A Comparison of Landsat TM Imagery Versus Aerial Photographs for Classifying and Monitoring Riparian Vegetation

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A COMPARISON OF LANDSAT TM IMAGERY VERSUS AERIAL PHOTOGRAPHS FOR CLASSIFYING AND MONITORING RIPARIAN VEGETATION

by
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A COMPARISON OF LANDSAT TM IMAGERY VERSUS AERIAL PHOTOGRAPHS FOR MAPPING AND MONITORING RIPARIAN VEGETATION

Abstract

Ouray National Wildlife Refuge contains important riparian habitats for fish and wildlife. The dominant woody plant species are *Populus fremontii*, *Salix* sps., and *Tamarix ramosissima*, a nonnative shrub that has become established in the Upper Colorado Basin in this century. *T. ramosissima* is quickly becoming the dominant riparian species, and could affect habitat quality and ecosystem processes such as nutrient cycling. A current vegetation map of the refuge was developed using Landsat thematic mapper imagery. Maps were also generated from aerial photographs to delineate areas of *Tamarix* invasion between 1936 and 1996. The two sources of remote sensor data were compared.

Introduction

Vegetation has a significant influence on ecosystem processes in riparian areas. Through various mechanisms, riparian vegetation dampens hydrologic fluctuations (Hickin 1984). It also provides structural cover for aquatic and terrestrial organisms (Magee *et al.* 1993), and contributes detritus to the adjacent river channel (Neckles and Neill 1994). Characteristics of detritus, such as its rate of decomposition, can affect the productivity of the entire ecosystem (Lindeman 1942, Ovington 1962). If riparian species exhibit different morphologies and rates of decomposition, their distribution should influence the spatial patterns of habitat quality and productivity. Given the links between vegetation and other components of riverine ecosystems, the study of riparian vegetation enhances our understanding of ecological processes.

The life histories of riparian plants are adapted to local hydrologic regimes. Riparian vegetation is especially sensitive to annual flow maxima and minima (Auble *et al.* 1994). In the southwest U.S., recruitment of native *Populus* and *Salix* sps. coincides with historical flow
patterns: seeds are released during spring floods, germinate in moist soils as the floods recede, and reach seedling stage as their roots grow downward to keep pace with the falling water table (Scott et al. 1993, Brock 1994, Johnson 1994).

The dams constructed along many southwestern rivers have changed hydrologic regimes, resulting in lower peak discharges and smaller annual fluctuations. Consequently, native riparian trees have experienced a decrease in recruitment (Stromberg et al. 1991, Snyder and Miller 1992, Stromberg 1993). Another significant change in riparian communities is the invasion of exotic Tamarix sps., which had become established in the Upper Colorado Basin by the 1950’s (Graf 1978). Tamarix sps. seem well adapted to the stable flows released by upstream dams (Stromberg et al. 1993, Brock 1994, Johnson 1994), which may partly explain their success.

Given these changes in riparian vegetation communities, it is logical to investigate their effects on ecosystem processes: Will they lead to changes in ecosystem functions such as nutrient cycling? At a larger scale, will the size and spatial arrangement of vegetation dynamics affect ecosystem processes?

To answer the latter question, we must understand the distribution and spatial arrangement of vegetation types, as well as their dynamics. We can quantify changes by mapping vegetation types at several points in time, and then detecting temporal and spatial differences. This procedure has been used with remotely sensed data by Graf (1978), McCarthy (1992) and Gilvear et al. (1995; see also Ellis and Woitowich 1989). Remote sensing techniques are possible because canopy characteristics vary with respect to pigmentation, surface texture, orientation of leaves and branches, total biomass, and moisture

Two useful types of data are satellite imagery and aerial photographs. Multi-spectral thematic mapper images from the LANDSAT land observation satellite have been digitally processed to successfully create land cover maps (Jensen and Estes 1978, Quirk and Scarpace 1982). Digital analysis of aerial photographs also produces vegetation maps with good results (Snook et al. 1987). The purpose of this paper is to describe digital analysis methods used to map vegetation types at Ouray National Wildlife Refuge (NWR), Utah, from Landsat thematic mapper (TM) data and aerial photographs.

