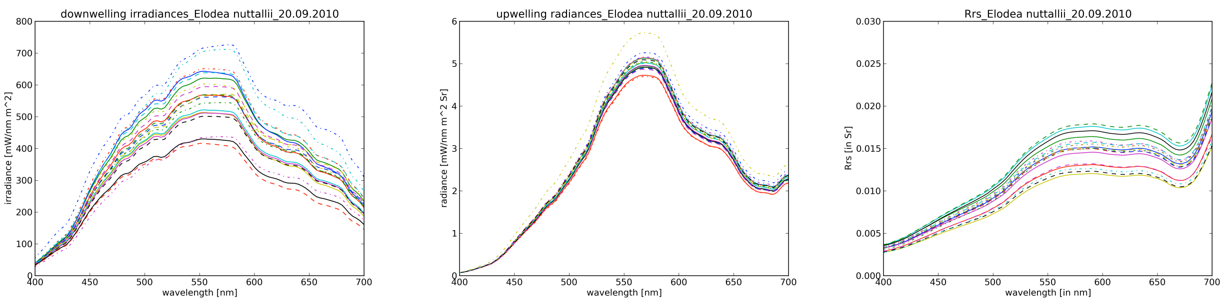

Figure 1: downwelling irradiances E_d (left), upwelling radiances L_u (centre) and remote sensing reflectance R_{rs} (right) of Elodea nuttallii on 20.09.2010.

A mean was calculated from resulting R_{rs}. Therefore, three different ways were tested and the results compared. First, an average mean was calculated out of all remote sensing reflectances (Figure 2, solid blue line). Secondly, an average mean was calculated of only those remote sensing reflectance spectra, which were within the single standard deviation, calculated out of all R_{rs} (Figure 2, dashed blue line). Thirdly, a median was calculated out of all R_{rs} (Figure 2, dotted blue line). The dotted gray lines in Figure 2 show the R_{rs} spectra.

For all spectra in Figure 2 it was assumed, that during record the sensors were arranged 20cm above vegetation surface. Figure 3 (left) shows, how R_{rs} changes, when the sensors are assumed to br 0cm and 35cm above the surface, respectively. For the correction of the water column, the wavelength dependent attenuation factors K_d were calculated using Equations 2 [8] and then introduced to Equation 3b [9].

