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Multispectral Aerial Photography for Wetland Vegetation Mapping

For the area around Shelburne Pond, Vermont, color infrared photography was best, and conventional color was better than color enhanced multi-band imagery.

Abstract: *Vegetation in a variety of wetland types in the Shelburne Pond, Vermont area was mapped using small scale aerial photographs. Color infrared, conventional color, and black-and-white multi-band photographs were studied using a zoom stereoscope and additive color enhancement techniques. The floristic composition of plant canopy associations and corresponding recognition characteristics are presented. Emphasis is given to ground control and a familiarity with plant ecology, as requisite elements in the interpretive process. Selected observations are made regarding the ecological significance of signature pattern. Film types were evaluated based on three parameters: association discrimination, size of minimum mapping unit, and ease of interpretation. Color infrared was found superior for this application, and conventional color was better than the color enhanced multi-band, which was at a much smaller scale. However, the color enhanced multi-band imagery did offer more information about some plant groups than did color, especially where long wave reflectance was a key recognition element. The use of actinic infrared is recommended for future wetland vegetation investigations.*

Introduction

The importance of fresh water wetlands as fragile natural areas and as habitats for rare and endangered plant and animal species is widely accepted. Efforts to recognize and protect the most important natural areas are underway in every New England state. However, there is a lack of knowledge about many wetlands, especially regarding the spatial distribution and areal extent of natural plant associations, constituting what may be termed a factor of ignorance regarding valuable natural resources. This ignorance factor is of great significance because land-use change by man is a constant and on-going phenomenon, and any confusion about the character of a natural resource severely undermines the value of every planning decision that is made regarding its fate.

The operational use of remote sensing in resource analysis is a fundamental justification for the continued development of this field of science. Many authors have demonstrated the general applicability or potential of remote sensing to wetland vegetation analysis in a variety of settings. Seher and Tueller (1973) studied large-scale color and color infrared photographs of Nevada wetlands, concluding that film type made little difference in the accuracy and detail of maps produced. Cowardin and Myers (1974) described the use of a variety of medium-scale photographs to identify and classify small wetlands in Minnesota. In wetlands as-

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sociated with a delta, Enslin and Sullivan (1974) produced maps of Pointe Mouillee Marsh, Michigan, from medium-scale color infrared photographs. Color aerial photographs have been used for wetland vegetation mapping in the Missisquoi and Lamoille deltas of Lake Champlain by Howland (1977). Carter *et al.* (1979) used multi-date, small-scale color infrared photographs to produce maps of wetland vegetation on 7.5-minute quadrangle base maps of the Tennessee Valley area. In that study, a wetland classification system was developed based primarily on vegetation physiognomy, physical site characteristics, and hydrologic regimen. Of the six classes and twelve sub classes on the wetland maps produced, the size of the minimum mapping unit was 0.5 ha, with one dimension as small as 20 metres. Carter and Stewart (1975) have reported on activities of the U.S. Geological Survey in mapping wetlands at a scale of 1:24000, using seasonal color infrared photographs.

Some attention has been paid to automated wetland mapping including work by Egan and Hair (1971), and by Scarpace *et al.* (1975) who used analytical dye density values of color infrared photographs to map vegetation classes in Michigan. In these latter two studies and in many contemporary efforts, interpretations are heavily weighted toward image analysis, with little emphasis placed in field studies. A useful review of wetland investigations is that of Eitel (1974).

The need for a body of information concerning remote sensing applications to wetland investigations arises from the lack of practical alternative methods for the study of wetland areas. The modern methods of field ecology and phytosociology are often particularly difficult and time consuming to apply in wetlands and sometimes are simply impossible. In particularly fragile ecosystems, comprehensive biological field studies can cause far more physical damage than would an appropriate ground control program in a small portion of the area, and subsequent image analysis.

Civco *et al.* (1978) have paid close attention to the specific problem of the definition of inland wetlands in Connecticut, calling upon the experience of a team of photointerpreters from a variety of user fields. The composite agreement map they produced, while demonstrating the value of the Cell Analytical Method the authors proposed, also indicates the variability of subjective wetland boundary placement, in field and laboratory, even by experienced interpreters.

Wetland boundaries may be very difficult to define, both on aerial photographs and in the field, because a gentle gradient often exists between conditions that clearly are wet and those that are not. Carter *et al.* (1979) found that photographic coverage from several dates showing high and low water conditions allowed a reasonable placement of wetland boundaries. Brown (1978) has described some of the problems in delineating boundaries of coastal wetlands in New York and New Jersey. In this large-scale study, characteristic plant species were the primary wetland identification parameter, and Brown considered a knowledge of plant ecology a necessary element of interpretation. As a progression of Brown's view, in the Vermont study the dependance on ground control, and associated with this a familiarity with wetland plant ecology, is emphasized. In this study, wetlands are defined in terms of surface ground water conditions and associated plant communities. Specific characteristics are indicated in Table 2.

