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Special Reflectance of Hydrophytes

Robert G. Best

SPECTRAL REFLECTANCE OF HYDROPHYTES

BY

ROBERT G. BEST

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SPECTRAL REFLECTANCE OF HYDROPHYTES

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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SPECTRAL REFLECTANCE OF HYDROPHYTES

Abstract

ROBERT G. BEST

Identification of hydrophytes will improve the delineation and classification of wetlands on remotely sensed imagery. Spectral reflectance measurements of 10 species of hydrophytes were made with an Exotech radiometer during three phenological stages, flowering and early seed, senescence, and early emergent. Reflectance data were analyzed to determine significant ($\geq$.95) reflectance differences between species in each of four spectral regions during each phenological stage. Eight species had significantly ($\geq$.95) different reflectances during the flower and early seed stage. Only one species could not be spectrally separated during at least one phenological stage. The results indicate that films sensitive to both visible and infrared spectra (e.g. ektachrome infrared) should provide best results for recognizing different species of hydrophytes.

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SPECTRAL REFLECTANCE OF HYDROPHYTES

INTRODUCTION

Identification of hydrophytes is important in the classification and management of wetland habitat. In operational wetland classification utilizing remotely sensed imagery as the primary data source, water regime parameters can be determined only by the presence of indicator species of hydrophytes. The quality and quantity of wetland habitat can be estimated if hydrophytes can be identified.

Investigators have reported varying degrees of success in classifying hydrophytes from remotely sensed data (Lukens 1968, Anderson et al. 1973, Shima 1973, Cowardin and Myers 1974, Best et al. 1977, and numerous others); however, little is known on the optimal time for data collection or the spectral region best suited for differentiating species of hydrophytes.

The objectives of this project were to determine: (1) if reflectance differences exist between species of hydrophytes, (2) the phenological stage at which maximum spectral differences occur, and (3) the spectral region in which maximum reflectance differences occur. Measurements of reflected and incoming radiation were collected with an Exotech radiometer during different phenological stages for different species of hydrophytes. Reflectance data were analyzed statistically to determine if there were significant reflectance differences among hydrophytes. Additional reflectance data were collected with an Isco scanning spectroradiometer from samples of each vegetation type.

SOLAR ENERGY INTERACTIONS WITH PLANTS

Sunlight is transmitted through, absorbed or scattered by leaves and their cellular components. Typically, percent reflectance from a leaf is generally low in the visible spectral region with a slight peak in the green region. Percentage reflection is relatively higher in the near infrared (.7-1.2 μm) wavelengths (Knipling 1969). Leaf reflectance is less than 10% in the ultraviolet and thermal infrared (Gates and Tantraporn 1952). The amount of near infrared energy is relatively low in incident sunlight which compensates for the large differences in percentage reflectance.

The transmittance spectrum for a leaf has the same general characteristics as the reflectance spectrum (Gates et al. 1965). In contrast, the absorption spectrum is the inverse of the other two. Chlorophyll absorbs red light (.65 μm) which is converted photochemically into stored energy in the form of organic compounds through photosynthesis (Rabideau et al. 1946, Gates et al. 1965). Leaves and their components are moderately transparent to the green (.55 μm) spectral region (Woolley 1971).

Incident infrared solar energy penetrates the leaf cuticle and epidermis and is scattered and reflected by refractive index discontinuities among cellular components (Gates 1967, Gausman 1973, Gausman 1974). The cell-wall/air-space interface is the most important refractive index discontinuity (Gausman 1974). Woolley (1971) estimated that refractive index discontinuities other than the cell-wall/air-space interface account for about 8% of leaf reflectance at .8 μm wavelength. At maturity when leaves are desiccated, there is an increase in cell-wall/air-space interfaces with a subsequent increase in near infrared reflectance.

PROCEDURES

Pure dense stands of 10 species of hydrophytes common to the glacial wetlands of the "Prairie Pothole" region were selected for the project. The 10 species were: *Typha angustifolia* (narrow-leaved cattail), *Scirpus validus* (soft-stem bulrush), *S. fluviatilis* (river bulrush), *Phragmites communis* (common reed), *Alisma plantago-aquatica* (water plantain), *Scolochloa festucacea* (whitetop), *Sparganium eurycarpum* (bur reed), *Hordeum jubatum* (foxtail barley), *Polygonum coccineum* (water smartweed), and *Spartina pectinata* (prairie cord-grass). These species are persistent emergents with the exception of whitetop which is nonpersistent. No species of rooted submergents were selected.

Ten sample sites .75 m^2 were randomly selected within each stand of hydrophytes. Measurements of incoming and reflected radiation were made .5 m above the vegatation at each site with an Exotech* radiometer. The radiometer is sensitive to 4 wavebands 0.5-0.6 μm, 0.6-0.7 μm, 0.7-0.8 μm, and 0.8-1.1 μm. The respective spectral

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*Inclusion in this report of registered trade names or trademarks does not constitute an endorsement by the author.

regions represent green, red, and 2 near infrared, respectively. When vegetative cover appeared to be less than 100%, vegetation was clipped at the ground and the litter removed or vegetation was pushed below the water surface to make background reflectance measurements.

Reflectance data were collected during a 2 week period in August, 1978, when the hydrophytes were in a flowering or early seed stage, during a 2 week period in October, 1978, when the vegetation was in a senescent stage and a 2 week period in June, 1979, when vegetation was in an early emergent stage.

Percent reflectance was calculated as the ratio of reflected to incoming radiation. Use of percent reflectance minimized the variability due to differences in atmospheric conditions and sun angle. Measurements were made when sun angles were greater than 35° in the fall and 45° during the summer months in order to further reduce sun angle effects. An attempt was made to partition the effects of background radiation if vegetation density was less than 100% by using the following equation:

$$\rho = A_v \rho_v + A_w \rho_w$$

where: ρ = total % reflectance

A_v = % area of vegetative cover

ρ_v = % reflectance due to vegetation

A_w = % area of background

ρ_w = % reflectance of background

The percent area of vegetation cover and percent area of background were estimated with a random dot grid and enlargement prints of 35 mm vertical photographs of each site. Each estimate was an average of four counts of the dot grid which was rotated 90° and randomly dropped for each count. The equation is solved for the pure vegetative (ρ_v) component, with all other variables known.

Statistical means and standard deviations of reflectance measurements of each species of hydrophyte were calculated for each spectral band during the different phenological stages. Analyses of variance were used to evaluate the significance of hydrophyte species, spectral band and phenological stage delineations in the entire reflectance data set. In addition, species and stage were analyzed within band. Where the analyses of variance indicated that class membership accounted significantly for data variance, Duncan's Multiple Range tests (significant $\geq$.95) were used to order and separate the class means. Statistical analyses were performed using the Statistical Analysis System (SAS) procedures (Barr et al. 1976). For the purpose of this study it will be assumed that species of hydrophytes with statistically different reflectance means should appear differently on remotely sensed imagery.