Objectives

The main objective of this study was to develop a base vegetation map of the refuge from Landsat TM imagery at 30 meter resolution. A base map serves as a point of reference for identifying and quantifying changes in the size and distribution of vegetation types. By developing past or future vegetation maps from remote sensor data, and comparing them with a base map, we can detect and observe these changes.

The second objective was to utilize aerial photographs to quantify vegetation changes between 1936 and 1996 for part of Ouray NWR. *Tamarix ramosissima* had not yet become established at the refuge in 1936, nor had levees been constructed. These two events probably caused the distribution of vegetation types to be very different in 1996.

The final objective was to compare the efficiency and accuracy of Landsat TM versus aerial photographic data for mapping vegetation.
Study Site

Ouray NWR covers about 6,600 hectares around the Green River in the Uinta Basin, Utah. The area is characterized by wide floodplains that historically experienced annual spring floods. Dominant vegetation consisted of Populus and Salix spp. The upstream construction of Flaming Gorge Dam in 1962 altered hydrologic regimes at Ouray NWR. At about the same time, levees were constructed along the Green River to increase waterfowl habitat. These human-caused hydrological changes contributed to vegetation dynamics such as a decline in the recruitment of Populus and Salix spp. and an increase of Tamarix ramosissima (Graf 1978). Currently the U.S. Fish and Wildlife Service and Bureau of Reclamation are planning to remove some artificial levees and monitor the ecological changes that occur in restored floodplains.

Methods

Ground truth data were collected from 85 field plots in late July and early August, 1996. Data variables consisted of plot dimensions, geographic position, relative soil brightness, percent cover of each species, and average height of each species. Plots were homogeneous patches larger than 90 x 90 meters (3 x 3 pixels). Because current global positioning systems may be inaccurate by 30 meters in any direction, a 90 x 90 meter plot size ensures that the center of the plot captures the correct pixel value on the image (August et al. 1994). Relative soil brightness was estimated on a scale from one to ten (10 = most reflective).

The percent cover and height of each species were estimated ocularly, and included
only those species comprising at least five percent of the total cover. Ocular estimates do not require the assumption that percent cover is exact and static throughout the growing season or from year to year. Thus ocular methods provide a meaningful level of accuracy, as well as greater efficiency than more meticulous methods (Daubenmire 1959 and 1968).

Slope, aspect, and elevation data were not collected because the terrain shows little local relief. Furthermore, current technology for global positioning systems is not accurate enough to detect minor elevation changes (August et al. 1994).

Landsat TM imagery was acquired by the Landsat 5 satellite on 23 August 1993. Image preprocessing included subsetting the TM data to bands 2, 3, 4, 5 and 7 (Table 1). Next these five bands were separately adjusted for the effects of atmospheric distortion according to the procedures described by Turner (1978). The equation used to correct for atmospheric effects was:

\[
\text{adjusted pixel value} = \text{initial pixel value} - \text{bias}
\]

The bias for each band was equal to the minimum reflectance value for that band. By subtracting the minimum reflectance value from the data, we eliminate the statistical outliers that are created by atmospheric distortion.

To derive a vegetation map from the processed TM image, we first performed an unsupervised classification with 250 classes. By doing an unsupervised classification, we make no \textit{a priori} assumptions about the data; we simply divide the data into 250 groups that share similar spectral responses (see Jensen 1986, pp. 215-222).

Next a geographic information system was utilized to summarize the unsupervised
classification with field data. Output for the summary of field plot 15 with the unsupervised classification is presented in Table 2, which shows that unsupervised classes 78, 87 and 130 represent the mature cottonwood vegetation type. This procedure was repeated for all 85 plots. Preliminary vegetation types were assigned to each unsupervised class.

Rather than using a cluster approach to refine the initial classification, the classified image was divided along hydrological boundaries into 12 smaller images. Therefore each depression and terrace was considered separately. The classifications for each of the 12 areas were refined from field data and ground photographs. This process adjusted for the inaccuracies created different vegetation types with similar spectral responses. Thus it created 12 classified images with greater accuracy than the original unsupervised classification (Figure 1). A mosaic function stitched the 12 images into one classified image for the entire refuge.

The final classification consisted of 20 classes, which were labelled according to the dominant vegetation type. Dominant vegetation type was defined as either a woody species or a growth form other than woody (e.g., graminoids or annual forbs) that comprised greater than 25% total cover. In classes where more than one vegetation type constituted greater than 25% cover, multinomial labels were assigned. At 30 meter resolution, the dominant vegetation type is simply a characterization of a particular site, which may contain species that comprise less than 25% of the total cover and are thus not named in the vegetation type.

