Seasonal Consistency of Salt-Marsh Vegetation Classes Classified from Large-Scale Color Infrared Aerial Photographs

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ABSTRACT: CIR aerial photographs taken over a south-east Queensland salt-marsh in autumn and spring were enlarged to a scale of 1:1100. Print reflectances at sample sites-calculated from measurements through the neutral, blue, green, and red filters of a densitometer-were used as attributes in a divisive clustering procedure. The classes generated were compared in terms of their site membership, discriminating attributes, and relationship with vegetation data from field sampling. Although reflectances varied seasonally, the classification results were similar for each season and the vegetation characteristics corresponded well to the classes generated. The greatest seasonal differences occurred in reflectance through the red and blue filters, representing the infrared and green spectral bands. The photographs taken in autumn, with high red reflectances, provided maximum discrimination between the classes.

INTRODUCTION

COLOR INFRARED (CIR) remote sensing is a useful tool both to identify vegetation or habitat types and to monitor changes in vegetation. Identification of vegetation or habitat types most commonly involves recognizing, for a specific time, *a priori* defined categories (e.g., Cowardin and Myers, 1974). However, types can also be defined *a posteriori* by classifying the spectral characteristics of the photographs and relating the classes to vegetation sampled in the field (e.g., Thompson *et al.*, 1980; Dale *et al.*, under review). A question then to be considered is whether the season of photography has a significant effect on the classes defined. Ideally, classifying reflectances during one season would produce classes similar to those produced for a different season, that is, the inter-type relationships between vegetation and reflectance would be relatively stable over time.

Seasonal changes in reflectance have been shown from the ground based remote sensing work of Kimes *et al.* (1981) and Aase and Siddoway (1981) for crops and Hardisky *et al.* (1983), Bartlett and Klemas (1981), and Drake (1976) for salt-marshes. Carter and Anderson (1972) and Carter and Schubert (1974) related reflectance changes to environmental variables in coastal wetlands. Curran (1982) and Shima *et al.* (1976) reported seasonal changes in reflectance measured on large-scale CIR aerial photographs.

In this paper we compare large-scale CIR aerial photographs of a salt-marsh, one taken during autumn, the other during spring. We compare reflectance values and their classifications and evaluate the relationships between the classification results and vegetation characteristics obtained from field studies. If the vegetation types are consistently recognized, regardless of season of photography, then we would expect that, for each season, the results of the spectral classification (1) would be similar both in terms of class description and in the allocation of sample sites to classes and (2) that the plant variables would be similarly related to reflectance and the classes formed.

STUDY AREA AND METHODS

STUDY AREA

The study area (8 ha) forms part of a salt-marsh on Coomera Island (27° 51'S, 153° 23'E) in southeast Queensland, Australia. The vegetation consists primarily of *Sporobolus virginicus* (Saltmarsh couch) and *Salicornia quinqueflora* (Samphire) either alone or in association. Dale *et al.* (under review) identified four main habitat types which ranged from pure stands of tall dense *Sporobolus* on locally elevated areas to relatively dense stands of *Salicornia* with sparse stunted *Sporobolus* adjacent to drainage lines.

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AERIAL PHOTOGRAPHS

CIR aerial photographs (70-mm format) were taken of part of the island from a height of 1500-m on 7 May 1982 (autumn) and on 14 November 1983 (spring). A Hasselblad 500 EL/M camera with a 150-mm lens was used with Kodak Aerochrome Infrared film (2443) and a Wratten No. 15 filter.

The photographs were enlarged as positive paper prints to a scale of 1:1100 for the area of detailed study, and 136 points were randomly selected and located identically on each print. Photographic prints were used for convenience. Measurements were made on the prints and, after the classification was done, the same prints were taken into the field so that the sample sites could be accurately located. Image density at each point was measured directly on each of the prints using the reflection probe of a ESECO Speedmaster Densitometer (TRC-60D). Values were obtained through the neutral, and primary color filters of blue, green, and red because these separate, respectively, the "green, red, and infrared" spectral bands in the CIR image. Image density was converted to image reflectance by the formula