While it is clear that many studies have considered the potential of remote sensing of wetlands, there have been few such efforts addressing the broad variety of types of fresh wetlands which occur in northern New England. The primary objective of this study is to demonstrate and compare the application of remote sensing media and techniques of vegetation analysis in a variety of wetland types in Vermont. Small-scale color, color infrared, and four camera multi-band black-and-white photographs provided a data base for vegetation mapping. The Shelburne Pond study area was selected for analysis because it is comprised of diverse wetland types, including two large peatlands, and assorted marshes, carrs, swamps, and wet meadows. Moreover, while the area is now in a nearly natural state, it is experiencing significant development pressures, and the canopy vegetation maps produced provide a basis for evaluation of an important natural area.

Materials and Methods

Aerial photographs were obtained as duplicate positive transparencies from NASA RB-57 Mission 215 of 20 September 1972. The camera systems and film-filter combinations used in this study are described in Table 1. Wetland borders were drawn on the basis of field observations and subsequent stereo-analysis of color and color infrared photography. The color infrared coverage was photographically enlarged as a black-and-white print at a scale of 1:6,250 for use

TABLE 1. BASIC PHOTOGRAPHIC DATA

Roll	Film Type	Camera	Lens	Filter	Scale
1	KODAK AEROCHROME INFRARED Type 2443	RC-8	6 in.	W #12	1:52,000
2	KODAK EKTACHROME EF AEROCHROME Type SO-397	RC-8	6 in.	Clear A-V.	1:52,000
3	KODAK PLUS-X AEROGRAPHIC Type 2402	KA-62	3 in.	47B	1:104,000
4	KODAK PLUS-X AEROGRAPHIC Type 2402	KA-62	3 in.	57	1:104,000
5	KODAK PLUS-X AEROGRAPHIC Type 2402	KA-62	3 in.	25A	1:104,000
6	KODAK INFRARED AEROGRAPHIC Type 2424	KA-62	3 in.	89B	1:104,000

Platform: NASA RB-57
Altitude: 26,000 feet AMSL
Date: 20 September 1972
Processing; NASA-MSC Precision Processing Laboratory

in the construction of a planimetric map. These enlargements and base maps were used for annotations in the field study and during photo-interpretation.

MULTI-EMULSION PHOTOGRAPHY

With a Bausch and Lomb zoom stereoscope mounted on a light table, the wetlands were examined on both films, and areas of homogeneous appearance were noted. A preliminary classification of photographic characters was developed on the basis of tone, hue, texture, pattern, and the height of canopy. The signature classifications developed for color infrared film (2443) and color film (SO 397) were designed to categorize areas of similar signal characteristics such that every part of the four wetlands could be included in a description, but that maximum differentiation would be retained. The configuration and areal extent of signature areas was determined on the basis of gradients in the interpretation criteria described. Signature outlines were examined repeatedly and considerable effort was made to compare each class description within and between wetlands, wherever it occurred, to be as sure as possible of consistency. Signature areas were then transferred to work maps for use in field studies.

MULTI-BAND PHOTOGRAPHY

The interpretation of multi-band photographs was entirely visual through the use of color enhancement techniques. Each band was enlarged as a duplicate positive transparency using a Polaroid MP-3 Industrial View Camera and Polaroid Film 46-L. The enlargements were mounted and viewed in a Spectral Data Corporation multispectral viewer.

While four bands were prepared for use in the viewer, usually only three bands (green, red, and infrared) proved useful for signature enhancement. The blue band was not helpful due to severe atmospheric attenuation problems caused by the high altitude of the platform.

Canopy signatures were generally differentiated when red of strength seven (on a scale of one to ten) was assigned to the infrared band, green of strength six was assigned to the red band, and blue of strength two was assigned to the green band. It may be noted that the color assignments mentioned closely approximate the emulsion dyes used in false color films. For this reason, the hues described for the multi-band signatures are similar to those found with CIR film. However, during the interpretation of the color enhanced images many variations of the described color assignments and intensities were helpful in signature discrimination.

The differentiation of multi-band signatures was hindered by a basic problem in instrumentation and method. The assurance of consistency of signatures throughout the study area was left to the memory of the interpreter, guided by written descriptions of hue, texture, and pattern, because unlike the study of color and false color films, only one area at a time could be examined in the multispectral viewer. Cross checking to ensure signature consistency between wetlands involved removing the transparencies of one area and replacing them with those of another, realigning the images, and perhaps adjusting light intensity.

It was necessary to adjust light intensity for different sets of transparencies to compensate for gamma variations of the duplicate positive transparencies (Polaroid) resulting from slight fluctuations in processing time.

Signatures were traced from the viewing screen on mylar and transferred to a base map similar to that used for other films. The outlines of the wetland areas on the base map were borrowed from the work map used in the study of film 2443 because wetland boundaries could not reliably be determined with multi-band photography alone.