The accuracy of the map was assessed by generating 100 random points and comparing mapped vegetation type with actual vegetation type at those points. Accuracy assessment was performed independently of ground-truth data collection.
The aerial photographic analysis included only the portion of the refuge known as Old Charley Wash. This site was selected because it includes a human-made wetland area that is scheduled to be drained and restored as a floodplain, and vegetation changes are likely to occur as a result. Another reason for limiting the area of the photographic analysis is the data-intensity of the high-resolution photos. The two photographs were scanned to a resolution of about 1 meter. One was a grayscale photograph acquired on 9 September 1936, and the other was a color infrared photograph from 20 May 1996.

The 1936 photograph was analyzed with unsupervised classification techniques. Only 20 unsupervised classes were derived based on three assumptions. First, Old Charley Wash should show less variation of vegetation types than the entire refuge. Second, the grayscale photograph should enable less detailed differentiation among vegetation types than multispectral imagery. Third, the lack of ground-truth data from 1936 prohibits us from classifying vegetation types that we cannot differentiate from the photograph. Therefore species of grasses and forbs were not distinguished.

To assign vegetation types to the 20 unsupervised classes, types were ocularly estimated from the original photo. Several classes represented the same vegetation type, so these classes were clustered together. This ocular technique is somewhat subjective, but no ground-truth data exist for 1936. Furthermore, the high resolution of the photograph allowed identification of individual trees and their canopy morphologies. Vegetation types were categorized into six classes.

A 20-class unsupervised classification was also derived from the 1996 photograph. Based on the six classes in the 1936 classification, vegetation types were assigned to each
unsupervised class by summarizing the classes with 1996 ground-truth data. The classification closely resembled the map derived from Landsat TM imagery, so no further refinement was necessary.

The 1 x 1 meter classifications from 1936 and 1996 were compared by quantifying the total area in each of the six classes.

All digital analyses were performed with ERDAS/Imagine 8.2 on a UNIX workstation.

Results

The Landsat-based classification produced a map of 20 vegetation types at 30 meter resolution (Figure 2). Vegetation types are described in Table 3. Although *Salix amygダloid'es* and *S. exigua* are common at the refuge, they were not detectable at this resolution. Therefore there are no classes for these species. In contrast, patches of *Tamarix ramosissima*, *Populus* spp., and the herbaceous perennial *Lepidium latifolium* were identifiable; Table 3 contains classes dominated by these species. Classification accuracy was calculated to be 83%.

The analysis of two aerial photographs produced two vegetation maps (Figure 3) containing six vegetation types (Table 4) at 1 meter resolution. Due to the quality of the 1936 photograph, mud flats and water showed similar spectral responses. Therefore they were lumped together in one class. A comparison of these two maps allows the quantification of vegetation changes between 1936 and 1996. Figure 1 shows the areas of each vegetation type in both years. It shows that *T. ramosissima* has become established since 1936. Another apparent shift in vegetative cover is the increase of emergent vegetation and open water that followed levee construction in the 1960's. Consequent to the increase in wetland area, the
abundance of cottonwoods and willows has decreased since 1936.

**Discussion**

Since we now have a baseline vegetation map of the refuge, it is possible to use remote sensor data to quantify past and future vegetation dynamics. Analysis of historical photographs can yield historical vegetation maps. By quantifying the differences among these maps, we can delineate vegetation changes and calculate rates of change (e.g., the rate of invasion by *T. ramosissima*). Sites of changing vegetation can be autocorrelated with other spatial variables such as soil type or geomorphic feature. When combined with empirical data, the results of such autocorrelation could be integrated to form a predictive model for riparian vegetation in this area. Validation of such a model would be possible at wetland sites where floodplain restoration is occurring, such as Old Charley Wash. Future vegetation changes at these sites can be monitored with remote sensor data.