Laboratory Reflectance Measurements

Vegetation samples were collected and stored in plastic bags during fall and spring data collections. Reflectance measurements were made on these samples in the laboratory with an Isco scanning spectroradiometer. The system includes a specimen chamber with a constant light source which was constructed specifically for this purpose (Fig. 1). The specimen chamber was painted with a non-reflective black paint and the ring light source produced light in only the visible spectra (0.4-0.75 μm). The detector was shielded from direct radiation from the light source by a non-reflective cylinder which also restricted the "look" angle of the detector. Vegetation samples were cut to fit under the specimen chamber and the entire look area was covered with vegetation. Replicate measurements were made to evaluate possible sources of procedural or equipment errors. Percent reflectance curves were plotted from the scans. This method did not simulate natural conditions, but provided supportive data or data of narrow wavebands in spectral regions for which the Exotech was not sensitive.

RESULTS AND DISCUSSION

Pure dense stands of each species were selected whenever possible in order to minimize confusing effects from background radiation. The characteristics of some of the species made it impossible to find stands that were 100% vegetated during each phenological stage (Table 1).

Reflectance values were adjusted by partitioning the background radiation if vegetative cover was less than 100%. The adjusted reflectance data were an estimate of the reflectance from vegetation only. The values that were not adjusted represented the reflectance from natural stands of each species and were more closely

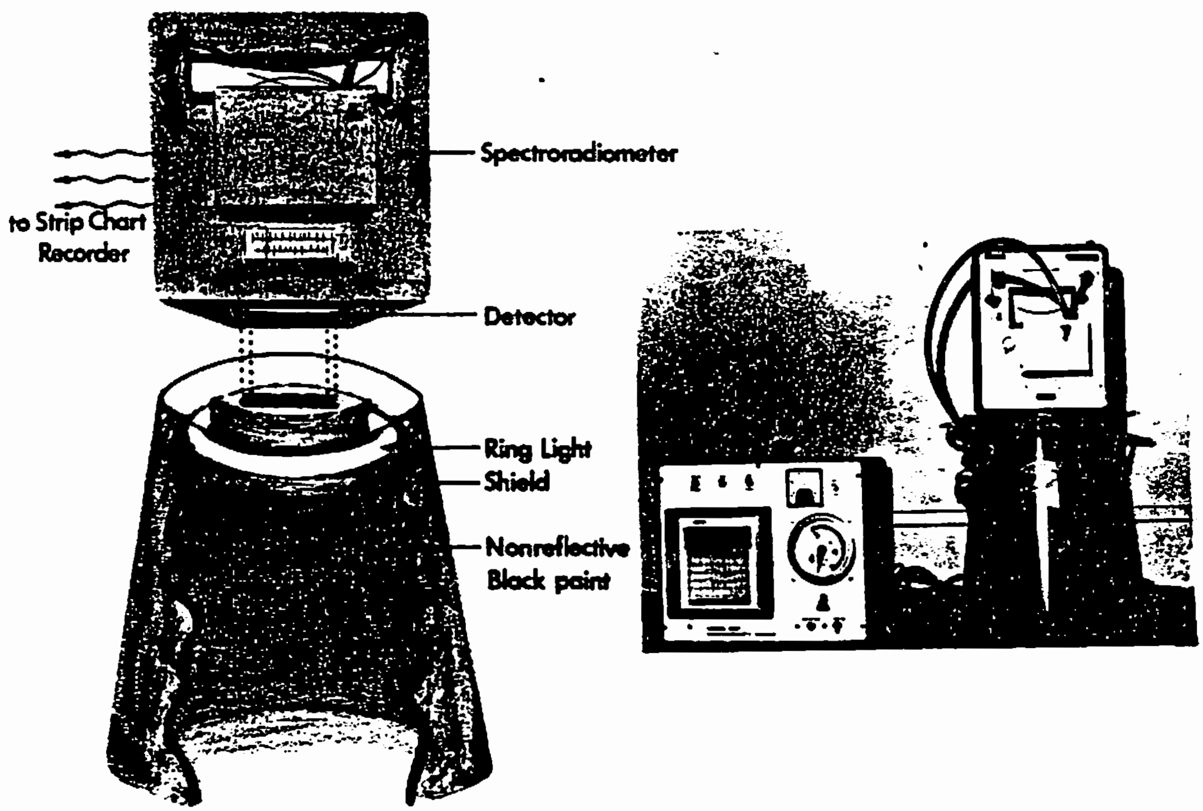


Fig. 1. Illustration of specimen chamber and Isco scanning spectroradiometer used for laboratory reflectance measurements.

Table 1. Average percent vegetative cover for each species during three phenological stages.

Species of Hydrophyte	Average % Vegetative Cover					
	Flower and Early Seed		Senescent		Emergent	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Alisma plantago-aquatica	100.0		100.0		28.3	7.0
Hordeum jubatum	100.0		100.0		100.0	
Phragmites communis	100.0		100.0		100.0	
Polygonum coccineum	100.0		100.0		37.9	6.0
Scripus fluviatilis	100.0		100.0		67.9	4.5
Scirpus validus	76.4	3.7	69.0	17.0	31.8	3.8
Scolochloa festucacea	86.3	3.2	70.0	21.0	73.3	1.3
Sparganium eurycarpum	80.9	3.2	100.0		79.4	1.9
Spartina pectinata	100.0		100.0		100.0	
Typha angustifolia	100.0		100.0		77.4	5.1

related to their appearance on imagery. The adjusted reflectance values were calculated to evaluate the effects of plant characteristics and density on reflectance from natural stand.

Interpretation of species composition makes it possible to determine the extent of wetlands and water regime parameters. The species of hydrophyte present relates to the depth of the water and the duration of inundation (Stewart and Kantrud 1971). The 10 species of hydrophytes in this study can be grouped into 3 classes relating to water regime zones as described by Steward and Kantrud (1971). *Hordeum jubatum* and *Spartina pectinata* are commonly found in the wet-meadow zone which occupies the central area of many shallow basins and commonly occurs as a peripheral band on deeper more permanent marshes. Hydrophytes common in the shallow-marsh zone, areas where surface water is present for extended periods during the spring and summer and usually dry by late summer and fall, are: *Alisma plantago-aquatica, Polygonum coccineum, Scolochloa festucacea,* and *Sparganium eurycarpum.* The deep-marsh zone, which maintains surface water throughout the year in a normal year is characterized by *Phragmites communis, Scirpus fluvitalis, S. validus,* and *Typha angustifolia.* Species composition is also necessary to determine the value of wetlands relating to both food and cover for wildlife.