GROUND TRUTH

A field study was conducted during the months of June through September to identify those ground conditions responsible for film signals. The black-and-white photo enlargements with mylar overlays of tentative signature outlines were used in the field survey as a base map. Nearly every signature area was visited and subjectively classified as one of the following wetland types: peatland, swamp, carr, marsh, wet meadow, or open water (see Table 2). Wetland types were differentiated on the basis of physiognomy, hydrology, and substrate. Type recognition was the first step in sorting the myriad species and life forms into manageable groups.

A more intensive field study was then conducted to determine the floristic composition of the canopy of each signature. A central representative sample site was delineated for a selection of 140 signature areas. These typical central sites were located in the field by landmark and compass, and a visual assessment was made of the spatial dominance of species represented in the canopy. Photographs were taken of the less familiar sites in order to supplement field notes and to aid in the interpretation of the field maps. Representatives of each important canopy species were identified in the field or collected and keyed in the laboratory. On two occasions during the field program the study area was photographed from a light aircraft at 500 feet altitude. The large-scale 70 mm and 35 mm oblique color transparencies from these flights were very useful, serving as a conceptual catalyst in the construction of associations from field notes and photographic signatures. Canopy type and composition were compared between similar signatures areas, with the similarities and differences serving as a basis for readjustment of the tentative photo signature scheme. A final step was the consolidation of field notes to describe canopy vegetation assocations which corresponded to the photographic signatures and were consistent throughout the study area. This was done first for color infrared film, which offered the greatest degree of discrimination, and subsequently for color film and multi-band enhancements.

RESULTS

Tone and hue were initially the most important recognition factors by which signals were detected and differentiated. Tonal dis-

TABLE 2. MAJOR WETLAND TYPES OF THE SHELBURNE POND STUDY AREA

MARSH	Canopy is dominated by herbaceous aquatic plants such as cattails, sedges, and water parsley. Substrate is composed of recently aggraded muck deposits. The water table is above or near the ground surface throughout the year.
CARR	Canopy is dominated by shrubs such as alder or willow, or stunted trees such as red maple. Substrate is composed of muck and or peat deposits, typically exhibiting a hummock and hollow terrain. Acid conditions may exist. The water table is above or near the ground surface throughout the year.
SWAMP	Canopy is dominated by trees such as red maple, larch, and black spruce. Substrate is composed of muck or peat deposits, typically exhibiting a hummock and hollow terrain. Acid conditions may exist. The water table is above or near the ground surface throughout the year.
PEATLAND	Canopy is dominated by sphagnum, sedges, and heath plants with occasional acid-tolerant small trees, exhibiting a hummocky surface. Substrate of peat is actively forming or has accumulated in the past. Conditions are acid. The water table is seasonally at the surface.
WET MEADOW	Canopy is dominated by grasses and sedges in meadows. Substrate is typically muck and clay. The water table is seasonally at the surface.
POOLS AND BAYS	Canopy is dominated by low, floating aquatic plants such as duckweed. The water table is above the ground surface.

crimination was of greater importance with color than with color infrared film because plant canopies are, in general, represented on the former as many tones of a single green hue, while on the latter a much greater dynamic range of hue and tone occurs. However, the other recognition elements, texture, pattern, and the height of the canopy, were for many signatures the differentiating factors. The hues and patterns of color enhanced images were the definitive factors in the classification of multi-band signatures. Texture was often difficult to assess on the matte viewing screen and height could not be differentiated. Another recognition element, stand pattern, was especially important in the peatlands. The associations established for signatures of each film type are detailed in Tables 3, 4, and 5, and are shown in a selection of annotated images in Plate 1.

Discussion

In this study, the approach to vegetation mapping and ground control required the acceptance of photographic signature differentiation as a rational deterministic basis for the classification of canopy vegetation. Because of this canopy perspective, the associations described are probably not identical to those that would be obtained by other methods of vegetation analysis.

In several cases, signatures were referable to one obviously dominant species. This was the case with Hybrid Cattail Marsh, heavily dominated by *Typha glauca;* with Broadleaf Cattail Marsh, dominated by *Typha latifolia;* with Water Willow Marsh, dominated by *Decodon verticillatus;* with Alder Carr, dominated by *Alnus rugosa;* and with Red Maple Swamp, dominated by *Acer rubrum.* Wet meadows often showed a distinctive signature but, because the signature is derived from many intermingled species of similar form and stature, they were classified in terms of general plant groups, as in the case of Sedge Meadow and Graminoid Wet Meadow. The Graminoid Wet Meadow and the Sedge Meadow associations which could be differentiated with color infrared film were indistinguishable on color film and were combined as Wet Pastures. The descriptions of swamp and carr associations are also more generalized for color than for color infrared film.