The two types of data used here are suited to slightly different purposes with respect to vegetation mapping. Data selection is most closely related to questions of scale. Due to its resolution, Landsat TM imagery is useful for detecting patches of vegetation larger than 30 x 30 meters in the absence of subpixel analysis. In contrast, high resolution aerial photographs can distinguish between vegetation types at the one meter scale. Patches of *Salix amygdaloides* and *Salix exigua* at Ouray National Wildlife Refuge illustrate this point. They were discernible from aerial photographs, but not from Landsat TM data. However, high resolution aerial photographs are more data-intensive than Landsat TM imagery, and are therefore less computationally efficient for mapping vegetation types over large areas. For example, a single Landsat TM scene covers an area equivalent to thousands of high-resolution...
aerial photographs (Jensen 1986). Because aerial photographs require georectification and edge matching, computer time increases rapidly with the size of the study area.

Monitoring utility is another criterion for selecting remote sensor data. Historical and future availability determine the respective utility of detecting past vegetation changes or monitoring future changes. Landsat TM data became available in 1982 and is acquired every 16 days (Jensen 1986). Thus its historical use is limited, but it is reliable for future monitoring. Aerial photographs can be acquired on a regular basis, but the availability of past photographs depends on the previous research done in a particular area.

Aerial photographs of our study area date back to 1917, and will be acquired annually for the next few years by the U.S. Bureau of Reclamation. Given the small patch size of some riparian vegetation types (e.g., Salix sps.), as well as the availability of photographs and the total size of the study area, photographs should be somewhat less efficient, but more accurate, than Landsat TM imagery.

The techniques described here to derive vegetation maps are accurate, repeatable procedures. By analyzing the size and spatial arrangement of vegetation types, we can investigate the links between processes at small scales and those at large scales. For example, what are the effects of very large patches of T. ramosissima on productivity and food webs? The obvious vegetation dynamics in the last sixty years lead to the question: how does a decline of native vegetation and an increase of wetland areas affect small-scale ecosystem processes? As the experiment of floodplain restoration is carried out, remote sensing techniques can aid in monitoring multi-scale effects on ecosystem processes.
Literature cited


## APPENDIX: TABLES AND FIGURES

Table 1. Spectral characteristics of Landsat TM bands (from Jensen 1986). Asterisks denote bands that were used to classify vegetation.

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength (µmeters)</th>
<th>Portion of the spectrum</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45-0.52</td>
<td>Blue</td>
<td>Penetration of water bodies (affected by atmospheric scattering)</td>
</tr>
<tr>
<td>2*</td>
<td>0.52-0.60</td>
<td>Green</td>
<td>Blue and red chlorophyll absorption; green reflectance</td>
</tr>
<tr>
<td>3*</td>
<td>0.63-0.69</td>
<td>Red</td>
<td>Red chlorophyll absorption</td>
</tr>
<tr>
<td>4*</td>
<td>0.76-0.90</td>
<td>Near infrared</td>
<td>Indication of the amount of biomass present</td>
</tr>
<tr>
<td>5*</td>
<td>1.55-1.75</td>
<td>Mid-infrared</td>
<td>Indication of the turgidity of plants and moisture of soil</td>
</tr>
<tr>
<td>6</td>
<td>2.08-2.35</td>
<td>Mid-infrared</td>
<td>Discrimination of geologic rock formations</td>
</tr>
<tr>
<td>7*</td>
<td>10.4-12.5</td>
<td>Far infrared</td>
<td>Amount of infrared radiant flux</td>
</tr>
</tbody>
</table>
Table 2. Summary of plot 15 (mature cottonwood) with a 250-class unsupervised classification. Pixels refer to the number of 30 x 30 meter picture elements that fall inside plot 15.

<table>
<thead>
<tr>
<th>Unsupervised class</th>
<th>Pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>78</td>
<td>4</td>
</tr>
<tr>
<td>87</td>
<td>1</td>
</tr>
<tr>
<td>130</td>
<td>1</td>
</tr>
</tbody>
</table>
### Table 3. Vegetation classes derived from Landsat TM imagery.

