Original Paper

Estimation of Plant Abundance and Distribution of *Miscanthus sacchariflorus* and *Phragmites australis* Using Matched Filtering of Hyperspetral Image

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ABSTRACT

More than 40 endangered plants listed in the national red list are growing in moist tall grasslands of Watarase wetland, the largest lowland wetland, in Japan. The dominant plants in grasslands are *Miscanthus sacchariflorus* and *Phragmites australis*, and each endangered species is associated with the habitats where either grass species is predominate, or both are mixed more evenly. Therefore, estimation of the relative dominance of *M. sacchariflorus* or *P. australis* may help in evaluation of the potential habitat area of the individual endangered species. In this study, matched filtering (MF), a specialized type of spectral mixture analysis, was used to estimate the abundance and distribution of *M. sacchariflorus* and *P. australis* from Airborne Imaging Spectrometer for Applications (AISA) data. Correlation analysis of the MF results and ground truth data was conducted to determine the accuracy of the estimates. Overall performance of MF for estimating amount of *M. sacchariflorus* was good with correlation coefficient of 0.89 for shoot density, and 0.78 for total stem volume. However, a poor estimate was obtained for *P. australis* with correlation coefficient of 0.43 for shoot density and 0.58 for total stem volume. Possible reasons for the difference in the accuracy estimates were discussed in this paper.

Key words : Matched filtering, *Miscanthus sacchariflorus*, *Phragmites australis*, Shoot density, Total stem volume

1. Introduction

Conservation of endangered plant species in wetlands has been proposed as one of the important components of environmental conservation worldwide. In Watarase wetland, the biggest lowland wetland located in central Japan, more than 40 endangered vegetation species listed in the national red list are growing in moist tall grasslands. The dominant plants in the moist tall grasslands are *Miscanthus sacchariflorus* and *Phragmites australis*. Each endangered plants are associated with a certain habitat where either grass species is predominate, or both are mixed more evenly. In recent years, however, rapid environmental change by human interventions is suggested to alter the growth, quantity and distribution of *M. sacchariflorus* and *P. australis*, and thus the potential habitat area of the endangered plants growing. Therefore, estimation of the relative dominance of *M. sacchariflorus* or *P. australis* may help in evaluation of the potential habitat area of the endangered species.

A cost-effective, large-scale, and long-term documentation and monitoring of the dominant plants population is very important for assessing the plant biodiversity in wetland such as moist tall grassland. Ground survey work in large areas is prohibitively expensive and time-consuming (Everitt et al., 1995). Moreover, data generated from ground survey work are quickly outdated as vegetations change due to abiotic and /or biotic factors and control measures. Hence, a method which can quickly and efficiently collect data over a large area on a routine basis is needed for efficient monitoring of major characteristics of vegation such as coverage or abundance of dominant plants in wetlands.

Using remotely sensed data to map *M. sacchariflorus* and *P. australis* could provide a valuable tool for documenting their abundance or distribution. Imaging spectrometers, or hyperspectral sensors, provide high spectral resolution data and continuous spectrum for every pixel. By using spectral mixture analysis to model each pixel spectrum as a linear combination of a finite number of spectrally distinct signatures or “endmembers”, subpixel estimates of endmember abundance can be obtained (Williams and Hunt, 2002). The main goal of this research was to map area based abundance of *M. sacchariflorus* and *P. australis* using hyperspectral data, in which the accuracy was evaluated by comparison with the ground estimates of shoot density and total stem volume. The total stem volume refers to the combined measured stem diameter and plant heights in a given area by the following expression, which gives an indication of the growth condition of the plants.

$$\text{Total stem volume} = (d/2)^2 \times h \times \pi \quad (1)$$

Where, d is the diameter of the stem and h is the plant height.

2. Method

2.1 Study area

The study area is around 2,500 ha moist tall grasslands areas in Watarase wetland which is located at latitudes 36º11´ to 36º17´ north and longitudes 139º40´ to 139º42´ east. Precipitation at Koga station near the study area averages to 1,197 mm annually from 1977 to 2004 year. The study area has a relatively hot-wet summer and cold-dry winter because the area lies in the inland part of Japan. There are nearly 600 species of wetland plants (Ohwada and Ogura, 1996), and dominant plant species are the *Miscanthus sacchariflorus* and *Phragmites australis*. *M. sacchariflorus* and *P. australis* in Watarase wetland start to grow after the wetland is burned usually in March. They grow fast and reach their maximum height around 4 meters in July and August. *P. australis* grows a little faster than *M. sacchariflorus*. The plants reach maturity in during September to October and bear fruits in November and December. The ground leaves and stems wither in winter.

