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Intermountain plant community classification using Landsat TM and SPOT HRV Data

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Abstract

Rangeland plant communities of the Intermountain West differ in their ecology and management requirements. Successful management of extensive areas at plant community-level resolution first requires an efficient, cost-effective means of plant community classification and mapping. We evaluated the influence of image acquisition date and satellite imaging system on the accuracy of plant community maps created from multispectral satellite imagery of Reynolds Creek Experimental Watershed (RCEW) (234 km^2) in southwestern Idaho. Maps delineating 6 native and 2 non-native Intermountain plant communities were created from Landsat 5 TM and SPOT 3 HRV data using a maximum likelihood classification procedure. Map accuracy was assessed using ground reference points. Maps created from satellite data acquired during dry-down (early August) had higher overall accuracy ($\bar{x}$ = 70.5%) than from data acquired during peak growth (early June) ($\bar{x}$ = 54.4%). Overall accuracy of maps generated by Landsat ($\bar{x}$ = 60.1%) and SPOT ($\bar{x}$ = 65.5%) were statistically similar. Given their broad spatial coverages (3,600 to 31,450 km^2 scene^{-1}, respectively), moderate resolutions (20 to 30 m pixels, respectively), and potential to provide high classification accuracies, the SPOT 3 HRV and Landsat 5 TM satellite systems were well-suited for classifying plant communities in the Reynolds Creek Watershed and similar areas of the Intermountain West. Practical procedures for plant community classification and map accuracy assessment are presented for use by natural resource managers.

Key Words: Cover type, maximum likelihood, multispectral, rangeland, remote sensing, satellite imagery, supervised classification, vegetation.

Resumen

Las comunidades de plantas del los pastizales intermontanos del oeste difieren en su ecología y requerimientos de manejo. El manejo exitoso de áreas extensivas a nivel de resolución de comunidad de plantas, primero, requiere un medio eficiente y efectivo en términos de costos para el mapeo y clasificación de las comunidades de plantas. Evaluamos la influencia de la fecha de adquisición de imagenes y del sistema de imagen de satélite en la certeza de los mapas de comunidades de plantas creados a partir de imágenes multiespectrales de satélite de la Cuenca Hidrológica Experimental "Reynolds Creek" (RCEW) (234 km^2) del suroeste de Idaho. Se crearon mapas delineando 6 comunidades de plantas intermontanas nativas y 2 comunidades no nativas a partir de datos de Landsat 5 TM y SPOT 3 HRV utilizando el procedimiento de clasificación de máxima probabilidad. La certeza del mapa se evaluó utilizando puntos de referencia terrestres. La certeza de los mapas creados de datos de satélite adquiridos durante época seca (inicios de Agosto) tuvieron una certeza general más alta ($\bar{x}$ = 70.5%) que los datos adquiridos durante el pico de crecimiento de las plantas (inicios de Junio) ($\bar{x}$ = 54.4%). La certeza general de los mapas generados por Landsat ($\bar{x}$ = 60.1%) y SPOT ($\bar{x}$ = 65.5%) fueron estadísticamente similares. Dada su amplia cobertura espacial (3,600 a 31,450 km^2 escena^{-1}, respectivamente), resoluciones moderadas (20 a 30 m por pixel respectivamente) y el potencial para proveer certezas de clasificación altas, los sistemas de satélites SPOT 3 HRV y Lansat 5 TM fueron apropiados para clasificar las comunidades de plantas en la Cuenca Hidrológica "Reynolds Creek" y áreas similares de la región intermontana del oeste. Se presentan procedimientos prácticos para evaluar la certeza de la clasificación y mapeo de las comunidades de plantas para el uso por manejadores de recursos naturales.

The Intermountain region of the western United States is dominated by extensive rangelands containing a diverse assemblage of plant communities differing in their ecology and management needs. Classification and mapping plant communities across extensive areas by conventional methods, such as aerial photograph interpretation and ground survey, can often be cost prohibitive. Consequently, managers of these rangelands commonly lack the appropriate spatial information needed to properly manage these plant communities.

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Multispectral satellite imagery can be efficiently used for vegetation classification and mapping on extensive rangelands (Tueller 1989, Pickup et al. 1994). Although satellite-based classification and mapping techniques for rangeland vegetation have been developed, tested and refined for nearly 3 decades (e.g., Tueller et al. 1975, Graetz and Gentle 1982, Kremer and Running 1993, Jakubauskas et al. 1998), range managers have not yet embraced this technology. Inadequate computer hardware/software and high imagery costs no longer constrain rangeland application of satellite technology. A lack of remote sensing training in range managers seems to be the only critical limitation to adoption of satellite-based rangeland management tools.