<table>
<thead>
<tr>
<th>Vegetation type</th>
<th>Dominant species and description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Rivers, lakes, or other open water without vegetation</td>
</tr>
<tr>
<td>Deep marsh</td>
<td><em>Phragmites australis</em>; numerous emergent rushes, cattails, bullrushes and sedges in water deeper than one foot</td>
</tr>
<tr>
<td>Shallow marsh</td>
<td><em>Phragmites australis</em>; numerous emergent rushes, cattails, bullrushes and sedges in water not deeper than one foot</td>
</tr>
<tr>
<td>Skunkbrush</td>
<td><em>Rhus trilobatum</em></td>
</tr>
<tr>
<td>Russian olive</td>
<td><em>Elaeagnus angustifolia</em></td>
</tr>
<tr>
<td>Old cottonwood mosaic</td>
<td><em>Populus fremontii</em> taller than 20 feet; may include <em>Tamarix ramosissima</em>, <em>Lepidium latifolium</em> and numerous grasses; characterized by an open canopy</td>
</tr>
<tr>
<td>Old cottonwood</td>
<td><em>Populus fremontii</em> taller than 20 feet; characterized by a denser canopy than the ‘old cottonwood mosaic’ class</td>
</tr>
<tr>
<td>Regenerating cottonwood</td>
<td><em>Populus fremontii</em> of varying heights</td>
</tr>
<tr>
<td>Young cottonwood</td>
<td><em>Populus fremontii</em> less than 20 feet tall</td>
</tr>
<tr>
<td>Cottonwood/saltcedar</td>
<td><em>Populus fremontii</em> of varying heights and <em>Tamarix ramosissima</em></td>
</tr>
<tr>
<td>Saltcedar/willow</td>
<td><em>Tamarix ramosissima</em> and <em>Salix amygdaloides</em> and/or <em>Salix exigua</em></td>
</tr>
<tr>
<td>Saltcedar</td>
<td><em>Tamarix ramosissima</em></td>
</tr>
<tr>
<td>Saltcedar/pepperweed/grass</td>
<td><em>Tamarix ramosissima</em>, <em>Lepidium latifolium</em> and numerous grasses</td>
</tr>
<tr>
<td>Pepperweed/grass</td>
<td><em>Lepidium latifolium</em> and numerous grasses</td>
</tr>
<tr>
<td>Grass</td>
<td>Numerous grasses</td>
</tr>
<tr>
<td>Sagebrush</td>
<td><em>Artemisia spinescens</em>; some <em>Chrysothamnus linifolius</em>, <em>C. nauseosus</em> ssp. <em>consimilis</em>, <em>Sarcobatus vermiculatus</em> and grasses</td>
</tr>
<tr>
<td>Rabbitbrush</td>
<td><em>Chrysothamnus linifolius</em> and <em>C. nauseosus</em> ssp. <em>consimilis</em>; some <em>Artemisia spinescens</em>, <em>Sarcobatus vermiculatus</em> and grasses</td>
</tr>
<tr>
<td>Greasewood</td>
<td><em>Sarcobatus vermiculatus</em>; some <em>Artemisia spinescens</em>, <em>Atriplex confertifolia</em>, <em>A. corrugata</em>, <em>Chrysothamnus linifolius</em>, <em>C. nauseosus</em> ssp. <em>consimilis</em> and grasses</td>
</tr>
<tr>
<td>Barren</td>
<td>Bare soil, mud flats, sandbars or bare rock</td>
</tr>
<tr>
<td>Irrigated agriculture</td>
<td>Various irrigated cropland</td>
</tr>
<tr>
<td>Class</td>
<td>Dominant species</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Water or mud flat</td>
<td>No vegetation</td>
</tr>
<tr>
<td>Emergent vegetation</td>
<td><em>Phragmites australis</em>; numerous rushes, cattails, bullrushes and sedges</td>
</tr>
<tr>
<td>Cottonwood</td>
<td><em>Populus fremontii</em></td>
</tr>
<tr>
<td>Willow</td>
<td><em>Salix amygdaloides, Salix exigua</em></td>
</tr>
<tr>
<td>Tamarisk</td>
<td><em>Tamarix ramosissima</em></td>
</tr>
<tr>
<td>Grass/forb</td>
<td>Numerous graminoids and forbs</td>
</tr>
</tbody>
</table>
Figure 1. Unsupervised (a) and final (b) classifications based on Landsat TM imagery. In the final classification, vegetation types with similar spectral responses have been differentiated.
Figure 2. Final classification based on Landsat TM imagery.
Figure 3. Vegetation classifications based on aerial photographs from 1936 (a) and 1996 (b).
Figure 4. Comparison of area in each vegetation type in 1936 and 1996.