While only seven classes were distinguishable with the multi-band photography and several of these were very non-specific, two classes, Hybrid Cattail Marsh and Sedge Meadow, maintained the same distinction found with color infrared film. While Sedge Meadow was clearly identifiable with color enhancement, not every stand was recognized, indicating a threshold stand size and density.

Of the many signature characteristics presented, a few are very distinctive. A bright green hue is representative of Hybrid Cattail Marsh on color infrared film and multi-band color enhancements, in contrast to the hues for all other associations, including Broadleaf Cattail Marsh. The latter association is represented by a dull green-red on color infrared film and is not differentiable on multi-band enhancements. A less striking contrast (variable pink to dull green-red) separates these two associations on color film. The canopy of Hybrid Cattail Marsh is homogenous and completely dominated by *Typha glauca,* while the canopy of the Broadleaf Cattail Marsh includes several species, with *Typha latifolia* comprising only about 70 percent of the association. It seems likely that the green component of both of these signatures of color infrared film is contributed by *Typha* spp., and that the red component of Broadleaf Cattail Marsh may be attributed to the other important members of the canopy. Other causes for the striking contrast between these two associations include the life form (*Typha glauca* grows to 3 metres height while *T. latifolia* seldom exceeds 1.5 metres height), the growth form (*Typha glauca* occurs in dense homogeneous clones), and phenology.

Phenological variations may be especially subtle with wetland species, and field evidence suggests that senescence of *Typha glauca* slightly precedes that of *T. latifolia.* Earlier senescence may be attributable to the greater exposure of leaf tissue of *Typha glauca* to early frost, due to its greater height and, conversely, the closer proximity of *T. latifolia* to water.

The typical mid-season false color signature for *Typha* species in general is a strong crimson or magenta; however, Garvin and Wheeler (1973) have reported a similar bright green signature for *Typha* when it is homogeneous, and a duller green signature when mixed with other important canopy members (*Hibiscus palustris*). Enslin and Sullivan (1974) report a range in color for cattails and bur-reed from red to blue-green. The signature shift from crimson to green indicates a decrease in infrared reflectance associated with the dehydration of mesophyll cellular structures (Knipling, 1970), and an increase in red reflectance due to chlorophyll degeneration, accompanying early (pre-visual) senescence.

Sedge Meadow was clearly portrayed on color infrared film and multi-band color en-

TABLE 3. SIGNATURE CHARACTERISTICS AND ASSOCIATION COMPOSITION, FILM 2443

SIGNATURE CHARACTERISTICS				
Hue	Texture	Height	ASSOCIATION	COMPOSITION*
Bright to Dull Green	Fine	Low	Hybrid Cattail Marsh	*Typha glauca* Godron (100%) usually in dense clonal forms.
Dull Green-Red	Fine	Low	Broadleaf Cattail Marsh	*Typha latifolia* L. (70%) usually in stands of moderate density, in association with *Asclepias incarnata* L., *Sium suave* Walter, *Sagittaria latifolia* Willd., *Acorus calamus* L., *Impatiens capensis* Meerb., *Dryopteris spp.* Adams, *Carex spp.* L., and in the small pools, *Lemna minor* L., *Spirodela polyrhiza* (L.) Schleiden, and *Wolffia columbiana* Karsten.
Grey-Green	Fine	Low	Graminoid Wet Meadow	A variable association generally dominated by members of Graminae and Cyperaceae with many species present, often in dense colonies. Also in this class are commonly found *Iris versicolor* L., *Typha latifolia*, *T. glauca*, *T. angustifolia* L., *Asclepias incarnata*, *Sium suave*, *Sparganium spp.* L., and *Sagittaria spp.*, in small scattered patches.
Bright to Dull Pink	Fine	Low	Sedge Meadow	Usually a homogeneous stand of *Scirpus spp.* L., *Carex spp.*, or *Eleocharis spp.* R. Br.
Bright Red	Fine	Low	Water Willow Marsh	*Decodon verticillatus* (L.) Ell. (90%) usually in association with *Impatiens capensis* (10%).
Bright Red	Coarse	Medium	Dense Alder Carr	*Alnus rugosa* (DuRoi) Sprengel (nearly 100%) in a dense stand
Red	Coarse	High	Red Maple Swamp	*Acer rubrum* (80%) dominating its association with *Alnus rugosa* and occasional *Salix spp.* L.
Magenta-Violet	Coarse (Mottled)	Medium	Alder Carr	*Alnus rugosa* (50-60%) of moderate density, often in association with *Cornus stolonifera* Mx. and *Salix spp.*, with many small pools of water supporting a canopy of *Lemna minor*.
Magenta-Violet-Red	Coarse (Mottled)	High	Red Maple-Alder Swamp	*Acer rubrum* L. and *Alnus rugosa* more or less evenly distributed, with occasional *Cornus stolonifera*.
Dull Violet-Magenta	Coarse (Mottled)	Medium	Alder-Willow Carr	*Alnus rugosa* in variable proportion with *Salix spp.* often including *Cornus stolonifera*, with many small pools supporting a canopy of *Lemna minor*.
Violet, White	Coarse (Mottled)	Low to Medium	Alder-Duckweed Carr	*Alnus rugosa* with dead and live vegetation mixed in varying proportions. Areas of open water throughout supporting a canopy of *Lemna spp.*, *Spirodela polyrhiza*, and *Wolffia columbiana*.
Dull Magenta	Grainey	Low	Leatherleaf-Cattail Peatland	*Cassandra calyculata* (L.) D. Don (40%) and *Typha latifolia* (40%) with an understory of *Sphagnum spp.*
Dull Green-Magenta	Fine	Low	Leatherleaf-Sphagnum Peatland	*Cassandra calyculata* and *Sphagnum spp.* nearly evenly distributed.
Green, Orange	Grainy	Low	Sphagnum Peatland	*Sphagnum spp.* (30%), *Cassandra calyculata* (30%), and *Eriophorum spp.*