2.2 Acquisition of hyperspectral imagery

Hyperspectral sensors, i.e., imaging spectrometers which acquire digital imagery of earth material in many narrow contiguous spectral bands can be used to detect small spectral features. In this study, we hypothesize that because of the narrow spectral channels of hyperspectral sensors, it can detect relatively dominant plants at a species-level, which is not possible using multi-spectral scanner. AISA (Airborne Imaging Spectrometer for Applications) is operated by the SPECIM LTD (Spectral Imaging LTD) and collects data in the spectral range of 398 to 993 nm sampled by 68 spectral channels with a nominal 10 nm sampling. It also has very high radiometric resolution (16 bit), resulting in an increased ability to distinguish fine differences in reflectance values among pixels.

AISA imagery was acquired over the study area on May 21, 2004. The phenology of the two dominant plants of *M. sacchariflorus* and *P. australis* indicates that they are in their mid growing period when we acquire the imagery and conducted field survey. Because *P. australis* grows a little faster than *M. sacchariflorus,* the two plants show the biggest differences in height and plant form. They will become more and more similar to each other and make the discrimination more difficult when they reach maximum maturity.

The image was acquired from aircraft flown at an altitude of 1,438 m with each pixel representing a ground area of approximately 1.5 m × 1.5 m. Four scenes (each approximately 10 km × 1 km) were selected that covered the study area. Each AISA scene was radiometrically corrected and was then atmospherically corrected to apparent surface reflectance using the Fiber Optic Downwelling Irradiance System (FODIS) incorporated with the AISA sensor. The FODIS allows for the concurrent measurement of downwelling and upwelling radiance by the AISA sensor head. A diffuse collector installed on the top of the plane is connected to the AISA head via fiber optic cable and collects downwelling irradiance in the same bandwidth configurations as the areas being imaged. The calibration of the FODIS coupled with the AISA sensor allows for the calculation of apparent at-platform reflectance.

2.3 Ground calibration

Extensive ground data collection was conducted on May 22 to June 14, 2004. Nine 5 × 5 square meter plots were placed to determine the *M. sacchariflorus* abundance, while fifteen plots, *P. australis* abundance. These plots included pure stands predominated by either the species, and some mixed stands. The specific location of the four corners of each plot was recorded using Trimble GPS Pathfinder ProXR. These locations were transferred onto the AISA imagery with an estimated positional error of less than 1 pixel. Shoot densities and total stem volume of the plots were estimated from the averages obtained from three 1 × 1 square meter subplots arbitrarily sampled. The average values of the shoot density and total stem volume were calculated and regarded as the estimates of the shoot density and total stem volume for the whole plot.

2.4 Image processing and analysis

2.4.1 Matched filtering analysis

The measured reflectance of a pixel represents the integration of all reflectance from all the surface material within the ground instantaneous field of view (GIFOV). When the size of the pixel includes more than one type of terrain cover, mixed pixels are generated. Spectral mixture analysis decomposes each image pixel into a linear combination of reference spectra, referred to as "endmembers" that characterize the various spectrally unique components of landscape (McGwire, Minor and Fenstermaker, 2000). Spectral mixture analysis utilizes the high dimensionality of the AISA imagery to produce a suite of abundance or fraction images for each endmember. Each fraction image shows a subpixel estimate of endmember relative abundance as well as the spatial distribution of the endmember (Williams and Hunt, 2002).

Matched filtering (MF), a special type of spectral mixture analysis, is based on well-known signal processing methodologies (Harsanyi and Chang, 1994). MF filters the input image for good matches to the chosen target spectrum by maximizing the response of the target spectrum within the data and suppressing the response of everything else (which is treated as a composite unknown background to the target). The background material's data histogram is centered around 0.0, and the target data distribution occurs in the upper tail of the histogram (Research Shystem, Inc. 2003). Like Complete Unmixing, a pixel value in the output image is proportional to the fraction of the pixel that contains the target material. (where 1.0 is a perfect match). One major advantage of the method is that MF does not require finding the signatures for the other endmembers that occur in the scene (Boardman, Kruse and Green, 1995). In Watarase wetland, a large number of plant species coexist in the same stand, MF method is possibly a suitable algorithm to extract the information of one or two given plant species such as *M. sacchariflorus* and *P. australis.*

2.4.2 Image processing and analysis

In order to successfully employ MF, endmember of interest must be selected accurately. In the study plots, the selection of *M. sacchariflorus* and *P. australis* endmembers from the image data is possible because they occur in dense stands which are more or less covering most of the area.