To address the need for accurate, up-to-date plant community maps and to facilitate in-service training in remote sensing, range managers in the Intermountain region need a set of practical procedures for plant community classification and mapping using multispectral satellite imagery. Objectives of this study were to: (1) compare the accuracy of 2 satellite remote sensing systems, Landsat 5 TM and SPOT 3 HRV, for Intermountain plant community classification, 2) evaluate the effects of imagery acquisition date on Intermountain plant community classification accuracy, and 3) present a set of practical procedures and recommendations for use by range managers to classify and map Intermountain plant communities using satellite imagery.

Materials and Methods

Study Area

The study was conducted in the Reynolds Creek Experimental Watershed (RCEW) located 80 km south of Boise in southwestern Idaho (43° 11' N, 116° 46' W). The RCEW is 234 km^2 in extent and ranges in elevation from 1,097 m to 2,252 m (Fig. 1). The area is typical of the shrub steppe and subalpine rangelands occurring throughout the Intermountain region. Mean annual precipitation at the Watershed ranges from 250 mm at lower elevations to 1,270 mm at higher elevations but is also affected by position relative to incoming storms. Locations on the western side of the Watershed receive about 1.5 times more precipitation than those on the eastern side at the same elevation. About 75% of the precipitation in the higher elevations falls as snow. Summers are very dry throughout the Watershed.

Soils in the Reynolds Creek Watershed are derived primarily from basalt (63% of the Watershed), granite (18%), alluvium/lacustrine sediments (12%) and welded tuff (6%) (Stephenson 1977). Aridisols dominate the lowest elevations and Mollisols are most common elsewhere. Soils derived from granite are generally in coarse-loamy families and the others are generally in fine loamy families. Except in valley bottoms and snow drift areas, soils are shallow, rocky and steep.

Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle and Young) and salt desert shrub are the dominant native plant communities in the lower elevations (< 1,400 m) of the Watershed. Principal species in the Wyoming big sagebrush community are Wyoming big sagebrush, bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve), and Sandberg bluegrass (*Poa secunda* J. Presl.) (Spaeth et al.

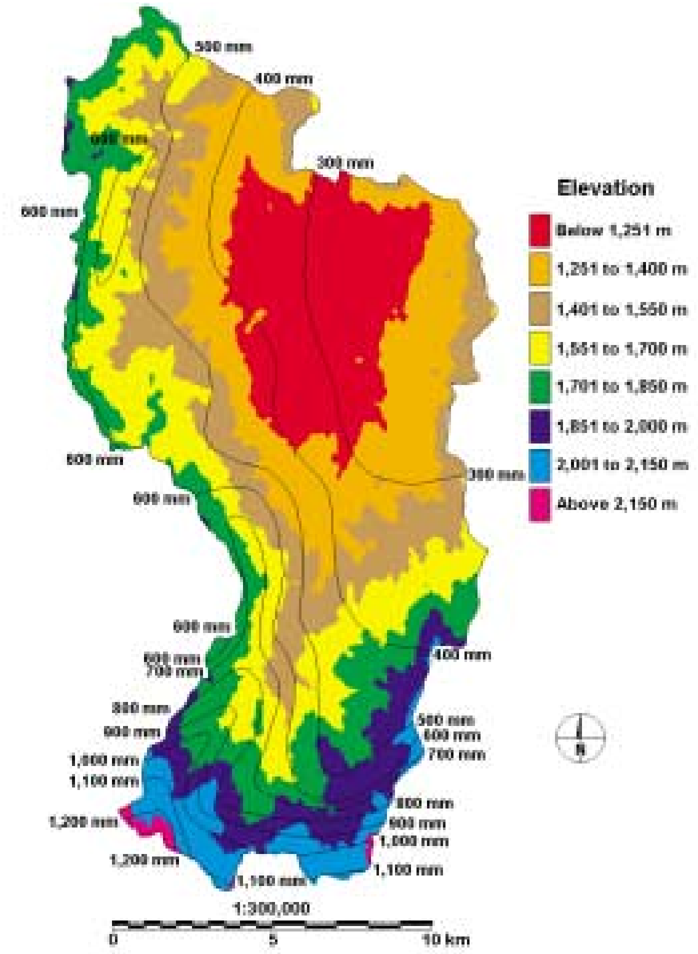

Fig. 1. Elevation (shaded polygons) and annual precipitation (line contours) of Reynolds Creek Experimental Watershed in southwestern Idaho.

