Assessing Community Type, Plant Biomass, Pigment Composition, and Photosynthetic Efficiency of Aquatic Vegetation from Spectral Reflectance*

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We studied the reflectance spectra of the aquatic vegetation of Seaworld Lake in coastal central California using a high spectral resolution hand-held spectroradiometer. The three aquatic types—submerged, floating, and emergent—exhibited clear differences in their spectral reflectance and can be distinguished on the basis of discriminant analysis using reflectance parameters. This technique can be used in large-area mapping of aquatic plants. The normalized difference vegetation index (NDVI) and the simple ratio (SR) were well correlated with chlorophyll content, photosynthetic efficiency, and biomass in the emergent species. New, narrow-bandwidth indices and reflectance indices calculated from first and second derivate spectra were strongly correlated with the ratio of secondary and protective pigments to chlorophyll a and with epoxidation state of the xanthophyll cycle pigments, and therefore, with photosynthetic efficiency. These new indices may be useful in the remote sensing of plant physiological status.

INTRODUCTION

Remote sensing provides a rapidly growing source of practical tools for characterizing types and quantifying processes of the Earth’s vegetation. Satellite measurements of spectral radiance have been successfully used for identifying crop species and estimating vegetated area and primary productivity (MacDonald and Hall, 1980; Running, 1990). Although the reflectance spectra of water masses has been often studied in terms of the scattering and absorption of light by various constituents within the water column (Raitala and Lampinen, 1985), the reflectance of aquatic plants themselves has been studied less (Ackleson and Klemas, 1987; Dervieux and Taminier, 1987), mainly because of difficulties of interpretation resulting from water absorption in the infrared.

An open water surface effectively absorbs in the near-infrared wavelengths that are strongly reflected by green vegetation and various sediments. Because pure water has strong absorption in the red but less absorption and increased scattering in the blue, the upwelling radiance from clear oligotrophic water is blue-dominated. Chlorophyll has strong absorption in the blue and red but an absorption minimum in the green. Thus, chlorophyll in water tends to increase the ratio of green to blue upwelling radiance. This difference provides a basis for estimating the chlorophyll content of aquatic systems (Parshall and Harris, 1990). The blue/green ratio is also affected by other constituents but because of covariation between substances like dissolved organics or nonphototrophic particulates and chlorophyll, it seems that the empirical relationships between the blue/green ratio and chlorophyll may be very tight (Gordon and Morel, 1983). In the visible, water bodies

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are quite transparent, allowing the green and yellow radiation to include information from a depth of several meters or several tens of meters in the case of turbid and clear water, respectively. The spectral reflectance of aquatic areas is then dependent on water depth (Arkima and Raitala, 1984), bottom type (Raitala et al., 1984a), the type and abundance of aquatic plants (Raitala et al., 1984a,b), and water quality (Raitala et al., 1984c).

We centered our work on aquatic plant reflectance by studying the relationships between spectral reflectance, type (emergent, submerged and floating), and physiological characteristics of plants growing in shallow areas of similar bottom type and water quality. Given the different ecological role of emergent, floating, and submerged macrophytes, one of our main aims was to distinguish among them using high spectral-resolution reflectance for future applications in remote sensing. Although attempts have been made to classify marine macroalgae by fluorescence signatures (Topinka et al., 1990) and to monitor algae utilizing aircraft multispectral scanner data (Zibordi et al., 1990), we are unaware of previous studies that classify aquatic species based on high spectral-resolution reflectance.

Another aim was to assess the prospects for assessing pigment composition and photosynthetic behavior using narrow spectral bands selected according the absorbance spectra of the different photosynthetic pigments. These studies focused on broad-leaved, emergent species for which photosynthesis can be measured in the field and for which interference for water masses was minimal.

We analyzed spectral signatures with a variety of statistical treatments, including linear regression, principal components analysis, and other multivariate analyses such as cluster and discriminant analysis. We also developed new indices for plant stress, based on our previous work on xanthophyll signals (Gamon et al., 1990; 1992) and pigment ratios (Peñuelas 1984a,b). We used first and second derivative spectra to decrease the dependence of the signatures on water (and soil) background signals (Demetriades-Shah et al., 1990; Hall et al., 1990). Moreover, as differentiation leads to resolution of overlapping spectra, it offers prospects for separate estimates of leaf pigments such as carotenoids and chlorophyll. Photosynthetic efficiency, carotenoid, and chlorophyll content, LAI (leaf area index), and biomass were related to these spectral characteristics.