A minimum noise fraction (MNF) transformation (Green et al., 1988; Lee, Woodyatt and Berman, 1990) of AISA image was first performed in this study. By examining the eigenvalues and the spatial information contained in the output MNF-transformed images, the first 15 MNF images (with large eigenvalues) were chosen for further analysis. This is because only the bands with large eigenvalues contain data, while bands with eigenvalues near 1.0 contain only noise. The MNF eigenvalue plot is shown in Figure 1.

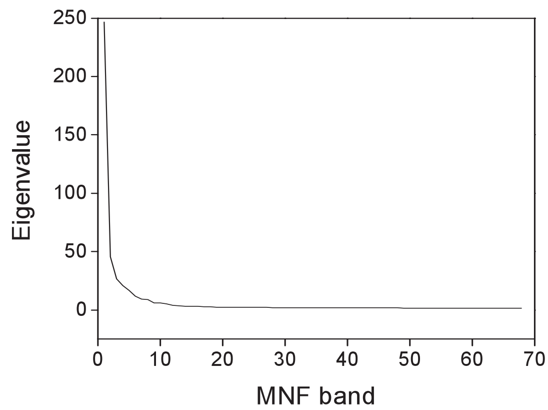

Fig. 1 Minimum Noise Fraction (MNF) transformation analysis

The *M. sacchariflorus* endmember and *P. australis* endmember derived from the AISA image by ground investigation were used as the endmember in the MF analysis. The relationships between MF estimates of subpixel *M. sacchariflorus* and *P. australis* and ground estimates of their shoot density and total stem volume were examined using simple linear correlation analysis for all sites.

3. Results and discussion

3.1 Spectra of two plants

From appereance, *Miscanthus sacchariflorus*, differs from *Phragmites australis* in Watarase wetland due to the presence of white veining in the center of the leaf. In *P. australis* this white veining does not exist. In addition, the leaves of *M.*

sacchariflorus are light green, while the leaves of *P. australis* are relatively darker green. These differences should yield different spectra, which can help discriminate the grasses from each other in the imagery.

In remote sensing imagery, the reflectance spectra of the two plants differed from each other in some wavelengths (Figure 2(a)). *M. sacchariflorus* was consistently brighter than *P. australis* in the range of 500-650 nm. The reflectance of *M. sacchariflorus* also appeared higher in the NIR (from 750 nm to 920 nm) than *P. australis*. Figure 2(b) shows the ratio of spectra of *M. sacchariflorus* and *P. australis* indicating the difference in spectral shape between the two grasses.

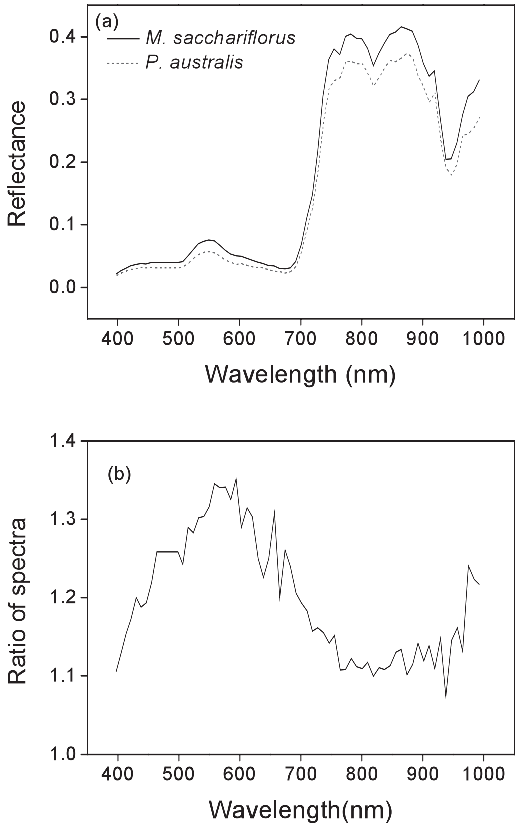

Fig. 2 (a) Spectra of *M. sacchariflorus* and *P. australis*, (b) Reflectance ratio of *M. sacchariflorus* to *P. australis*

3.2 Matched filtering fraction images

Figure 3(a) shows the false color composite of AISA scene. This is a subset image which shows a part of the Watarase wetland. The red area represents vegetation. The light red color areas which lie between the water and road are relatively pure stands of *M. sacchariflorus*, while the dark red areas are those of *P. australis* (Figure 3(a)). However, reliance on color alone caused some spectral confusion because of the presence of underlying plants.