Reflectance Data

Reflectance data for hydrophytes in flowering or early seed, senescent and early emergent stages are presented in Tables 2-4,

Table 2. Spectral reflectance* means for hydrophytes in the flowering or early seed stage.

Vegetation Species	.5-.6 μm		.6-.7 μm		.7-.8 μm		.8-1.1 μm	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Alisma plantago-aquatica	5.1	0.4	5.8	0.3	18.4	2.2	24.9	1.5
Hordeum jubatum	7.9	0.5	10.1	0.5	20.5	1.1	22.1	7.3
Phragmites communis	3.9	0.4	3.3	0.6	19.4	2.2	28.0	3.2
Polygonum coccineum	5.9	0.4	6.3	0.3	22.5	2.2	34.3	3.1
Scirpus fluviatilis	4.3	0.4	3.9	0.4	24.7	3.1	39.2	7.4
Scirpus validus	3.3	0.3	4.3	0.7	16.6	1.4	24.9	1.7
Scolochloa festucacea	5.3	0.7	4.9	0.7	22.1	4.1	31.0	4.9
Sparganium eurycarpum	4.6	0.3	4.0	0.4	25.6	5.1	34.0	5.7
Spartina pectinata	4.4	0.4	4.5	0.5	29.2	1.3	46.1	2.2
Typha angustifolia	4.8	0.5	5.3	0.5	34.7	6.1	56.7	3.3

*Reflectance data reported as a percentage of the incident.

Table 3. Spectral reflectance* means for hydrophytes in senescent growth.

Vegetation Species	.5-.6 μm		.6-.7 μm		.7-.8 μm		.8-1.1 μm	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Alisma plantago-aquatic	7.4	0.6	9.7	0.8	21.7	2.0	29.1	4.8
Hordeum jubatum	9.4	0.9	12.6	1.3	21.3	2.3	27.1	3.5
Phragmites communis	6.8	0.8	11.2	1.6	19.3	2.4	22.9	1.8
Polygonum coccineum	3.8	0.7	6.0	0.5	15.1	2.3	21.1	0.23
Scirpus fluviatilis	9.0	1.1	13.8	2.5	23.1	3.0	32.1	5.0
Scirpus validus	6.4	1.7	9.2	2.6	16.3	4.5	19.5	5.2
Scolochloa festucacea	21.1	5.7	30.7	7.1	62.0	15.8	69.6	11.8
Sparganium eurycarpum	6.5	0.5	10.1	0.6	21.9	2.1	28.7	2.5
Spartina pectinata	13.8	2.1	23.7	3.2	43.8	3.7	59.6	4.5
Typha angustifolia	8.4	1.7	16.5	4.8	31.2	7.9	40.5	8.1

*Reflectance data reported as a percentage of the incident.

Table 4. Spectral reflectance* means for hydrophytes in early emergent stage.

Vegetation Species	.5-.6 μm		.6-.7 μm		.7-.8 μm		.8-1.1 μm	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Alisma plantago-aquatica	7.7	0.6	8.3	0.7	26.3	1.4	34.4	3.2
Hordeum jubatum	6.3	0.6	6.3	0.8	33.5	3.0	45.3	6.5
Phragmites communis	7.9	1.5	10.8	3.5	19.8	6.3	27.1	4.6
Polygonum coccineum	3.6	0.4	3.4	0.4	12.8	1.5	16.7	2.3
Scirpus fluviatilis	3.8	0.2	3.4	0.3	13.7	0.8	18.2	1.5
Scirpus validus	4.7	0.7	5.0	0.6	15.9	4.7	20.0	2.0
Scolochloa festucacea	5.3	0.2	4.9	0.5	24.4	2.8	32.8	4.6
Sparganium eurycarpum	3.4	0.3	3.5	0.4	22.2	1.2	18.2	1.0
Spartina pectinata	8.9	0.5	10.3	0.8	17.6	1.6	20.6	2.1
Typha angustifolia	4.7	0.7	4.9	0.6	19.6	4.2	26.0	3.2

*Reflectance data reported as a percentage of the incident.

respectively. The values have not been corrected for differences in stand density and represent reflectance from a natural stand. Reflectance was higher in the reflective infrared (.7-.8 and .8-1.1 μm) than in the visible spectra (.5-.6 and .6-.7 μm) during all phenological stages. This is common for most plants and is the motivation for reflective infrared sensitive films. Near infrared energy is scattered or reflected from leaves by refractive index discontinuities, the cell-wall/air-space interface being the most important (Gausman 1974). Near infrared reflectance increases as plants become desiccated during senescence which increases the cell-wall/air-space interfaces (Gausman 1974, Gausman et al. 1977). Senescent vegetation generally does not appear deep red or magenta on infrared films because of the associated increase in visible reflectance and the dye sensitivity of the film (Knipling 1969).

Reflectance data adjusted for vegetative densities less than 100% for the 3 different phenological stages are presented in Tables 5-7, respectively. Adjusted reflectance values were generally slightly higher than those for the natural stand. This can be attributed to separating the effects of background reflectance. Background was open water with low turbidity or very wet organic soils, both of which have very low reflectance in visible and reflected infrared spectra. This relatively low background reflectance would cause a lower overall reflectance from the natural stand depending on the ratio of vegetative cover to background.

Table 5. Means of adjusted spectral reflectance for hydrophytes in flowering or early seed stage.

	.5-.6 μm		.6-.7 μm		.7-.8 μm		.8-1.1 μm	
Vegetation Species	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Scirpus validus	3.4	0.8	4.3	1.0	19.6	2.4	29.5	3.0
Scolochloa festucacea	5.6	0.6	5.1	0.6	29.7	4.4	35.0	5.2
Sparganium eurycarpum	4.4	0.3	4.3	0.7	30.4	6.2	41.1	7.2

Table 6. Means of adjusted spectral reflectance for hydrophytes in senescent stage.

	.5-.6 μm		.6-.7 μm		.7-.8 μm		.8-1.1 μm	
Vegetation Species	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Scirpus validus	6.8	3.0	13.1	6.4	21.6	7.5	27.0	9.2
Scolochloa festucacea	23.7	6.6	34.6	7.6	70.1	17.1	78.8	11.8

Table 7. Means of adjusted spectral reflectance for hydrophytes in early emergent stage.