TABLE 3—*Continued*

SIGNATURE CHARACTERISTICS			ASSOCIATION	COMPOSITION*
Hue	Texture	Height		
				L. (30%), the remainder of this association includes *Kalmia polifolia* Wang., *K. angustifolia* L., *Osmunda cinnamomea* L., *Sarracenia purpurea* L., and at the margin of the bog mat, *Calla palustris* L., *Larix laricina* (DuRoi) K. Koch, and *Picea mariana* (Miller) BSP.
Light Magenta	Grainy	Low	Duckweed Pools and Bays	Open water with a canopy of *Lemna minor, L. trisulca* L., *Spirodela polyrhiza,* and *Wolffia columbiana.*
Magenta-Red, Violet	Coarse	High	Mixed Upland Forest	Many species occur with varying dominance: *Acer saccharum* Marsh, *Fagus grandifolia* Erhr., *Tsuga canadensis* (L.) Carr., *Thuja occidentalis* L., *Quercus rubra* L., *Pinus strobus* L., *Tilia americana* L., *Carya ovata* (Miller) K. Koch, *Carpinus caroliniana* Walter, and *Ulmus americana* L. are prominent.

* Nomenclature is as per Seymour (1969)

TABLE 4. SIGNATURE CHARACTERISTICS AND ASSOCIATION COMPOSITION, FILM SO-397

SIGNATURE CHARACTERISTICS			ASSOCIATION	COMPOSITION
Hue	Texture	Height		
Variable Pink	Fine	Low	Hybrid Cattail Marsh	*Typha glauca* (100%) usually in dense clonal forms.
Dull Green-Red	Fine	Low	Broadleaf Cattail Marsh	*Typha latifolia* (70%) usually in stands of moderate density, in association with *Asclepias incarnata, Sium suave, Sagittaria latifolia, Acorus calamus, Impatiens capensis, Dryopteris spp., Carex spp.,* and in the small pools, *Lemna minor, Spirodela polyrhiza,* and *Wolffia columbiana.*
Light Grey-Green	Fine	Low	Mixed Wet Pastures	A variable association generally dominated by members of Graminae and Cyperaceae with many species present. This association includes large, dense, and homogeneous stands of *Scirpus spp., Carex spp.,* and *Eleocharis spp.,* known as sedge meadows. Also in this class are commonly found *Iris versicolor, Typha latifolia, T. glauca, T. angustifolia, Asclepia incarnata, Sium suave, Sparganium spp.,* and *Sagittaria spp.,* in small scattered colonies.
Green	Fine	Low	Water Willow Marsh	*Decodon verticillatus* (90%) usually in association with *Impatiens capensis* (10%).
Green, White	Coarse	Medium	Alder Carr	*Alnus rugosa* in stands of variable density (40-100%), often in association

TABLE 4—*Continued*

SIGNATURE CHARACTERISTICS				
Hue	Texture	Height	ASSOCIATION	COMPOSITION
				with *Salix spp.* and *Cornus stolonifera*, with many small pools of water supporting a canopy of *Lemna minor.*
Green	Grainy	Medium to High	Mixed Swamp	*Acer rubrum, Alnus rugosa,* and *Salix spp.* in variable proportions with occasional *Cornus stolonifera* and scattered small pools supporting a canopy of *Lemna minor.*
Green	Grainy	High	Red Maple Swamp	*Acer rubrum* (80%) dominating its association with *Alnus rugosa* and occasional *Salix spp.*
Green, White	Coarse (Mottled)	Low to Medium	Alder-Duckweed Carr	*Alnus rugosa* with dead and live vegetation mixed in varying proportions. Areas of open water throughout supporting a canopy of *Lemna spp., Spirodela polyrhiza,* and *Wolffia columbiana.*
Dull Green	Coarse (Mottled)	High	Mixed Upland Forest	Association is composed of many members of varying dominance: *Acer saccharum, Fagus grandifolia, Tsuga canadensis, Thuja occidentalis, Quercus rubra, Pinus strobus, Tilia americana, Carya ovata, Carpinus caroliniana,* and *Ulmus americana* are prominent
Green-Pink	Grainy	Low	Sphagnum Peatland	*Sphagnum* spp. (30%), *Cassandra calyculata* (30%), and *Eriophorum spp.* (30%), the remainder of this association includes *Kalmia polifolia, K. angustifolia, Osmunda cinnamomea, Sarracenia purpurea,* and at the margin of the bog mat, *Calla palustris, Larix laricina,* and *Picea mariana.*
White	Fine	Low	Duckweed Pools and Bays	Open water with a canopy of *Lemna minor, L. trisulca, Spirodela polyrhiza,* and *Wolffia columbiana.*