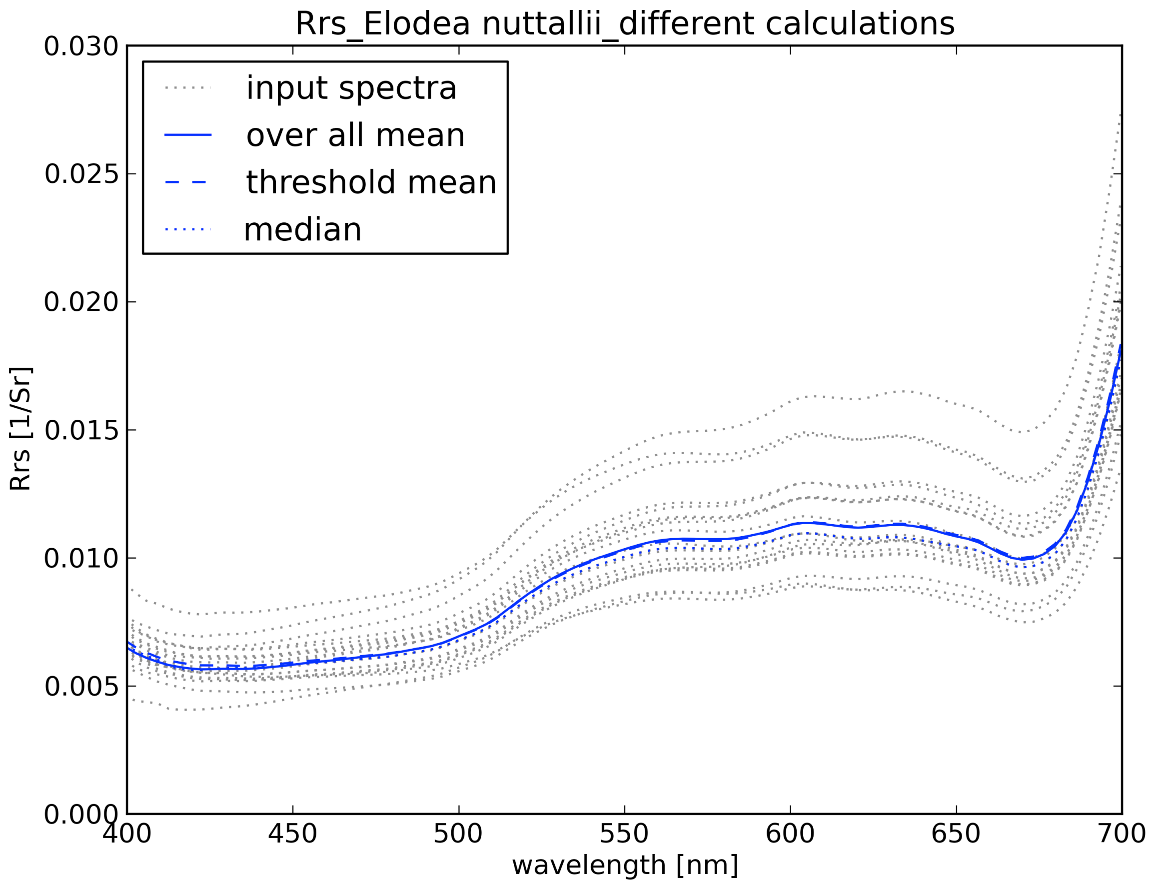

Figure 2: R_{rs} of Elodea nuttallii (gray, dotted) and three different calculated mean values: averaged mean out of all R_{rs} spectra (blue, solid), averaged mean only out of R_{rs} spectra within single standard deviation (blue, dashed) and median out of all R_{rs} spectra (blue, dotted)

In Figure 3 (right) the deviations of the radiance spectra, according to different inclination conditions are plotted, again in case of a 20cm distance to the object.

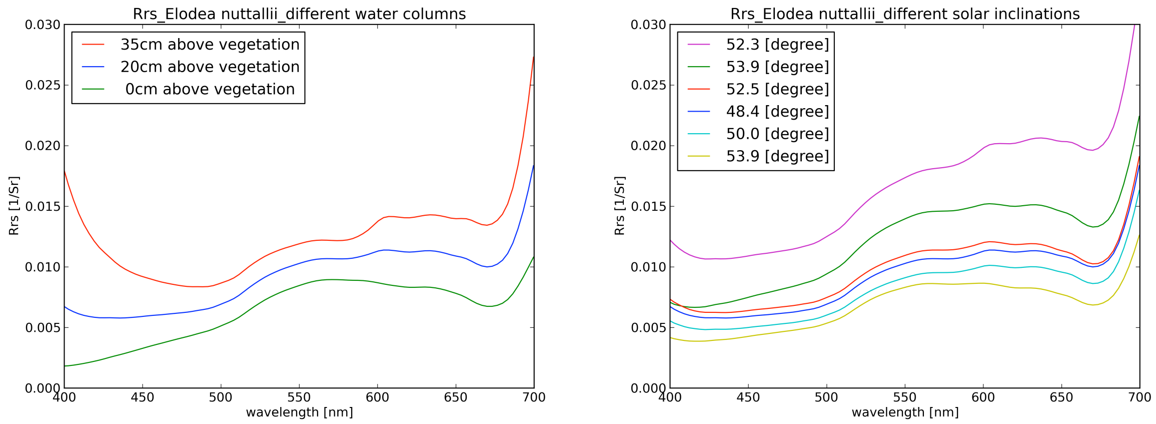

Figure 3: deviations of the R_{rs} spectra, depending on the distance of the sensors to the vegetation surface (left); deviations of the R_{rs} spectra according to different inclination conditions (right)

$$K_d = \frac{\ln \frac{E_d(\lambda, z_1)}{E_d(\lambda, z_2)}}{z_1 - z_2} \tag{2}$$

$$R_{rs} = R_{rs_\infty}(1 - e^{-kw}) + R_{rs_{bottom}} * e^{-kw} \tag{3a}$$

$$R_{rs_{bottom}} = \frac{R_{rs}}{e^{-kw}} \tag{3b}$$

where: R_{rs} = remote sensing reflectance

E_d = downwelling irradiance

i = number of repetitions per cast

K_d = k = attenuation coefficient

λ = wavelength

z_1 = z_2 = sensor depth

$R_{rs\infty}$ = deep water remote sensing reflectance

$R_{rsbottom}$ = bottom remote sensing reflectance

e = Euler's number = 2.718

w = 2 times the depth of the water column between sensor and object

Finally, for all shown data, the first and second order derivatives were calculated (Figures 4 & 5).