Vegetation Species	.5-.6 μm		.6-.7 μm		.7-.8 μm		.8-1.1 μm	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Alisma plantago-aquatica	12.8	2.7	11.8	2.3	54.9	12.9	69.0	22.7
Polygonum coccineum	4.2	1.4	3.3	1.6	28.3	4.2	38.3	4.0
Scirpus fluviatilis	3.9	0.4	3.0	0.4	18.1	1.3	24.3	2.5
Scirpus validus	9.2	2.4	8.9	2.0	42.7	16.2	56.4	7.5
Scolochloa festucacea	6.2	0.3	5.5	0.7	30.5	3.9	42.1	6.3
Sparganium eurycarpum	3.4	0.4	3.8	0.5	27.1	1.5	21.9	1.2
Typha angustifolia	5.3	1.1	5.4	0.9	24.6	6.2	32.9	5.5

Analysis of Variance

Statistical analyses of variance (ANOVA) were used to determine if reflectances differed with species of hydrophytes and/or spectral regions. F-tests were used to determine significance. The analysis of variance does not indicate which differences may be considered statistically significant only that differences occur.

F-values were calculated from the analysis of variance for spectral region within species during each phenological stage (Table 8). F-values for natural stands and adjusted data were highly significant for all species. These values indicate that highly significant reflectance differences were present among spectral regions for each species, which justified the collection of data in all spectral regions.

Analysis of variance was used to determine if reflectance differed with species within each spectral region. F-values calculated by analysis of variance for species within spectral region during each phenological stage are presented in Table 9. All F-values were highly significant which indicated the reflectance variation contribution of species membership in these spectral regions and phenological stages. These results suggest that some of the species should be distinguishable during each phenological stage.

F-values were calculated from the analysis of variance to determine if reflectance differed among phenological stages for each species and spectral region (Table 10). Phenological stage contributed significantly to reflectance variation for each species in each

Table 8. F-values calculated by analysis of variance for spectral region within species.

Species	Flower or Early Seed		Senescent		Early Emergent	
	Natural Stand	Adjusted	Natural Stand	Adjusted	Natural Stand	Adjusted
Alisma plantago-aquatica	516.52**		150.12**		576.19**	64.14**
Hordeum jubatum	709.69**		127.93**		298.25**	
Phragmites communis	381.21**		175.19**		40.76**	
Polygonum coccineum	534.51**		232.59**		230.85**	326.64**
Scirpus fluviatilis	181.36**		100.95**		743.40**	541.24**
Scirpus validus	755.15**	397.03**	25.63**	16.79**	91.15**	70.42**
Scolochloa festucacea	157.57**	184.95**	47.29**	53.86**	264.18**	242.28**
Sparganium eurycarpum	157.53**	152.93**	378.55**		1405.12**	532.35**
Spartina pectinata	2380.03**		348.67**		157.31**	
Typha angustifolia	519.59**		54.49**		160.81**	111.93**

**Significant at .99 level

Table 9. F-values calculated by analysis of variance for species within spectral regions.

Phenological Stage	Spectral Region .5-.6 μm	.6-.7 μm	.7-.8 μm	.8-1.1 μm
Flower or early seed	85.12**	149.67**	27.40**	69.08**
Adjusted	70.41**	112.14**	23.09**	54.20**
Senescent	52.14**	55.53**	56.83**	87.06**
Adjusted	50.08**	48.13**	59.67**	88.97**
Early Emergent	89.98**	50.27**	38.14**	69.40**
Adjusted	43.85**	40.58**	24.86**	41.82**

**Significant at .99 level

Table 10. F-values calculated by analysis of variance for phenological stage within species for each spectral region.

Species of Hydrophyte	Spectral Region			
	.5-.6 μm	.6-.7 μm	.7-.8 μm	.8-1.1 μm
Alisma plantago-aquatica	70.33**	100.93**	44.41**	17.39**
Hordeum jubatum	52.73**	121.73**	102.87**	61.05**
Phragmites communis	42.76**	37.52**	0.06	6.31**
Polygonum coccineum	60.04**	155.99**	109.83**	125.74**
Scirpus fluviatilis	187.94**	158.73**	56.06**	41.46**
Scirpus validus	21.31**	28.98**	0.11	6.56**
Scolochloa festucacea	76.69**	130.46**	54.72**	77.19**
Sparganium eurycarpum	168.38**	550.92**	4.10*	49.60**
Spartina pectinata	133.95**	265.42**	290.94**	395.52**
Typha angustifolia	38.57**	55.94**	16.05**	82.29**

*Significant at .95 level

**Significant at .99 level

spectral band with the exception of *Phragmites communis* and *Scirpus validus* in .7-.8 μm spectral region. These results justify the collection of data during different phenological stages.

Duncan's Multiple Range Test

Duncan's Multiple Range Test was used to determine differences and similarities in species reflectance. Duncan's analyses were completed for each spectral region within each phenological stage. In each Duncan's analysis, species underscored by the same line are statistically members of a common parent reflectance population. Species underscored by the same line do not have significantly different reflectance means and cannot be distinguished from one another. Duncan's results for reflectance data from natural stands are presented in Table 11 where:

Alism	=	*Alisma plantago-aquatica*
Horde	=	*Hordeum jubatum*
Phrag	=	*Phragmites communis*
Polyg	=	*Polygonum coccineum*
Scirp f.	=	*Scirpus fluviatilis*
Scirp v.	=	*Scirpus validus*
Scolo	=	*Scolochloa festucacea*
Sparg	=	*Sparganium eurycarpum*
Spart	=	*Spartina pectinata*
Typha	=	*Typha angustifolia*

Table 11. Duncan Multiple Range Test results for natural stands of hydrophytes.

Flower or Early Seed

.5-.6 μm

Horde	Polyg	Scolo	Alism	Typha	Sparg	Spart	Scirp f.	Phrag	Scirp v.

.6-.7 μm

Horde	Polyg	Alism	Typha	Scolo	Spart	Scirp v.	Sparg	Scirp f.	Phrag

.7-.8 μm

Typha	Spart	Sparg	Polyg	Scirp f.	Scolo	Horde	Phrag	Alism	Scirp v.

.8-1.1 μm

Typha	Spart	Scirp f.	Polyg	Sparg	Scolo	Phrag	Horde	Alism	Scirp v.

Table 11. Continued

Senescent

.5-.6 μm

Scolo	Spart	Horde	Scirp f.	Typha	Alism	Phrag	Sparg	Scirp v.	Polyg

.6-.7 μm

Scolo	Spart	Typha	Scirp f.	Horde	Phrag	Sparg	Alism	Scirp v.	Polyg

.7-.8 μm

Scolo	Spart	Typha	Scirp f.	Sparg	Alism	Horde	Phrag	Scirp v.	Polyg

.8-1.1 μm

Scolo	Spart	Typha	Scirp f.	Alism	Sparg	Horde	Phrag	Polyg	Scirp v.