$$\text{reflectance} = \frac{1}{\text{antilog}_{10}\ \text{Density.}}$$

CLASSIFICATION

Values in each spectral band for image reflectance, which is the ratio of reflected to incident light expressed as a percentage, were treated as attributes for each site, and the sites were classified for each season separately using a divisive classification procedure DIPCOM (Lance and Williams, 1975) from the TAXON package (Ross, 1983) on the CSIRO Cyber 76. This clustering procedure is based on a principal component analysis to identify the axis of greatest variation. Sites are then separated into two classes to maximize differences between them in terms of their scores on this axis, and the process is repeated for each of the classes so formed and their subclasses until a suitable stopping point is reached. In this study the stochastic test RATLAN (Ratkowsky and Lance, 1978) was used to indicate the appropriate stopping point in the classification.

To see if there was a simple linear relationship between the reflectances at each season, Pearsons' correlation coefficients were calculated. Then, to evaluate similarity between the classifications, we compared the major discriminating variables and the classes identified.

The major discriminators were ranked using the CRAMER program (Lance and Williams, 1977) which is similar to an analysis of variance. Differences between classes were evaluated using the GCOM program (Lance et al., 1968) which, for each dichotomy, identifies the major discriminating variables (listing their mean value for the group and their contribution to the intergroup distance, measured as standardized Euclidean distance). To see if sites were similarly allocated to classes by the classification for each season, class correspondence in terms of site membership was tested (at the four-class level) using the chi-squared test.

RELATIONSHIPS BETWEEN REFLECTANCE, CLASSIFICATION, AND VEGETATION

To establish the relationships between the reflectance derived classes and the vegetation, samples were collected at the same time as the spring 1983 aerial photography. Details are given in Dale *et al.* (under review). Three sites, where possible, were chosen from each of the eight-classes selected from the classification of the earlier photograph (autumn 1982). Seven of the classes contained three samples and the eighth had two. These 23 sample sites were later rearranged for analysis into the spring 1983 classes, resulting in an average of 2.56 sites per class (S.D. 1.42). Two samples of above-ground vegetation were collected from each site and the quantity, size, and dry weight of each species was measured.

To see if there were simple linear relationships between reflectances at each time and the plant variables, Pearson's correlation coefficients were calculated. The vegetation data were also used to measure class coherence in terms of the plants. The CRAMER and GCOM programs were again used to identify discriminating variables and interclass differences. Because the vegetation data were not used to generate the classification, significance tests could be used to interpret the results.

RESULTS AND DISCUSSION

SPECTRAL CHARACTERISTICS OF THE 136 SAMPLE SITES

It is expected that differences between photographs acquired at different times will be due to variables of the photographic system, solar altitude and azimuth, as well as the dynamics of the subject matter itself. In this type of study the photographic system, which includes the camera, illumination, film, and print processing, can produce results which are not comparable without the use of reference color standards such as ground targets for calibration. However, such calibration between the acquisitions was not included as the intent was to investigate reflectances only within each wavelength independently. Variations owing to the photographic system within a single wavelength are only expected to affect amplitude without impinging on reflectances of other wavelengths. That is, if the red tones, for example, were to be exaggerated within an image, they would still contain their allocated range of information even if on a somewhat attenuated scale. Other tones would behave likewise. Thus, reflectances within individual wavelengths can be compared across time irrespective of the photographic system anomalies. We processed a second batch of prints from the original film (autumn). Although the reflectances are not exactly the same, the classification produced results similar to those reported here.

The autumn and spring photographs were visually quite dissimilar. The autumn photograph appeared to be predominantly red, orange, and yellow with relatively high infrared reflectance, whereas for spring the color was largely in tones of blue with much lower infrared reflectance. Table 1 shows the average print reflectances measured through each filter for both photographs.

Despite the differences between the photographs, the print reflectances in each wavelength were significantly correlated (P <.01) between the two seasons (Table 2). This suggests that print reflectance varied in a consistent way between seasons.

TABLE 1. PRINT REFLECTANCES FOR PHOTOGRAPHS TAKEN IN AUTUMN AND SPRING.