hancements, in both cases by a pink signature. However, Sedge Meadow could not be differentiated from the Wet Meadow class (of color infrared film) on color film; therefore, the two were combined and referred to as Wet Pastures. The ease of discrimination of Sedge Meadows with color infrared film and multi-band photography, and the lack of definition on color film, indicates that moderate reflectivity in the actinic infrared is the determining recognition characteristic.

ANALYSIS OF SIGNATURE PATTERNS

In any analysis of canopy signatures in wetlands, patterns and shapes of individual stands will be obvious. Such signature pattern elements are of great importance, both in the interpretation of the identity of the plants under study, and in the development of insights into dynamic ecological relationships which are readily apparent. Several such interpretations of key spatial arrangements were made for the Shelburne Pond wetlands.

One notable feature characteristic of peatland associations in the west and southeast wetlands is an inter-associational pattern of concentricity. A Sphagnum Peatland in the west wetland is surrounded by a Red Maple Alder Swamp and the shape of the southern part of the peatland is approximated by a narrow band of Red Maple Swamp. In the southeast wetland, a Leatherleaf-Sphagnum Peatland is bordered by a horseshoe-shaped Leatherleaf-Cattail association. It is probable that these zona-

TABLE 5. SIGNATURE CHARACTERISTICS AND ASSOCIATION COMPOSITION, MULTI-BAND COLOR ENHANCED PHOTOGRAPHY

SIGNATURE CHARACTERISTICS			
Hue	Texture	ASSOCIATION	COMPOSITION
Bright Green	Fine	Hybrid Cattail Marsh	*Typha glauca* (100%) usually in dense clonal forms.
Variable Blue-Green, Red	Grainy	Mixed Carr and Marsh	*Alnus rugosa* and *Salix spp.* dominate the carr vegetation, often in association with *Cornus stolonifera*. Many small pools occur supporting a canopy of *Lemna minor*. *Typha latifolia* dominates the marsh vegetation in association with *Asclepias incarnata, Sium suave, Sagittaria latifolia, Acorus calamus, Impatiens capensis, Dryopteris spp., Carex spp.*, and in the small pools, *Lemna minor, Spirodela polyrhiza*, and *Wolffia columbiana*.
Bright Pink-Magenta	Grainy	Sedge Meadow	Usually a homogeneous stand of *Scirpus spp., Carex spp.*, or *Eleocharis spp.*
Bright Red	Coarse	Dense Alder Carr or Red Maple Swamp	*Alnus rugosa* or *Acer rubrum* dominating this association with occasional *Salix spp.* in a dense stand.
Dull Magenta, Red	Coarse	Mixed Swamp	*Acer rubrum* usually dominating its association with *Alnus rugosa* and occasional *Salix spp.*
Bright Red	Coarse	Mixed Upland Forest	Association is composed of many members of varying dominance: *Acer saccharum, Fagus grandifolia, Tsuga canadensis, Thuja occidentalis, Quercus rubra, Pinus strobus, Tilia americana, Carya ovata, Carpinus caroliniana* and *Ulmus americana* are prominent.
Dark Blue	Fine	Pools and Bays	Open water, sometimes with a floating canopy of *Lemna minor, L. trisulca, Spirodela polyrhiza*, and *Wolffia columbiana*.

tions are plant responses to gradients in environmental conditions, such as pH, which might be expected where acid peatlands occur in this region of limestone bedrock. Concentricity is suggested as a key recognition factor for peatland conditions. Sedge meadows are common in the northeast wetland, exhibiting distinctive circular shapes similar to those of Hybrid Cattail Marsh.