Table 11. Continued

Early Emergent

.5-.6 μm

Spart	Phrag	Alism	Horde	Scolo	Scirp v.	Typha	Scirp f.	Polyg	Sparg

.6-.7 μm

Phrag	Spart	Alism	Horde	Scolo	Scirp v.	Typha	Sparg	Scirp f.	Polyg

.7-.8 μm

Horde	Alism	Scolo	Sparg	Phrag	Typha	Spart	Scirp v.	Scirp f.	Polyg

.8-1.1 μm

Horde	Alism	Scolo	Phrag	Typha	Spart	Scirp v.	Scirp f.	Sparg	Polyg

The maximum number of separations of species was during the flower and early seed phenological stage where 8 species had distinct reflectances in the spectral regions tested. In the .5-.6 μm spectral region 3 species, *Hordeum jubatum, Polygonum coccineum* and *Scirpus validus,* had different reflectance means. Two additional species, *Alisma plantago-aquatica* and *Phragmites communis,* could be separated in the .6-.7 μm spectral range. Two species, *Spartina pectinata* and *Typha angustifolia,* had distinct reflectance means in the .7-.8 μm spectral range. *Scirpus fluviatilis* could be separated in the .8-1.1 μm spectral range. These data indicate that these 8 species should appear differently on visible and reflected infrared sensitive imagery.

Four species had distinct reflectance characteristics during senescence. *Polygonum coccineum, Scolochloa festucacea,* and *Spartina pectinata* were separable in the visible (.5-.6 μm, .6-.7 μm) spectral ranges. *Typha angustifolia,* which was not separable in the visible spectral ranges could be separated in the near infrared (.7-.8 μm, .8-1.1 μm).

Hordeum jubatum had a distinct reflectance in all spectral regions in the early emergent stage. Three other species could be distinguished in the visible spectra, *Scolochloa festucacea* and *Spartina pectinata* in the .5-.6 μm spectral range and *Alisma plantago-aquatica* in the .7-.8 μm range.

Only *Sparganium eurycarpum* could not be distinguished during at least one phenological stage. It would not be common for all 10 species to be present in a single wetland. If only one species from a common reflectance population is present it will be separable from others when delineating within a single wetland. Duncan's results can be referred to in order to determine separability if fewer classes are present. Grouping of species with similar characteristics will also improve separability. Apparent textural and positional differences may make species more identifiable on imagery.

Results from the Duncan's analysis of reflectance data adjusted for density differences are presented in Table 12. Reflectance data were adjusted only for species with vegetative density less than 100%. It was assumed that reflectance data from plots with 100% vegetative density were due solely to the vegetative reflectance. There was generally a slight increase in reflectance data by adjusting for background effects. There were fewer separations in the adjusted data. This indicates that stand density as well as hydrophyte characteristics may be a source of reflectance differences in natural stands.

Scanning Spectroradiometer Measurements

Reflectance curves were plotted from Isco scanning spectroradiometer for species collected during senescence and early emergent phenological stages (Fig. 2). This figure was prepared by plotting percent reflectance versus wavelength and can not be directly correlated with field reflectance measurements. The laboratory technique is designed to provide supplemental information about hydrophyte reflectance under very stringent controls. There are

Table 12. Duncan's Multiple Range Test results for hydrophyte reflectance data adjusted for density differences.

Flower or Early Seed

.5-.6 μm

Horde	Polyg	Scolo	Alism	Typha	Spart	Sparg	Scirp f.	Phrag	Scirp v.

.6-.7 μm

Horde	Polyg	Alism	Typha	Scolo	Spart	Sparg	Scirp v.	Scirp f.	Phrag

.7-.8 μm

Typha	Sparg	Spart	Polyg	Scolo	Scirp f.	Horde	Scirp v.	Phrag	Alism

.8-1.1 μm

Typha	Spart	Sparg	Scirp f.	Scolo	Polyg	Scirp v.	Phrag	Horde	Alism

Table 12. Continued

Senescent

.5-.6 μm

Scolo	Spart	Horde	Scirp f.	Typha	Alism	Scirp v.	Phrag	Sparg	Polyg

.6-.7 μm

Scolo	Spart	Typha	Scirp f.	Scirp v.	Horde	Phrag	Sparg	Alism	Polyg

.7-.8 μm

Scolo	Spart	Typha	Scirp f.	Sparg	Alism	Scirp v.	Horde	Phrag	Polyg

.8-1.1 μm

Scolo	Spart	Typha	Scirp f.	Alism	Sparg	Horde	Scirp v.	Phrag	Polyg

Table 12. Continued

Early Emergent

.5-.6 µm

Alism Scirp v. Spart Phrag Horde Scolo Typha Polyg Scirp f. Sparg

.6-.7 µm

Alism Phrag Spart Scirp v. Horde Scolo Typha Sparg Polgy Scirp f.