THE STUDY AREA

Searsville Lake is situated in Stanford University’s Jasper Ridge Biological Preserve (37°24' N, 122°13' W) in coastal central California (San Mateo County, California, USA). It is a small lake (20 ha) with luxurious aquatic vegetation. The maximum depth is only about 5 m in very limited areas, but most parts are very shallow, thus facilitating the growth of emergent macrophytes. The climate is Mediterranean, and the surrounding land area consists of grassland, chaparral, savanna, oak woodland, and riparian forest. The most abundant aquatic plants are the submerged Ceratophyllum demersum, Myriophyllum aquaticum, M. verticillatum, Chara sp., Potamogeton illinoisensis, P. pusillus, and P. foliosus; the floating Lemna minor, Azolla filiculoides, and various Chlorophyceae algae; and the emergent Myriophyllum aquaticum, M. verticillatum, Ludwigia palustris, Polygonum lapathifolium, P. coccineum, P. punctatum, and Typha latifolia (Thomas, 1961).

MATERIAL AND METHODS

Spectral Reflectance

The fieldwork was conducted during the summers of 1989 and 1990. We measured spectral reflectance in late morning and early afternoon on cloudless days with similar daily courses of photosynthetically active photon flux density (PFD). For each site, most of which had water depths less than 1 m and consisted of a single, predominant species, we made three to five replicate determinations of spectral reflectance with a spectroradiometer outfitted with 15 field-of-view optics (SE 590 Spectron Engineering, Inc., Denver, Colorado, USA). Our spectral camera, manufactured in 1988, did not yet include the second-order blocking filter built into newer instruments. During each measurement, the instrument was hand-held nadir-looking, approximately 1 m above the top surface of the emergent vegetation or above the water for submerged vegetation, and was thus detecting radiance from an area approximately 0.25 m in diameter. We tried to ensure that the vegetation always filled the 15° field of view of the radiometer whether underwater or on top of the water. However, it was not fully possible for Typha and Chara communities, which were sparse. The instrument detects 252 approximately even spaced spectral bands between 390 nm and 1100 nm. The half-bandwidth for each band is approximately 10 nm. Individual scans were remotely triggered from a portable computer, completed within 2–3 s, and saved to disk for later analysis. Apparent reflectance was calculated by dividing the radiance detected from the canopy by the radiance from a horizontal white halon panel used as reflectance standard (Gamon et al., 1990). Reflectance standard measurements were made immediately before and after each series of measurements, lasting 20–30 min, by holding the spectroradiometer in a nadir orientation 1 m above the leveled standard halon panel. To derive canopy reflectance, canopy radiance was divided by the reference radiance estimated from the linear interpolation of preceding and succeeding measurements of the halon panel. Maybe this could explain
Resolution Radiometer) on the NOAA weather satellites. Simple ratio (SR) and NDVI were then calculated from reflectance as:

$$SR = \frac{NIR}{VIS},$$

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)}.$$  

New narrow-waveband indices were calculated as indicated in Table 1. We explored two new spectral indices with the potential to reflect physiological status, based on previous work using absorbance ratios to evaluate the ratio of total pigments to chlorophyll a (Penualas 1984a,b) and the epoxidation state (EPS) of the xanthophyll cycle (Gamon et al., 1990: 1992). We tested the utility of a normalized total pigment to chlorophyll a ratio index (NPCI), defined as

$$NPCI = \frac{(R_{680} - R_{1380})}{(R_{680} + R_{1380})},$$

to estimate the ratio of total pigments to chlorophyll a. The ratio of total pigments to chlorophyll a should rise in decaying plants and decrease in healthy plants (Penualas, 1984a,b). The EPS of the xanthophyll cycle pigments should increase when plants are under stress (Dennig-Adams et al., 1989). We also examined a water band index (WBI), defined as

$$WBI = R_{650} / R_{690}$$

because the trough at 950 nm in the reflectance spectrum seems to be due to a water absorption band (Danson

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**Table 1.** Spearman Correlation Coefficients for the Relationships between Several Spectral and Physiological Indices.