Circular stands of Hybrid Cattail Marsh are found in all but the west wetland. Johannessen (1964), using aerial photographs in a study of marshland vegetation in Oregon, concluded that such circular forms generally indicate a condition of wetland expansion. For the specific moisture conditions required for *Typha glauca* establishment and expansion, see Bedish (1967). Such circular colonies are clonal in origin, having spread vegetatively from a single established pioneer. *Typha* species are known to be capable of very rapid vegetative reproduction, developing as many as 98 new aerial shoots and extending rhizomes in a network up to three metres diameter from one pioneer in a single growing season (Yeo, 1964:285). In this growth phase, *Typha glauca* increases its area of dominance radially until the homogeneous circular form encounters some ecological barrier. If the high water table which sponsors this expansion is lowered, the colony will eventually fall prey, through natural successional processes, to species better adapted to the new conditions. In this event there may be no reason for the colony to retreat concentrically; rather, a general degradation of dominance, loss of the typical clonal shape, and eventual obscurance by aggressive competition would be more likely.

Where the Hybrid Cattail Marsh occurs in the study area it is very dense and thrifty,

TABLE 6. LEGEND FOR PLATE 1

A—Color Infrared Photography	
O—Hybrid Cattail Marsh	R—Red Maple Swamp
C—Broadleaf Cattail Marsh	a—Alder Carr
G—Gramminoid Wet Meadow	RA—Red Maple—Alder Swamp
S—Sedge Meadow	ad—Alder Duckweed Carr
W—Water Willow Marsh	d—Duckweed Pools and Bays
A—Dense Alder Carr	F—Mixed Upland Forest
B—Color Photograph	
O—Hybrid Cattail Marsh	M—Mixed Swamp
C—Broadleaf Cattail Marsh	R—Red Maple Swamp
P—Mixed Wet Pastures	ad—Alder Duckweed Carr
d—Duckweed Pools and Bays	a—Alder Carr
F—Mixed Upland Forest	
C—Multi-band Color Enhancement	
O—Hybrid Cattail Marsh	RA—Dense Alder Carr or Red Maple Swamp
aC—Mixed Carr and Marsh	d—Pools and Bays
S—Sedge Meadow	F—Mixed Upland Forest
M—Mixed Swamp	

commonly reaching two to three metres in height. In the northwest wetland the Hybrid Cattail Marsh has invaded pastureland, crossed fences, and is distributed through the lowland of the small stream that joins the pond there. More than a dozen clones occur in the northwest wetland in conjunction with the Graminoid Wet Meadow association which frequently marks the transition from wet to dry conditions.

In each of the four wetlands the Hybrid Cattail Marsh is represented at the shoreline. This marginal location suggests that, if wetland conditions are expanding, the Hybrid Cattail Marsh may play a pioneer role in both the landward and the pondward progression. That the wetlands have prograded pondward is further suggested by a linear pattern of Red Maple Swamp and Hybrid Cattail Marsh which parallels the present shoreline in the southern part of the west wetland, and which probably represents a former shoreline.

The largest area of Hybrid Cattail Marsh occurs in the northeast wetland where several clones have coalesced along the path of the seepage which eventually forms Muddy Brook, the outlet to the Shelburne Pond drainage basin and local base level control. It has been known for years (Dansereau and Segadas-Vianna, 1952:492) that swamps and marshes promote sedimentation, thus improving drainage. Yeo (1964:284) notes specifically that cattail stands promote siltation. Increased sedimentation has undoubtedly occurred in the northeast wetland, but due to the choking effect of aggradation in the path of the seepy flow of the outlet, drainage has not improved; rather, the water level of Shelburne Pond has been raised behind a dam of organic and inorganic deposits at the outlet. The base level has thus been elevated, and the local water table has responded accordingly, causing the progradation in wetland conditions that is clearly indicated in the plant canopy patterns.

COMPARISON OF MULTISPECTRAL MEDIA

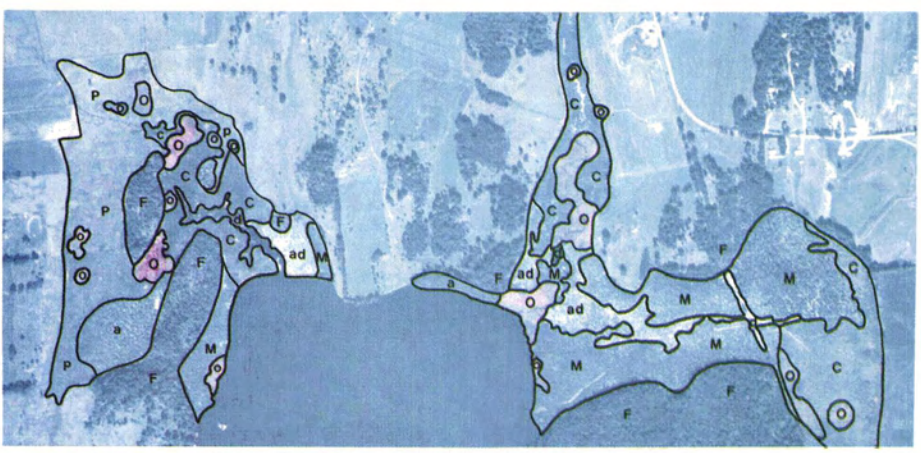
There are three basic parameters upon which an evaluation and comparison of sensors for vegetation mapping may be based. The first parameter is the degree of association discrimination possible, indicated by the complexity of the best classification possible. The second parameter is the size if the minimum mappable unit (*sensu* Gammon and Carter, 1979), an expression of the detail or fineness of useful information, as well as the character of the vegetated surface. Minimum mappable unit is similar to the term recognizability described by Rosenberg (1971). The third parameter is the ease of interpretation, which is a matter of the opinion of the interpreter.