.7-.8 µm

Alism Scirp v. Horde Scolo Polyg Sparg Typha Phrag Scirp f. Spart

.8-1.1 µm

Alism Scirp v. Horde Scolo Polyg Typha Phrag Scirp f. Sparg Spart

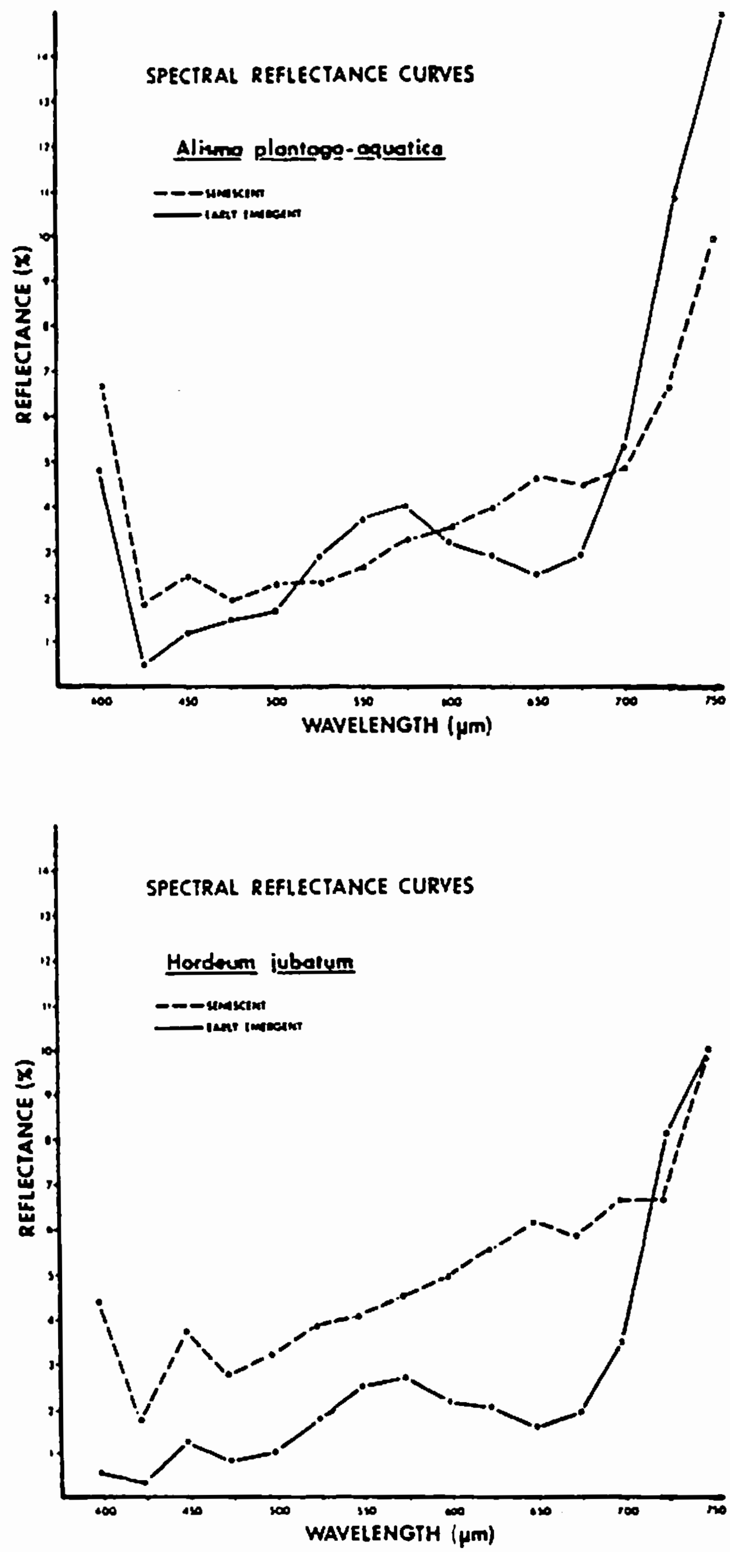
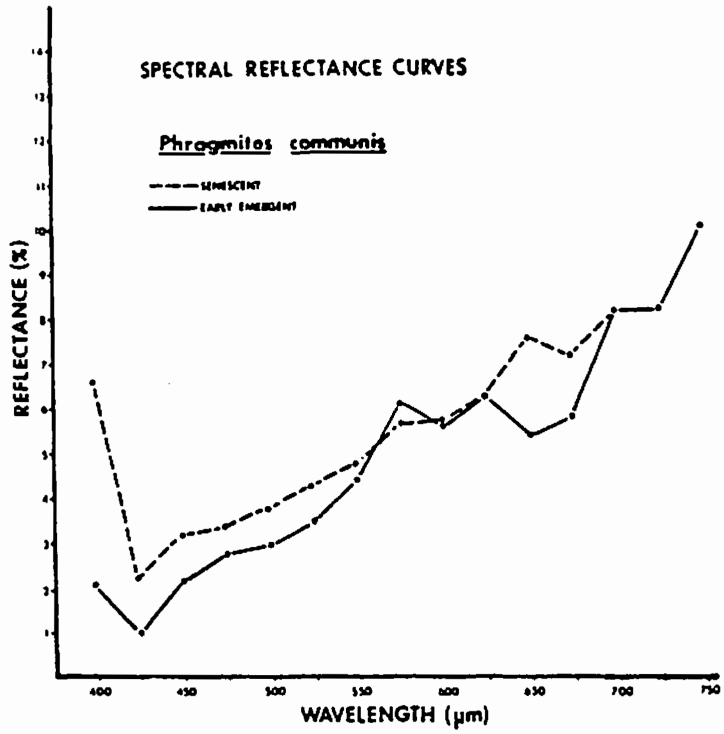


Figure 2. Spectral reflectance curves for hydrophytes in senescent and early emergent phenological stages, plotted from Isco spectroradiometer data.



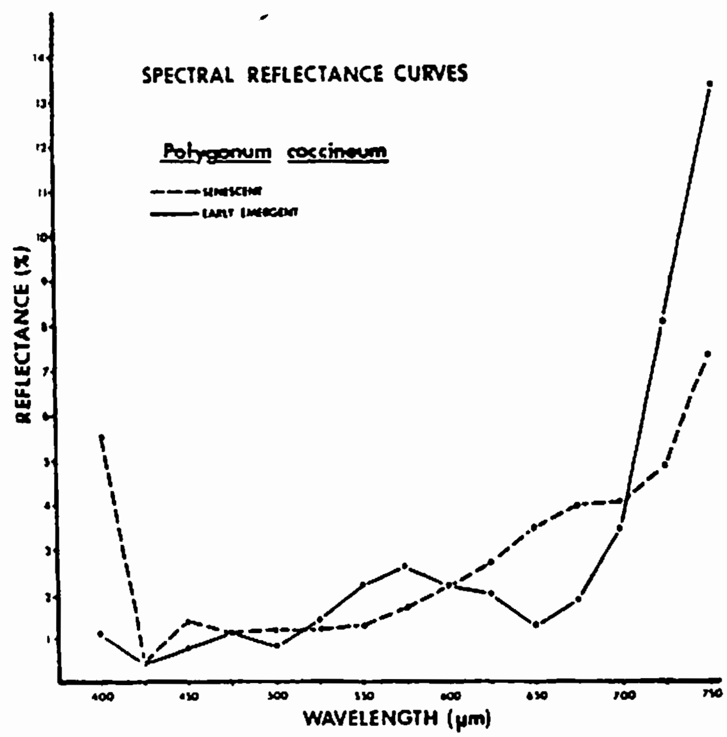
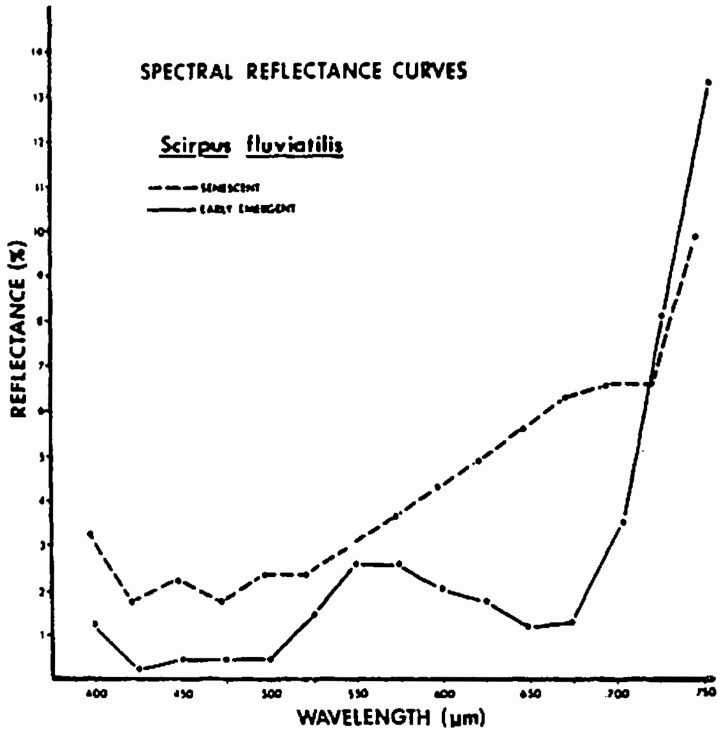