<table>
<thead>
<tr>
<th>Indices</th>
<th>Chl$^b$ a + b</th>
<th>ε$^c$</th>
<th>ε+LAI$^d$</th>
<th>EPS$^e$</th>
<th>Ctd$^f$/ Chl a</th>
<th>Neoxanthin / Chl a</th>
<th>Lutein</th>
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<tbody>
<tr>
<td>Reflectance indices</td>
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<tr>
<td>NDVI$^g$</td>
<td>0.955 (0.763)</td>
<td>0.847 (0.756)</td>
<td>0.924</td>
<td>0.915</td>
<td>-0.882</td>
<td>-0.962</td>
<td>0.951 (0.801)</td>
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<tr>
<td>NPCI$^h$</td>
<td>-0.792</td>
<td></td>
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<td>Derivative indices</td>
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<tr>
<td>EGFR$^i$</td>
<td>0.944 (0.639)</td>
<td>0.879 (0.775)</td>
<td>0.963 (0.931)</td>
<td>0.925</td>
<td>-0.819</td>
<td>-0.919</td>
<td>0.958 (0.807)</td>
</tr>
<tr>
<td>EGFN$^i$</td>
<td>0.947 (0.687)</td>
<td>0.836 (0.765)</td>
<td>0.935 (0.935)</td>
<td>0.936</td>
<td>-0.859</td>
<td>-0.962</td>
<td>0.947 (0.813)</td>
</tr>
<tr>
<td>GGFn$^i$</td>
<td>-0.901</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>GF$^i$</td>
<td>-0.838</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>RE$^m$</td>
<td>0.842</td>
<td>0.805</td>
<td>0.865</td>
<td>0.863</td>
<td></td>
<td></td>
<td>0.812</td>
</tr>
<tr>
<td>ddRE$^m$</td>
<td>-0.805</td>
<td></td>
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</tr>
</tbody>
</table>

$^a$ The spectral indices are: NDVI, NPCI, EGFR, EGFN, and GGFn. GF, RE, and ddRE. The physiological parameters are: photosynthetic efficiency, photosynthetic efficiency times LAI, chlorophyll a + b, EPS, carotenoid / chlorophyll a, neoxanthin / chlorophyll a, and lutein. n = 9 means of 3-5 measurements each, except for ε+LAI (n = 6); only significant correlations at the level p < 0.05 are listed. Numbers in parentheses are the significant correlation coefficients without the outlier chlorotic Ludwiga.

$^b$ Chl = Chlorophyll.

$^c$ Net CO$_2$ Uptake / PFD.

$^d$ LAI = Leaf Area Index.

$^e$ EPS = Epoxidation state = (violaxanthin + 0.5*antheraxanthin) / (violaxanthin + antheraxanthin + zeaxanthin).

$^f$ Ctd = Carotenoids.

$^g$ NDVI = (R$_{680}$ - R$_{1380}$) / (R$_{680}$ + R$_{1380}$).

$^h$ NPCI = (R$_{680}$ - R$_{1380}$) / (R$_{680}$ + R$_{1380}$).

$^i$ EGFR = Edge - green first derivative ratio = ratio of first derivative maxima at the red edge and in the green.

$^j$ EGFN = Edge - green first derivative normalized difference = normalized difference between the first derivative maxima at the red edge and in the green.

$^m$ GF = Green first derivative = value of the first derivative maximum in the green.

$^n$ RE = Wavelength of the red edge (defined by maximum in first derivative).

$^p$ ddRE = Value of the second derivative maximum at the red edge.
et al., 1992) that could indicate hydric status of emergent plants.

We tested other indices based on the most outstanding features related to pigment absorbance of first and second derivative spectra. Spectral differentiation was carried out with the program Igor (WaveMetrics, Inc., Lake Oswego, Oregon, USA) using the central difference for interior points, the forward difference for the first point and the backward difference for the last point. Binomial smoothing of data was carried out once.

Physiological Measurements

For each emergent macrophyte, we measured the net CO$_2$ uptake rate of 3–5 upper, mature leaves in the spectroradiometer field of view, near the canopy top. These leaves were probably typical of those that contributed most of the radiance detected by the spectroradiometer. Gas exchange rates were determined with a portable gas exchange system equipped with a 1/4-l leaf chamber (LI-6200, LI-COR, Inc., Lincoln, Nebraska, USA). Photosynthetic efficiency was determined as the ratio of net CO$_2$ uptake to the incident photosynthetically active photon flux density (PPFD) measured at the leaf chamber, corrected for the transmittance of the chamber lid.