FILTER	autumn mean %	 SD	spring mean %	 SD
Neutral	46.7	20.3	25.1	12.7
Red	83.6	15.8	22.0	14.3
Green	36.7	21.9	24.6	11.5
Blue	21.4	15.1	37.1	14.0

TABLE 2. PEARSON'S CORRELATIONS BETWEEN PRINT REFLECTANCES ON PHOTOGRAPHS TAKEN IN AUTUMN AND IN SPRING.

spring FILTER	autumn FILTER Neutral	Red	Green	Blue
Neutral	0.829	0.692	0.853	0.817
Red	0.777	0.630	0.813	0.802
Green	0.832	0.690	0.856	0.817
Blue	0.854	0.735	0.866	0.811

All values of r are significant at P<.01

TABLE 3. MAIN DISCRIMINATING REFLECTANCES FOR CLASSIFICATIONS OF AUTUMN AND SPRING SPECTRAL DATA.

	autumn		spring	
Filter	Cramer Value	F Value (df 9,126)	Cramer Value	F Value (df 9,126)
Neutral	0.9909	757.5	0.9903	709.9
Green	0.9861	494.5	0.9873	541.8
Blue	0.9698	221.2	0.9788	320.2

(Because the variables were used to classify the data, significance values are inapplicable.)

CLASSIFICATIONS

Because the reflectance values were positively correlated between each season, it is hardly surprising that the two classifications were fairly similar, both in terms of differentiating variables and site membership of classes.

For each classification, ten was the maximum number of classes requested and the RATLAN test indicated that four classes were optimal. The test, however, is considered to be conservative, and it was shown for the autumn results that subdivision of these into eight classes was useful in terms of vegetation (Dale *et al.*, under review). Here, although we focus on the four class level of the classifications, we refer also to results at higher levels of resolution.

The three major discriminating variables identified by the CRAMER program are shown in Table 3 for each season at the four-class level. The scaled CRAMER values lie between 0 and 1. A value approaching unity suggests that the variable is a very important class discriminator. In general, the classes were separated on, and arranged in order of, print reflectance, '*A*' classes with highest reflectances and '*D*' classes with the lowest. Neutral was a good discriminator at all levels of the hierarchy and at each time.

The GCOM results showed that reflectance through various filters discriminated differently between classes (Figure 1). For the autumn data, the blue and green filters discriminated best between the high reflectance classes (A_1 and B_1) while reflectance through the green and then red filters were best at low reflectances. In terms of print reflectance, this means that green tended to differentiate spectral types at high reflectances whereas at low reflectances the infrared was more useful. For the spring data, this pattern was largely reversed. Reflectance in neutral and through the red filter (infrared print reflectance) discriminated best in the higher reflectances (classes A_2 and B_2) whereas the blue and green filters (green and red print reflectance) differentiated well between the low reflectance classes (C_2 and D_2). Similar results occurred at the higher levels of resolution for both classifications.

Figure 1 also illustrates the consistent differences between autumn and spring data in terms of reflectance through the red and blue filters and particularly the high red reflectance in each class for autumn.

CORRESPONDENCE OF CLASS MEMBERSHIP BETWEEN EACH CLASSIFICATION

If the membership of the classes identified is relatively stable over time, then one would expect the same classification procedure to place sites observed at different times in similar classes.