Color infrared film allowed the greatest degree of association discrimination leading to the most detailed classification, 16 canopy associations. Eleven canopy classes were derived with color film, and only seven were possible with the multi-band color enhanced photography.

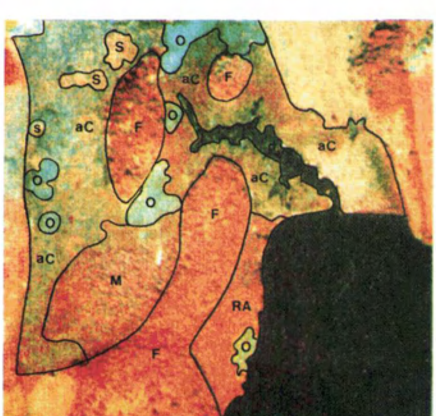
The size of the minimum mappable unit followed the same order of detail with color infrared film offering the smallest, color film next smallest, and multi-band the largest.

The smallest mappable stands of Hybrid Cattail Marsh were about 20 metres in diameter. Areas of Duckweed Pools and Bays are

A. Color Infrared: The northwest and northeast wetlands.



B. Color: The northwest and northeast wetlands.



C. Multi-band color enhancement: the northwest wetland.

PLATE 1. Annotated images allow a comparison of three kinds of photography. A and B were enlarged from 1:52,000, C from 1:104,000. See Table 6 for legend.

of a similar size, indicating a minimum unit of this dimension for color infrared film at the scale examined.

Several small areas of Duckweed Pools and Bays were mapped from color film, showing the minimum size of interpretable canopy association to be about 22 metres in diameter. It should be noted that, while canopy composition of Duckweed Pools and Bays and of Hybrid Cattail Marsh are, respectively, identical on 2443 and SO-397 films, the former showed 61 sites of these two associations and the latter only 29 sites. This difference represents both a larger minimum mapping unit size and a lower signature contrast for film SO-397.

The multi-band color enhancement techniques allowed a minimum mapping unit of about 30 metres in diameter, based on the minimum size of Sedge Meadow and Hybrid Cattail Marsh associations. However, the multi-band photography was at one half the scale of the color and color infrared photography. These values of minimum recognizable stand sizes are of significance in a relative sense, but it should be noted that stand density was not evaluated.

Ease of interpretation was greatest with color infrared film, followed by color film, and the multi-band color enhancements, respectively. Color infrared film exhibited a much higher contrast of hues than did color film, as indicated in Table 3. For this reason, signature patterns were depicted with greater clarity on color infrared film. The multi-band color enhancement techniques allowed a broad range of hues to be assigned to any signature, but other factors make the interpretation of multi-band photography more difficult. Unlike the color and color infrared photography, the multi-band color enhanced images could not be viewed in stereo. This disadvantage is severe when height of vegetation is an important recognition parameter. The multi-emulsion films could be magnified directly from the precision processed film, but the multi-band coverage had to be photographically enlarged as Polaroid positive transparencies, although the viewing system offered some additional enlargement. Polaroid reproductions are subject to variations in gamma caused by minor differences in film temperature or processing time, but with care this problem may be controlled and uniform images produced.

Conclusions

Color infrared photography (film 2443) was found to be superior to color photography (film SO-397) and the smaller scale multi-band color enhanced photographs, on the basis of association discrimination, minimum mapping unit size, and ease of interpretation. Association discrimination with color film was superior, for most purposes, to that of the multi-band color enhancements. As well, the minimum mapping unit size of color film was slightly smaller than that of the multi-band photography, and color film was easier to interpret than the multi-band photography.

This comparison has considered the photography used in this study, and it should be emphasized that the multi-band photography was at one half the scale of the color and the color infrared photography. With this in mind, the multi-band photography has shown an exceptional potential for application to wetland vegetation mapping. It is possible that multi-band photography of the same scale as the other modes of photography would have provided more information and greater ease of interpretation than color film. The manipulation of hue, value, and chroma, through additive color enhancement of multi-band photography, is of tremendous value in signature discrimination, although stereo observation was not possible with the equipment used. For all photography examined, the strongest basis for signature differentiation was found in the longer (red through infrared) wavelengths. For the broad variety of wetlands occurring in the northern New England area, the use of the actinic infrared in wetland vegetation analysis is recommended.

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