Five leaves of similar size, orientation, and canopy position to the gas exchange leaves were used for pigment analyses. Leaf disks were punched with a cork borer, rapidly frozen in liquid nitrogen, taken to the lab, and stored in the dark at -60°C for later analysis. Violaxanthin (V), antheraxanthin (A), zeaxanthin (Z), lutein, neoxanthin, a-carotene, b-carotene, chlorophyll a, and chlorophyll b extraction and analysis followed the HPLC procedure of Thayer and Bjorkman (1990). The epoxidation state (EPS) of the xanthophyll cycle pigments was defined as

$$\text{EPS} = (V + 0.5A) / (V + A + Z).$$

Each data point consisted of five samples extracted and assayed together and thus represents the mean of five top-canopy leaves.

To determine emergent biomass, we harvested all biomass within vertical cylinders 0.25 m in diameter. The material was transported to the lab in plastic bags on ice, and then oven-dried to constant mass at 65°C.

Leaf area index (LAI) was estimated with a plant canopy analyzer (LAI-2000, LI-COR, Inc., Lincoln, Nebraska, USA). LAI estimates were limited to emergent vegetation of relatively uniform canopy development, and the reported measurements were means of three determinations. Field-of-view restrictors were employed to avoid direct solar illumination of the detector.

Data Analysis

All the statistical analyses were done with Systat V 5.1 for the Macintosh (Systat, Inc., Evanston, Illinois, USA).

RESULTS AND DISCUSSION

Spectral Determination of Macrophyte Community Type

Figure 1 shows representative spectra for several aquatic species. Underwater plants were clearly distinguished by their lower absolute reflectances, especially in the near-infrared, which is absorbed by water. The Chara spectrum showed a very low, flat reflectance spectrum due to water absorption and sparse growth of this submerged species in the surveyed area. This spectrum is close to the reflectance of the background water. Ceratophyllum and Myriophyllum, which are also submerged, also had low reflectances, but were slightly higher than Chara in the near-infrared; these species were denser and healthier than Chara. Floating algae had higher absolute reflectances than submerged species because there was less water in the field of view. The floating algae spectrum was quite featureless, because this group was composed mostly of mats of dead material.

The reflectance spectra of emergent species were higher overall and had more distinct red/near-infrared boundaries than those of either submerged or floating species. Of the emergent species, Typha showed the highest red reflectance and the lowest near-infrared reflectance. This Typha canopy was sparser than that of the other emergent species, with some bare soil in the field of view. The high near-infrared reflectance and relatively low red reflectances of the Myriophyllum, Ludwigia, and Polygonum are consistent with the luxuriant canopy development of these emergent species.

The NDVI values for these same aquatic species are illustrated in Figure 2. NDVI tends to follow a pattern similar to the relative height of the near-infrared reflectance. In the submerged species, the low near-infrared reflectance associated with lower biomass and strong water absorption also yielded a low NDVI, except for Ceratophyllum, which was very luxurious; the emergent species with little water interference and dense canopy development tended to have the highest NDVI. However, NDVI and SR could not clearly separate underwater from floating or emergent plants, in part because each of these three communities had species with a range of densities and vigor. NDVI for Chara and Typha were low because of the sparse cover; and a substantial soil component in the reflectance spectrum tends to flatten out the spectral curve. For example, the submerged Ceratophyllum had a similar NDVI to the emergent Myriophyllum and Typha. NDVI or reflectance alone were not adequate to separate all species of these three groups. To better classify these species into submerged, floating, and emergent types, we used multivariate analysis and examined several new reflectance indices based on new combinations of narrow wavebands (Table 1).
Two multivariate statistical techniques, principle components analysis and discriminant analysis, allowed us to clearly separate the three groups. Principal component analysis calculated with the matrix of correlations and therefore not mean-corrected (maximizing the weight of IR wavelengths) gave, as expected, a first principal component (PC1) that separates underwater from floating and emergent plants. Discriminant analysis using variables derived from reflectance data, specifically the first three principal components (PC1, PC2, and PC3), yielded a clear separation of communities (Fig. 3). Discriminant Factor 2 was the primary distinguishing parameter. It was significantly correlated with the spectral parameters NDVI, PCI, and NPCI, and with the physiological parameters chlorophyll content, photosynthetic rate, photosynthetic efficiency, and biomass (measured in the emergent plants). Discriminant Factor 1 was not correlated with these physiological parameters. NDVI and PCI, indicative of the ratio of near-infrared/red reflectance, had the maximum weightings in both discriminant factors. Discriminant analysis based on only NDVI and the first three principal components began to separate the three types, but the inclusion of the other indices led to a better separation. The application of multivariate discriminant analysis using narrow bandwidth reflectances may thus have potential for use in large area mapping of aquatic plants.