Table 4 shows the relationship between classes

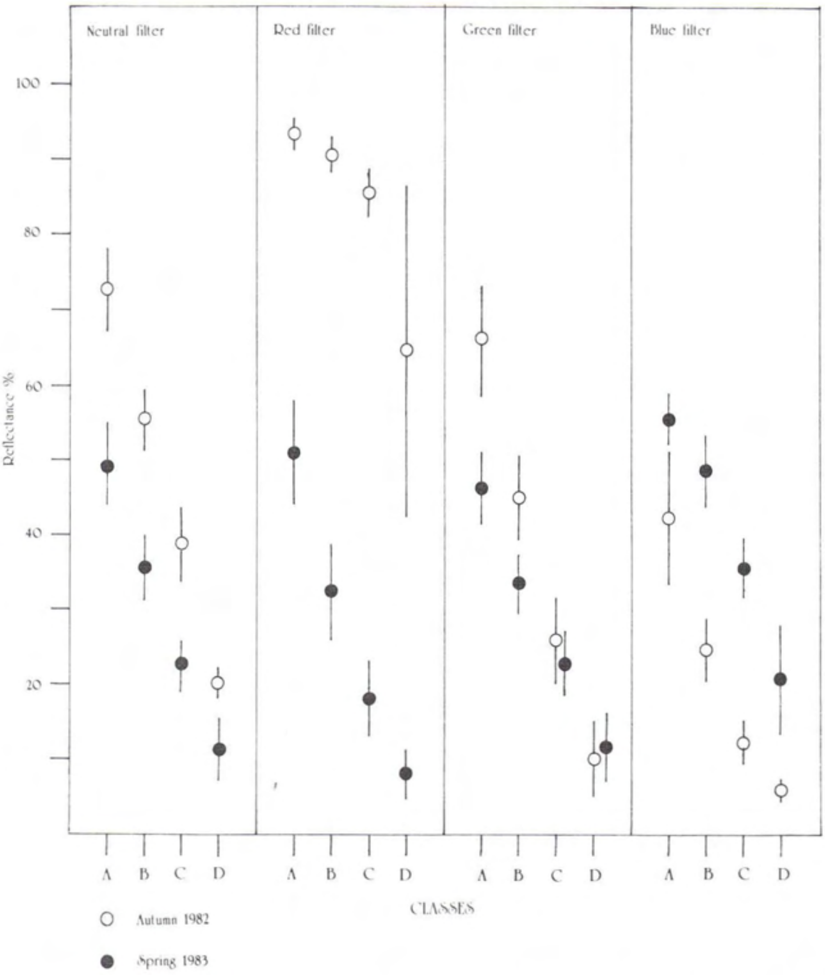

FIG.1. Mean print reflectances and standard deviation through neutral, red, green, and blue filters, for the classes from each classification at the four class level.

TABLE 4. CORRESPONDENCE BETWEEN MEMBERSHIP OF DIPCOM GROUPS FROM AUTUMN AND SPRING REFLECTANCE DATA. (NUMBERS IN BRACKETS SHOW THE DISTRIBUTION OF THE 23 FIELD SAMPLE SITES.)

autumn class	Number of sites spring class				
	A_2	B_2	C_2	D_2	TOTAL
A_1	11 (1)	20 (4)	4 (1)	1	36 (6)
B_1	3	10 (1)	15 (2)	2	30 (3)
C_1	0	4 (1)	23 (4)	10 (1)	37 (6)
D_1	0	0	6 (1)	27 (7)	33 (8)
TOTAL	14 (1)	34 (6)	48 (8)	40 (8)	136 (23)

$X^2 = 80.79$ df = 9 $P<.005$

from each classification at the four-class level. The X^2 test indicated a significant association between the classes at each season ($P<.005$). This suggests that sites which were spectrally similar to each other on the autumn photograph were also spectrally similar to each other on the spring one. Thus, although the actual reflectance values were different between the two seasons, they produced classes of similar composition. There was some overlap in membership between classes, which increased with decreasing reflectance. In part this is because the spring classes were of overall lower reflectance, resulting in a 'spillover effect' on the autumn classes which is related to the logarithmic data transformation. The effect may be accentuated by the divisive classification procedure in which the final division (in this case, a low reflectance class) will produce a class containing residuals. Of the spring samples, 64.7 percent were in low reflectance classes C_2 and D_2 while for autumn only 51.5 percent were in similar classes. Low reflectance on the spring photograph also affected the proportion of samples in the higher reflectance group A_2 (only 10.3 percent compared to 26.5 percent of the autumn samples in A_1). At the ten-class level there was a similar pattern of association but, because of small frequencies in some cells, the relationship was not tested statistically. The correspondence of membership between the classes tends to support the suggestion that the classes themselves are relatively stable over time.

Relationship between Remotely Sensed Data and Field Data

Reflectance values and plant data. Table 5 shows the correlations between reflectance through each filter at each time and dry weight, density, and size of *Sporobolus* and *Salicornia* collected in spring. Most were significant at $P<.001$, and all were significant at $P<.05$. Although the plants were collected simultaneously with the spring photography, only one third of the spring correlation coefficients were greater than those for autumn. Most of these were for reflectance measured using a red filter, which represents print reflectance in the near infrared. The highest correlations were between reflectance through the green filter, representing red print reflectance, and dry weight and size of plants, especially with *Sporobolus* and autumn reflectances.