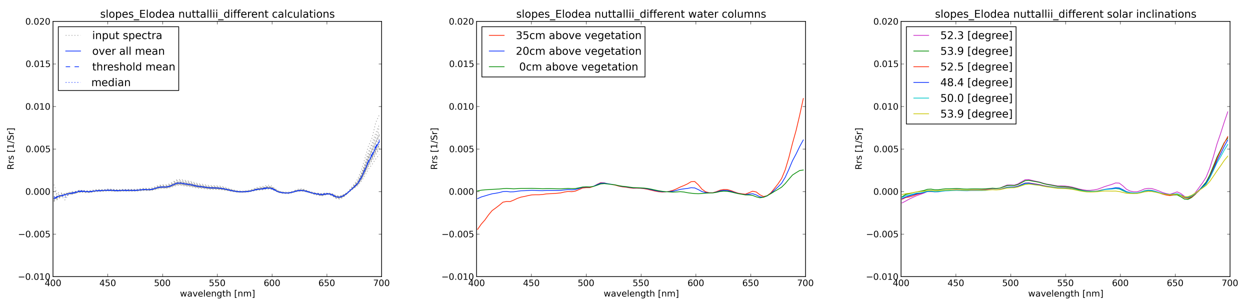

Figure 4: first order derivatives of the R_{rs} spectra of Figures 2 & 3

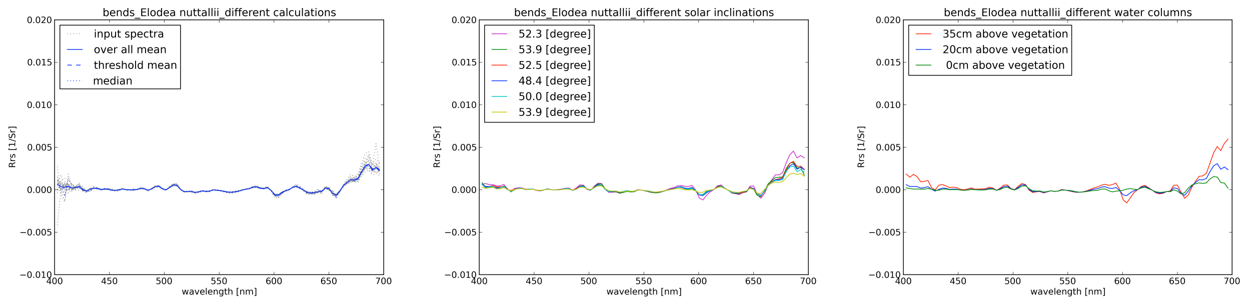

Figure 5: second order derivatives of the R_{rs} spectra of Figures 2 & 3

Pigment analysis

At each day, where spectral measurement took place, plant material was harvested for pigment analysis by scientific divers, using a frame covering an area of ¼ m². After removing the vast bulk of the material for biomass determination single plants were used for pigment analysis. Samples were cooled with lake water and transported to the laboratory and immediately frozen until treatment.

Out of 12mg of plant material, the pigments were extracted in 2ml of 100% acetone using mortar and pestle. After 10 minutes of centrifugation at 500*g* and 4°C (SIGMA 1K15 centrifuge), 1ml of the supernatant was filtered (0.45µm Nylon filter) into a brown glass vial. All operations were carried out under dark conditions.

The JASKO HPLC instrument consists of an autosampler, a pump, a degasser, a gradient unit and a detector. The lamps are a deuterium and a wolfram lamp. For separation a KNAUER C-18 column was used. As solvents (A) 0.5 M ammonium acetate in methanol and water (85:15, v/v), (B) acetonitrile and water (90:10, v/v) and (C) 100% ethyl acetate and a flow rate of 0.8ml/min were used [10].