**Figure 3.** Separation of emergent, floating, and submerged samples of macrophytes by discriminant Factors 1 and 2 based on Principal Components 1, 2, and 3, NDVI, NPCI, and WBI. Fifty percent of the samples were used to conduct the analysis and the other 50% to check it.

**Relationships among Spectral Indices, Biomass, Pigment Composition, and Photosynthetic Efficiency of Emergent Macrophytes**

When focusing on the emergent macrophytes, the physiological parameters we studied were significantly correlated with several of the tested spectral indices (Table 1, Fig. 4), even though the sample sizes were small (nine averages of three to five spectral replicates each). Many of the relationships were strongly driven by a single mean representing five scans on a chlorotic *Ludwigia* canopy. While this canopy was very distinct from the other aquatic canopies we sampled, we have no reason to believe that its responses are not on a single continuum with those of the other canopies in consonance with the different pigment composition of the different physiological states. This possibility needs to be tested with further studies. The correlations were, however, more believable when they were still significant without this chlorotic *Ludwigia* canopy (Table 1).

**Reflectance Indices**

NDVI and SR of the emergent aquatic plants were significantly correlated with biomass (Fig. 5), chlorophyll $a + b$, total carotenoids/chlorophyll $a$, neoxanthin, lutein, photosynthetic efficiency, and the epoxidation state (EPS) of the xanthophyll cycle pigments (Fig. 4, Table 1).

As the epoxidation state (EPS) and the pool size of the xanthophyll cycle pigments adjust rapidly to levels of excess PFD, they could be good indicators of realized photosynthesis under a wide range of conditions. Knowing the absorbed photosynthetically active radiation and the epoxidation state, it should be possible to predict the photosynthetic electron transport rate, a key determinant of photosynthetic CO₂ exchange (Thayer and Bjorkman, 1990). If spectral indices derived from reflectance signatures can indicate the epoxidation state,
it might be possible to closely follow the changes in photosynthetic processes under dynamic natural settings.

As hypothesized, EPS was correlated with photosynthetic efficiency (p = 0.01). EPS and photosynthetic efficiency (measured at the leaf level) were significantly correlated with NDVI (a canopy parameter) (Table 1), making it difficult to distinguish physiology from canopy structure and biomass. Future work must be done under conditions where canopy structure and biomass do not necessarily scale with physiological activity (e.g., drought-tolerant evergreens) and therefore where the role of each in the reflectance vegetation indices can be studied.

Even though NDVI was highly correlated with photosynthetic efficiency and pigment parameters (Table 1), we tested other indices likely to be somewhat independent of canopy structure and biomass and taking advantage of the high spectral resolution of the measurements.

NPCI was well correlated with chlorophyll content, carotenoid/chlorophyll a, lutein, and neoxanthin/chlorophyll a, as expected (Fig. 4, Table 1). Thus, NPCI behaved as a rough estimate of the ratio total pigments/chlorophyll a, decreasing in healthy plants and rising in stressed or senescing plants. Relative to chlorophyll a, carotenoid pigments occur in greater concentrations when plants are under stress. These carotenoid pigments may serve to protect the photosynthetic reaction centers from excess light or may persist longer than chlorophyll a in senescing leaves (Margalef, 1974).

The ratio $R_{950}/R_{800}$ (WBI) exhibited diurnal variation in Polygonum (Fig. 6). At midday, when these plants were probably less hydrated, the reflectance trough at 950 nm was smaller, corresponding to a relatively smaller absorbance (Fig. 6). The second-order error of our spectroradiometer resulted in the appearance of gradually decreasing reflectance through the 900–1100 nm region. However, the lack of water absorption features in the blue suggests that changes in the 950 nm trough are not results of second-order errors.