Figure 2. Continued



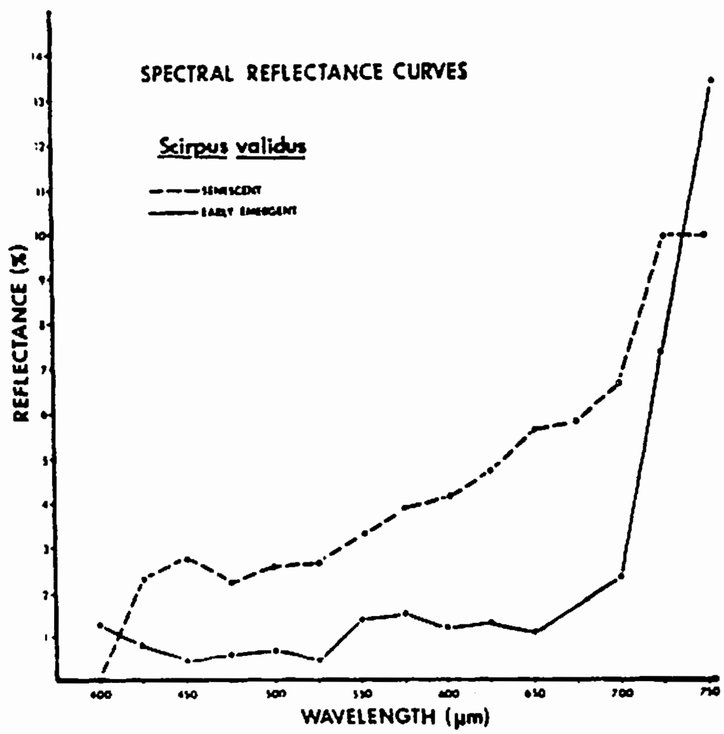
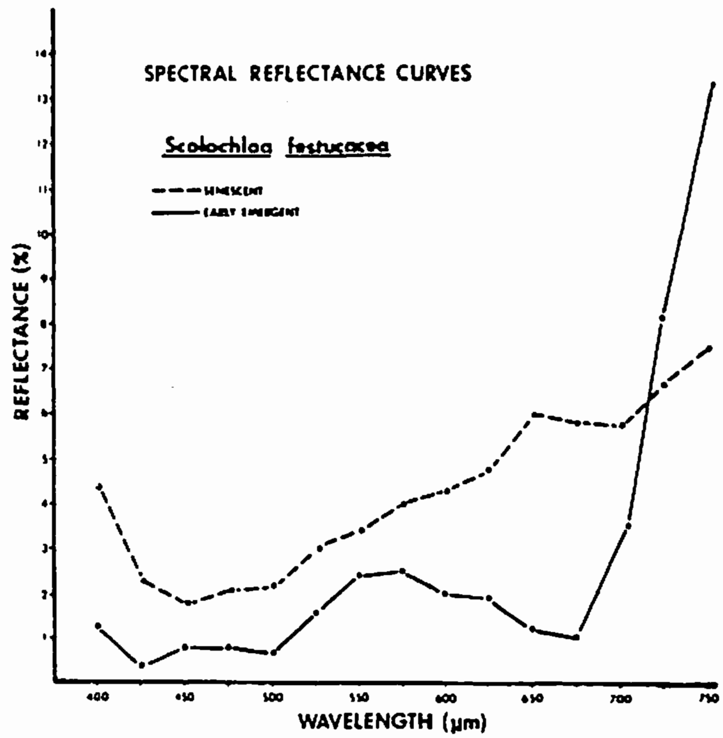