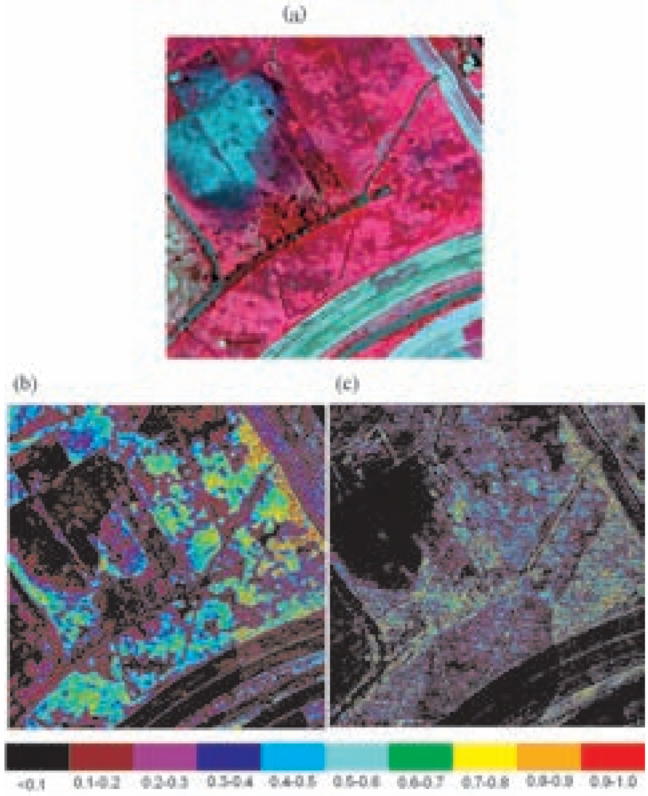

Fig. 3 (a) False color composite of the AISA scene in Watarase wetland. (b) MF fraction image for *M. sacchariflorus*. (c) MF fraction image for *P. australis*.
The top image points to the north. The bands used in the false color composite are blue-band 23 (585 nm), green-band 31 (657 nm), and red-band 52 (847 nm).

The output from the MF analysis was a fraction image with values for each pixel representing the relative abundance of *M. sacchariflorus* and *P. australis* as illustrated in Figure 3(b) and (c). Pixel with a high fraction value means high abundance of each plant in it. In MF, a threshold of 0.1 was used because it was determined to be the most appropriate values for detecting materials in hyperspectral imagery (Boardman, 1998). The performance of the MF for estimating shoot density and total stem volume for *M. sacchariflorus* was relatively good as shown by a significant correlation between the results of matched filtering and ground data. The correlation coefficient of MF fraction values against shoot density of *M. sacchariflorus* was 0.89 at significance level of 0.01 (Figure 4). For total stem volume the correlation coefficient was 0.78, at 0.05 level of significance (Figure 5). On the other hand, the correlation coefficient of MF fraction values against shoot density of *P. australis* was only 0.43 with no significance (Figure 6), and that against total stem volume was 0.58 (Figure 7) at significance level of 0.05. The MF analysis for *P. australis* didn't seem as effective as for *M. sacchariflorus*.

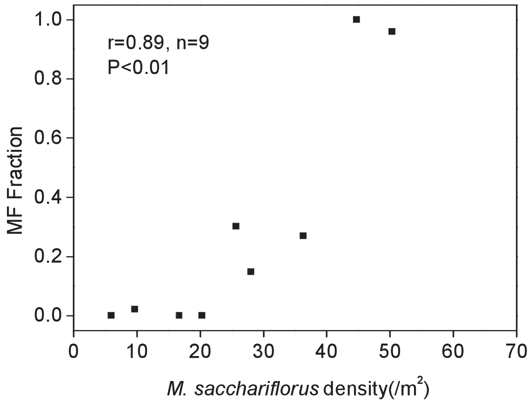

Fig. 4 Relationship between MF fraction values and shoot density of *M. sacchariflorus*.

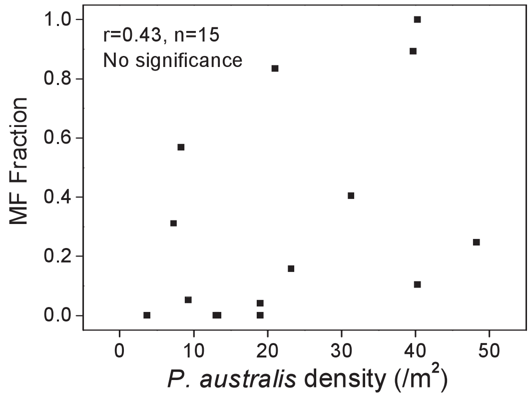

Fig. 6 Relationship between MF fraction values and shoot density of *P. australis*.