Summarizing the relationships of the tested reflectance indices, NDVI was a good general indicator of pigment composition and photosynthetic performance in emergent aquatic plants. NPCI behaved as a good indicator of carotenoid/chlorophyll a ratio but was less successful for epoxidation and efficiency; and WBI seems a promising tool for assessing water status for emergent vegetation in future work.
Derivative Reflectance Indices

We also used derivative techniques to search for better spectral indices. Derivative analysis is an established technique for eliminating background signals, resolving interference from overlapping spectral features such as those from soil and water reflectance, and avoiding turbidity interference in the assessment of aquatic chlorophyll (Demetriades-Shah et al., 1990).

Figures 6 and 7 show the morning and midday spectral reflectances of Polygonum and the midday spectral reflectances of chlorotic and green Ludwigia together with their first- and second-order derivatives. Differentiation diminishes the level parts of the spectrum (e.g., near infrared reflectance plateau) and highlights spectral regions of steep slopes. Subtle reflectance features in the green and red regions appear more clearly although noise increases in higher orders of derivative functions (Figs. 6 and 7).

Several spectral indices in the visible and near-infrared were calculated from the first- and second-order derivatives with criteria based in the most outstanding features of the spectra, mainly those due to the absorbance of photosynthetic and protective pigments. Some of the more successful derivative indices are listed with their correlation coefficients for various physiological parameters of the canopy in Table 1. Of these derivative indices, EGRF (edge-green first derivative ratio — ratio of first derivative maxima at the red edge and in the green window), EGFN (edge-green first derivative normalized — normalized difference between the first derivative maxima in the red edge and in the green), the GGFR (green-green first derivative normalized — normalized difference between maximum and minimum in the green) appeared to be good indicators of plant physiological status. These results might have been predicted from Shah (1985), who suggested that derivatives of canopy spectral reflectance might be useful in remote sensing by eliminating the effects of soil background reflectance and canopy architecture, thereby improving the estimation of certain variables such as leaf chlorosis. Chlorosis could this way be decoupled from measures of foliage density (Demetriades-Shah et al., 1990).

We also used the first derivative to locate the red edge, that is, the wavelength of maximum slope of the reflectance spectrum between 670 nm and 800 nm. Notice in Figure 6 the clearly different position of the red edge in chlorotic Ludwigia. The position of the red edge correlated with leaf chlorophyll content (Table 1) as has been reported by Dockray (1981) and Horler et
al. (1983), or by Rock et al. (1988), who related the position of the red edge to chlorophyll decline under air pollution damage in coniferous forests. The red edge is usually described as the wavelength of the main inflection point. It has, however, other features that may be influenced by different biological parameters (Boochs et al., 1990). To explore the sensitivity of the maximum slope to physiological parameters, we examined the EGFR and EGFN indices.

Other authors (e.g., Hall et al., 1990) have proposed the use of second derivative of the reflectance versus wavelength function to estimate the fraction of photosynthetically active radiation absorbed by vegetated land surfaces because this derivative is relatively insensitive to the reflectance of nonphotosynthetically active material beneath the canopy such as leaf litter or soil. In our study, though, the indices derived from the first derivative were better related with pigment composition and photosynthetic efficiency than those derived from the second derivative of reflectance (Table 1). The second derivative’s high sensitivity to noise might be the reason. Another explanation may reside in the fact that there was little nonphotosynthetically active material in most of the summer growth we studied.

Finally, the results presented here suggest that the biomass, pigment content, and photosynthetic efficiency of submerged macrophytes could also be assessed by these spectral indices, but this hypothesis should be tested with underwater physiological technologies.

CONCLUSIONS

The three different communities of aquatic vegetation—submerged, floating, and emergent—can be clearly distinguished with multivariate statistical treatments of narrow bandwidth reflectance spectra.

The data presented here show that the narrow bandwidth spectral and derivative indices proposed here are useful indicators of photosynthetic efficiency, the ratio of secondary pigments to chlorophyll a, and biomass of aquatic plants. Widely used indices such as NDVI are also useful indicators of these ecophysiological parameters of aquatic plants, probably as a consequence of their high proportion of green biomass.

REFERENCES


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