Figure 2. Continued



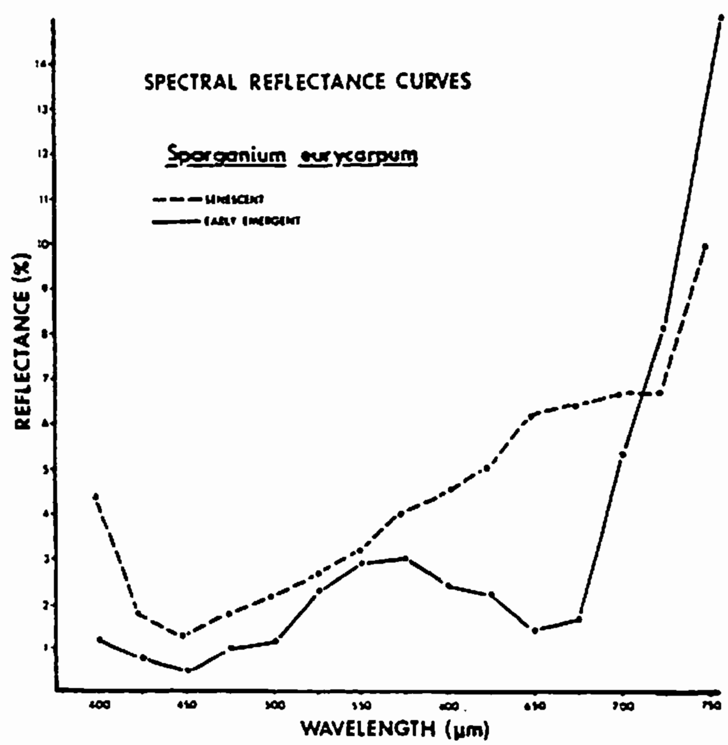


Figure 2. Continued

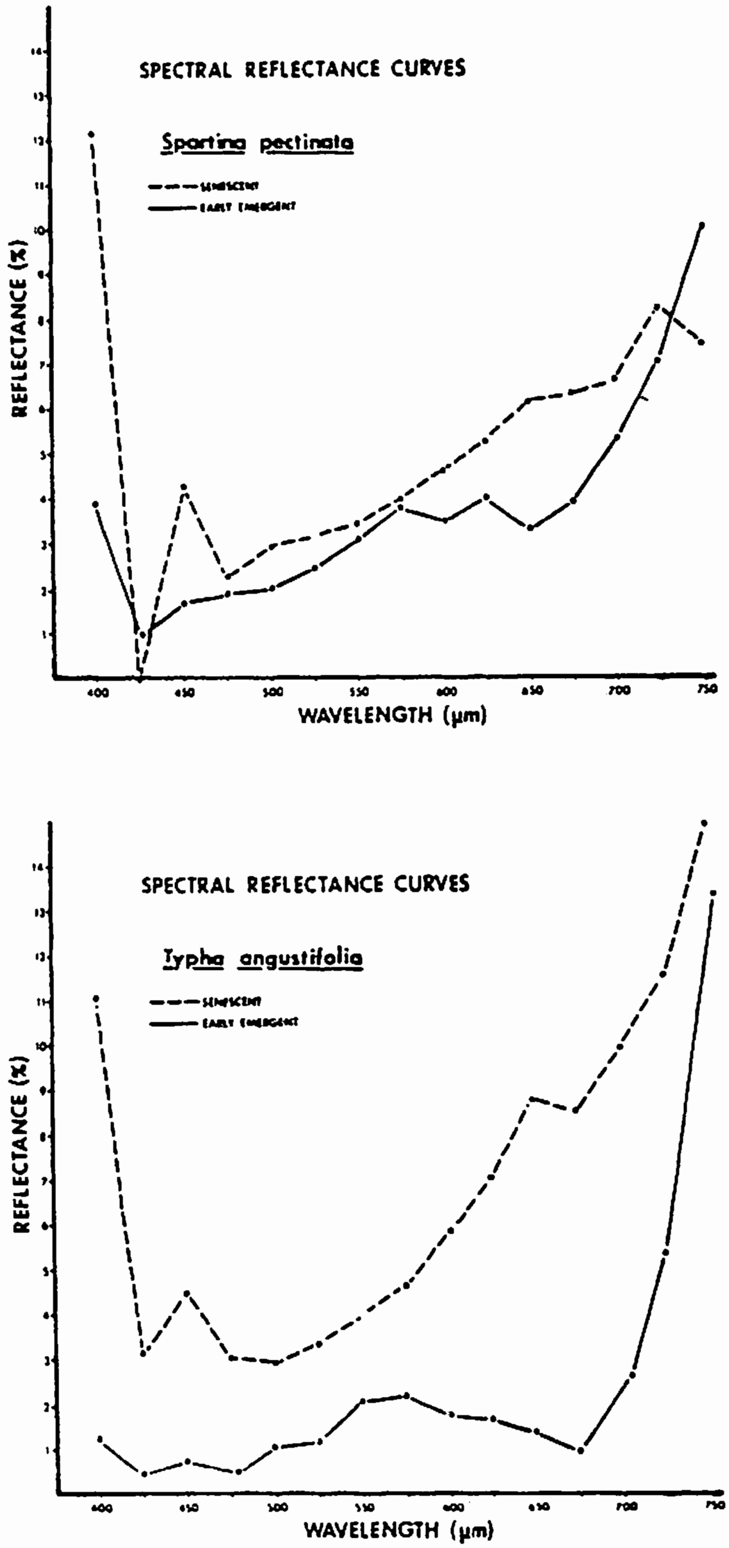


Figure 2. Continued

no effects from plant characteristics or shadowing. The figure can be used to make generalization about reflectance characteristics and provide data for specific wavelength rather than broad spectral bands.

Several trends could be seen in the reflectance curves for senescent vegetation. In almost every case there was a slight peak in the blue wavelength (.450 μm) and in the red wavelength (.650-.675 μm). The reflectance in the yellow-green (.550-.575 μm) portion of the spectrum was very similar for most species. *Polygonum coccineum*, which turns reddish brown during senescence, was a notable exception. A prominant peak in the green wavelength (.550-.600 μm) in the early emergent was evident. During that period all plants were green. The increase in the infrared (>.70 μm) was evident during both growth stages. The relatively higher reflectance of *Phragmites communis* during early emergence could be attributed to the high proportion of residual vegetation in the stand. These data confirm that reflectance differences occur. However, there is no procedure for determining if reflectance differences are significant on the reflectance curves.

.SUMMARY AND CONCLUSIONS

Spectral reflectance differences were statistically significant between the natural stands of hydrophytes from which measurements were made in the project. Maximum separation of species reflectance occurred during the flower or early seed stage

(Table 13). Checked (✓) species/spectral range combinations had distinct reflectance means. Only one species, *Sparganium eurycarpum*, had no separable reflectance during at least one phenological stage. In a natural wetland it would be unlikely for all ten species to be present. If only 1 species which had a similar reflectance with one or more other species was present it would also be separable. The Duncan's analysis results can be used to determine separability when fewer species are present.

Tone on a photographic image is a function of reflectance and film sensitivity. Narrow band black and white photography would not be effective for delineating species of hydrophytes unless the identification of a specific hydrophyte is required. Black and white or color films sensitive to the visible spectra would be more effective. The best results should be achieved with a color infrared (CIR) film which is sensitive to both visible and reflected infrared (.50-1.0 μm). The appearance on the image is also dependent on stand characteristics as well as reflectance from individual hydrophyte plants unless very high resolution imagery is used. The resulting photographic texture, impression of smoothness or roughness and position within the basin may improve separability of some species. The collection of multi-spectral aerial imagery during the same phenological stages could be used to substantiate these results and determine if photographic textural difference will improve separability.

Table 13. Summary of statistically significant reflectance differences between hydrophytes. (✓ different from all other species reflectance).

Vegetation Species	Flowers or Seed				Senescent				Early Emergent			
	.5-.6 m	.6-.7 m	.7-.8 m	.8-1.1 m	.5-.6 m	.6-.7 m	.7-.8 m	.8-1.1 m	.5-.6 m	.6-.7 m	.7-.8 m	.8-1.1 m
Alisma plantigo-aquatica		✓								✓		
Hordeum jubatum	✓	✓							✓	✓	✓	✓
Phragmites communis		✓										
Polygonum coccineum	✓	✓			✓	✓						
Scirpus fluviatilis				✓								
Scirpus validus	✓											
Scolochloa festucacea					✓	✓	✓	✓	✓			
Sparganium eurycarpum												
Spartina pectinata			✓	✓	✓	✓	✓	✓	✓			
Typha angustifolia			✓	✓			✓	✓				

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