Several authors have reported increased reflectance in the near infrared wavelengths during active plant growth (Curran, 1982; Bartlett and Klemas, 1981; Drake, 1976), normally during summer, although the specific response varies between plant types (Bartlett and Klemas, 1981) and according to the amount of dead biomass present (Hardisky *et al.*, 1983). Carter and Anderson (1972) related seasonal spectral reflectance variations to changes in plant physiognomy and alignment, the amount of flood-borne sediment deposited on plants, and the water status of the substrate. In particular, high reflectances in the near infrared were related to factors such as plant flattening and leaf orientation. Carter and Schubert (1974) related low spring reflectances to seasonal changes in vegetation density.

Results and conclusions from studies of temperate wetlands may not be wholly applicable to sub-tropical and tropical ones. In our study low print reflectances occurred in late spring and very high values were recorded in the near infrared towards the end of autumn. We monitored *Sporobolus* growth in the study area between 1981 and 1984 and found that the grass grew in mixed age stands of relatively consistent physiognomy and density. Therefore, these are unlikely to be the only cause of seasonal changes in reflectance. We believe that there may be two alternate explanations for low spring reflectances which are not necessarily mutually exclusive. One is that plant growth on the salt-marsh is sporadic, responding rapidly to local meteorological and tidal events. The other is that, in this area, growth continues into late autumn and new growth begins very late in spring or summer. In the first case we have found rapid growth during winter, apparently in response to rainfall, and slower growth during summer, possibly responding to tidal inundation and/or high salinity levels in the substrate. For the Sydney area (lat. 34°S) Clarke and Hannon (1970) and Pearcy and Ustin (1984) reported that growth of salt-marsh plants responds to salinity. In the second case, we know that plant growth was still active on the marsh in the autumn of 1982 when the first photographs were taken, with increases in

Table 5. Pearson's Correlations Between Reflectance At Each Season and Plant Variables (Spring 1983).

Filter	Dry Weight (g)				Number/100cm²				Mean height/length (mm)			
	Sporobolus		*Salicornia*		*Sporobolus*		*Salicornia*		*Sporobolus*		*Salicornia*	
	Autumn 1982	Spring 1983	Autumn 1982	Spring 1983	Autumn 1982	Spring 1983	Autumn 1982	Spring 1983	Autumn 1982	Spring 1983	Autumn 1982	Spring 1983
Neutral	0.803	0.800	−0.694	−0.618	0.734	0.728	−0.712	−0.697	0.895	0.836	−0.747	−0.577
Red	0.643	0.782	−0.492*	−0.578	0.663	0.691	−0.730	−0.637	0.790	0.797	−0.479*	−0.566
Green	0.815	0.789	−0.709	−0.629	0.732	0.719	−0.703	−0.716	0.898	0.839	−0.752	−0.569
Blue	0.799	0.790	−0.686	−0.628	0.697	0.728	−0.661	−0.733	0.888	0.851	−0.733	−0.566

All values are significant at $P<.01$ except for those marked * which are significant at $P<.05$.

both leaf size and leaf number, which are likely to result in high print reflectance in the near infrared. This may be related to the warm winters of the sub tropics and to the high level of soil moisture at the end of summer, when soil moisture recharge was complete. In the spring of 1983, when the second photographs were taken, growth was slow, not reaching a maximum, in terms of leaf size, leaf number, and height of plant, until mid summer.

Classes and plant data. Because reflectance was significantly related to the plant data for the 23 field sample sites, one would expect that the classes represented by these sites would be clearly discriminated.

The vegetation types corresponding to the spectral classes from the autumn data were described in detail in Dale *et al.* (under review) and are summarized in Table 6. After classifying the spring data and regrouping the sites and their associated plant variables, similar results were produced so that Table 6 could generally apply also to those types.

The plant variables which best differentiated between classes are shown in Table 7 together with the Cramer values and associated probabilities. Because these variables were independent of the classification, significance levels can be used to interpret the results. Thus, for both the autumn and spring classifications the mean height and dry weight of *Sporobolus* were the best discriminators.