The analysed pigments were Chlorophyll a and b and the Carotenoids Neoxanthin, Violaxanthin, Lutein and β-Carotin.

RESULTS

In situ measurements

Figures 2 and 3 partly show very high deviations of the calculated remote sensing reflectance. Reasons are the high sensitivity of the downwelling irradiance on waves (Figure 1, left) and the changing sun-object-sensor geometries during the day (Figure 3, right). The artificial calculated spectra with a changing water column between the sensors and the macrophytes (Figure 3, left) show that it is very important it is, to be aware of the recording conditions during field work. Rather unimportant is at least for these data, which mean value to calculate.

The use of first and second order derivatives seems to be very promising for spectral analysis, as diminishing the high variations of the R_{rs} spectra (Figures 4 and 5).

Figure 7 shows an overview of all remote sensing reflectances, first and second order derivatives.

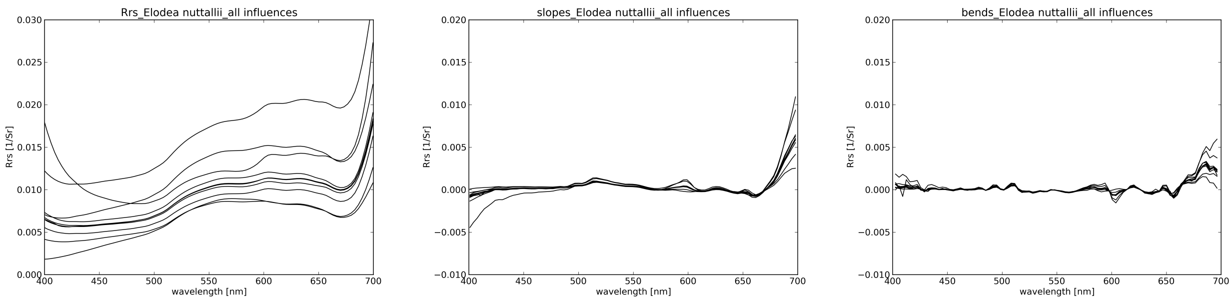

Figure 6: R_{rs} (left), first (centre) and second (right) order derivatives of Elodea nuttallii at 20.09.2010 (unsorted)

Pigment analysis

For *Elodea nuttallii* high peaks of chlorophyll a, chlorophyll b, Neoxanthin, Violaxanthin, Lutein and β-Carotin were delivered. Out of the amount of these pigments, different pigment ratios were calculated and then correlated with different indices of different spectra. Table 1 shows the correlation values of selected pigment ratios and calculated indices [11]. Promising values were only achieved in case of the first order derivative indices GF (maximum in the green of first order derivative, [12]) and RF (value at 605nm of first order derivative), which correlate high with the chlorophyll a/chlorophyll b and the total chlorophyll/total carotenoids ratio.

Indices	chl a / chl b	chl / caro	caro / chl a	beta / chl a
Reflectances				
NPCI	-0.218	0.361	-0.5323	-0.482
PRI	0.347	0.019	0.462	0.656
1st derivative				
GF	-0.474	**0.767**	-0.602	-0.530
RF	**0.897**	**-0.792**	-0.062	0.115
2nd derivative				
GS	-0.472	-0.674	0.473	0.432
RS	-0.669	0.599	-0.309	-0.471

Table 1: Correlations between calculated indices and selected pigment ratios; chl_a = Chlorophyll a; chl_b = Chlorophyll b; caro = total carotenoids; beta = β-Carotin; NPCI = Normalized Pigment Chlorophyll Index; PRI = Physiological Reflectance Index; GF = green first derivative; RF = red first derivative; GF = green second derivative; RS = red second derivative

CONCLUSION

The comparison of different influences on remote sensing reflectance reveals high deviations due to water column and the inclination conditions, but not to different mean calculations. Nevertheless, the first and second order derivatives are in terms very similar. Hence, none of the reflectance spectra can be entitled as wrong. Rather, in cases of generating reflectance libraries for submerse macrophytes, it is necessary to integrate a certain range of reflectance spectra for the same population, as even a pure and very dense stand is not totally homogeneous. However, for correlation analysis, as the main part for our reflection-/growth model, the derivatives are valuable and avoid the use of the high varying reflectance spectra.

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