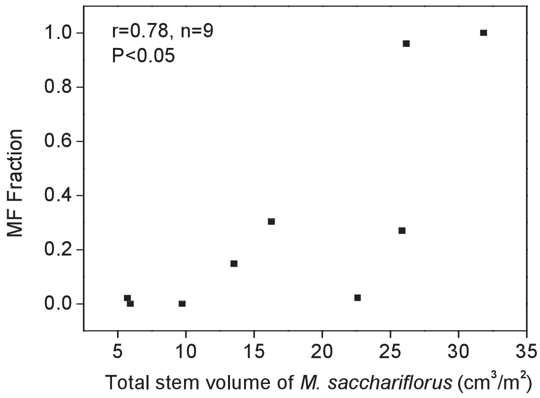

Fig. 5 Relationship between MF fraction values and total stem volume of *M. sacchariflorus*.

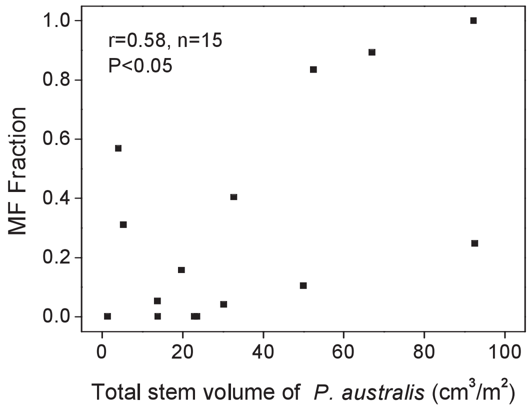

Fig. 7 Relationship between MF fraction values and total stem volume of *P. australis*.

3.3 Effect of plants type

Aside from the slight difference in color of the leaves of *M. sacchariflorus* and *P. australis*, there is also a little difference in the leaves orientation between the two grasses. The leaves of *M. sacchariflorus* tend to spread more horizontally because it has a relatively soft leaves. This makes the land surfaces and underneath plants to be covered almost entirely by the leaves of *M. sacchariflorus*. This enables the hyperspectral sensor to capture pure spectrum of *M. sacchariflorus* unaffected by the background materials such as soils, litters and short plants in the bottom layer. The leaves of *P. australis*, on the other hand, are relatively hard, erect and grow up straight that exposes the soil and underneath plants. Thus hyperspectral sensor captures a mixed spectrum of *P. australis*, underlying soil and short plants. The physical difference between the two plants provides the key in the effectiveness of the MF fraction to estimate the abundance and distribution of *M. sacchariflorus* and *P. australis* in the study area.

The selection of endmembers is a critical step in spectral unmixing. In our study, the endmembers were extracted from the image based on field ground data. The endmember selected for *M. sacchariflorus* represents the characteristics of this plant. On the contrary, because of the characteristics of the leaves of *P. australis*, pure endmember was not selected properly resulting to poor performance of MF for distinguishing this grass.

One of the limitations of MF method is the difficulty of distinguishing material of interest with almost similar reflectance to the background (Oki, Funakoshi and Inamura, 2000). However, in this study this limitation was not observed, particularly for *M. sacchariflorus*. The quantity and distribution was clearly known by the difference in reflectance between *M. sacchariflorus* and its background. That means to say (as this study found out) that the extent of difference between the grass and its background is enough to discriminate one from the other. In the MF fraction map of *M. sacchariflorus,* almost all of the *P. australis* areas with high density appeared low fraction value. In the same manner, good results can be expected if MF was applied using *M. sacchariflorus* as background to *P. australis* providing that correct endmember was selected.

4. Conclusions

The study demonstrated the capability of high spectral and spatial resolution hyperspectral imagery in estimating the abundance and distribution of dominant tall grass species of wetland *Miscanthus sacchariflorus* and *Phragmites australis*. This study showed that *M. sacchariflorus* could be satisfactorily estimated by MF spectral unmixing method using goundtruth-derived endmember. For *P. australis*, however, this method did not work well because of the difficulty of selecting pure pixel or endmember for it. Further study is needed to focus on the endmember selection to get accurate estimation of *P. australis*.

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