The plant variables differentiated more effectively between classes for the autumn classification than for the spring one, when the data were collected (Table 8). This is probably related to the relative vigor of plant growth at the two seasons although amount of dead biomass, salinity, and water status of the substrate may also be important. In autumn, when plants were still growing quite rapidly, the differences between vegetation types were accentuated in terms of their reflectance, especially in the near infrared. This is illustrated by the F values, which were generally higher for the autumn classes than for the spring ones (Table 8). Details from Table 8 also complement the more general descriptions of vegetation types shown in Table 6 and emphasize the overall similarity of the classes identified for each season.

CONCLUSION

The results show that spectral reflectance, especially in the near infrared, varies markedly at different times for a salt-marsh. This can be related to plant variables such as size, dry weight, and density and to other environmental factors such as local me-

Table 6. Summary of Vegetation Types Classified On the Autumn 1982 Reflectance Data (Adapted From Dale *et al.*, Under Review). Numbers In Brackets Refer to Class.

	Four-Class level		Eight-Class level
A	Tall dense *Sporobolus* dominant, *Salicornia* absent.	A(1)	Very tall dense *Sporobolus*.
		A(2)	Tall, very dense *Sporobolus*.
B	Medium-tall *Sporobolus* dominant, *Salicornia* present but rare.	B(3)	Medium-tall *Sporobolus* dominant, *Salicornia* present but rare.
C	Mixed medium size *Sporobolus* and *Salicornia*, both of relatively low density.	C(4)	*Salicornia* usually present, low-medium sparse *Sporobolus*.
		C(5)	medium *Salicornia*, *Sporobolus*, common.
		C(7)	Small *Salicornia* abundant, low sparse *Sporobolus*.
D	Large *Salicornia* dominant, Small sparse *Sporobolus*.	D(8)	Large *Salicornia* abundant, medium, sparse *Sporobolus*.
		D(9)	Very small *Salicornia* abundant, very small *Sporobolus* rare.

TABLE 7. VARIABLES IDENTIFIED BY THE CRAMER PROGRAM WHICH DIFFERENTIATED BEST BETWEEN CLASSES AT THE FOUR-CLASS LEVEL, $P<.05$. (*SP* = *SPOROBOLUS*, *SAL.* = *SALICORNIA*)

Autumn Classification				Spring Classification			
Rank	Name	Cramer Value	P	Rank	Name	Cramer Value	P
1	Mean height of *Sp.*	0.8988	<.00	1	Mean height of *Sp.*	0.7908	<.00
2	Dry weight of *Sp.*	0.8695	<.00	2	Dry weight of *Sp.*	0.7760	.001
3	Mean length of *Sal.*	0.7920	<.00	3	Number of *Sal.*	0.6914	.007
4	Number of *Sal.*	0.7918	<.00	4	Number of *Sp.*	0.6885	.008
5	Number of *Sp.*	0.7881	<.00				
6	Dry weight of *Sal.*	0.7769	<.00				

TABLE 8. MEANS, F, AND P VALUES OF DISCRIMINATING PLANT VARIABLES FOR AUTUMN AND SPRING CLASSES.

	AUTUMN CLASS				df = 3,19		SPRING CLASS				df = 3,19	
	A_1	B_1	C_1	D_1	F	P	A_2	B_2	C_2	D_2	F	P
Mean height of *Sporobolus* (mm)	253.3	151.0	111.8	47.64	26.4	.000	230.5	225.7	121.4	53.33	10.02	.000
Mean dry weight of *Sporobolus* (g/100cm^2)	21.14	14.19	4.06	1.69	19.63	.000	24.14	18.21	6.07	2.33	9.08	.001
Mean density of *Salicornia* (number/100cm^2)	0	22.67	34	75.25	10.64	.000	0	7.00	34.00	70.88	5.49	.007

teorological and tidal events. However, because similar vegetation types were identified by the classification of reflectances for each season, it seems that such types are relatively stable over time and moreover can be identified from CIR aerial photographs which are themselves quite different from each other. For such photographs calibration and standardization between prints appears not to be essential for achieving consistent results. Overall print reflectance in the neutral wavelength was a very good discriminator while print reflectance in green and infrared (measured through blue and red filters) would be useful to identify seasonal changes. The growing period for plants in our study area is responsive to local meteorological and tidal events rather than being strictly seasonal. For classification, CIR aerial photographs should be taken during periods of plant growth because there was greater discrimination between classes during such a period.

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