2000). Greasewood (*Sarcobatus vermiculatus* [Hook.] Torr.), bud sagebrush (*Picrothamnus desertorum* Nutt.), spiny hopsage (*Grayia spinosa* [Hook.] Moq.), and squirreltail (*Elymus elymoides* [Raf.] Swezey) dominate the salt desert shrub community. Cultivated hay fields and Siberian wheatgrass (*Agropyron fragile* [Roth] P. Candargy) seedings also occur in the lower elevations of the Watershed. The hay fields are primarily flood-irrigated fields of orchardgrass (*Dactylis glomerata* L.). The Siberian wheatgrass seedings were degraded stands from the Wyoming big sagebrush and salt desert shrub communities which were prescribed burned and seeded to Siberian wheatgrass in 1984.

Low sagebrush and big sagebrush/bitterbrush plant communities are the dominant vegetation in the mid elevations (1,400 m to 1,600 m). Low sagebrush (*Artemisia arbuscula* Nutt.), Sandberg bluegrass, and arcane milkvetch (*Astragalus obscurus* S. Wats.) are the principal species of the low sagebrush community (Spaeth et al. 2000). Wyoming big sagebrush, antelope bitterbrush (*Purshia tridentata* [Pursh] DC.), bluebunch wheatgrass, and Idaho fescue (*Festuca idahoensis* Elmer) dominate the big sagebrush/bitterbrush community.

Mountain big sagebrush, aspen, and mixed-conifer are the dominant plant communities in the higher elevations (> 1,600 m). The principal species in the mountain big sagebrush community are mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle), mountain snowberry (*Symphoricarpos oreophilus* Gray), mountain brome (*Bromus marginatus* Nees ex Steud.), elk sedge (*Carex garberi* Fern.), lupine (*Lupinus* L.), and sticky cinquefoil (*Potentilla glandulosa* Lindl.) (Spaeth et al. 2000). The aspen community is characterized by a tree overstory of quaking aspen (*Populus tremuloides* Michx.) and an herbaceous understory of mountain brome, western needlegrass (*Achnatherum occidentale* [Thurb. ex S. Wats.] Barkworth), Kentucky bluegrass (*Poa pratensis* L.), veiny meadowrue (*Thalictrum venulosum* Trel.), and mountain sweetroot (*Osmorhiza chilensis* H. &

A.). Douglas- fir (*Pseudotsuga menziesii* [Mirbel] Franco) and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) form the tree overstory of the mixed-conifer community. Western needlegrass, elk sedge, veiny meadowrue, and mountain sweetroot occur as a sparse understory.

Satellite Data and Preprocessing Levels

Landsat 5 TM scenes acquired 6 June 1996 and 1 August 1993 were purchased from Space Imaging[1] (formerly EOSAT Corp., Thornton, Colo.). The SPOT 3 HRV scenes acquired 17 June 1993 and 16 August 1994 were purchased from SPOT Image Corp.[1] (Reston, Virg.). Landsat 5 TM acquires data in 3 visible bands, blue (0.45 to 0.52 m), green (0.52 to 0.60 m), and red (0.63 to 0.69 m), 1 near-infrared band (0.76 to 0.90 m), 2 mid-infrared bands (1.55 to1.75 and 2.08 to 2.35 m), and 1 thermal infrared band (10.4 to 12.5 m) of the electromagnetic spectrum. Landsat 5 TM stores data from the visible, near-infrared and mid-infrared bands as 30-m pixels with 8-bit radiometric resolution (256 brightness levels). Landsat 5 TM stores thermal infrared data as 120-m pixels. Landsat 5 has a sun-synchronous, near-polar orbit with a 16-day repeat cycle. The ground swath width of the Landsat 5 TM is 185 km and Landsat scenes are 185 km by 170 km (31,450 km^2) in size.

The SPOT 3 HRV acquires data in 2 visible bands, green (0.50 to 0.59 m) and red (0.61 to 0.68 m) and 1 near-infrared band (0.79 to 0.89 m) of the spectrum. The SPOT 3 HRV color and near-infrared imagery are stored as 20-m pixels with 8-bit radiometric resolution. The SPOT 3 HRV also has a panchromatic band with a 10-m pixel size. The SPOT 3 has a sun-synchronous, near-polar orbit with a 26-day orbit cycle. Pointable optics on SPOT 3 permit off-nadir viewing which can decrease the time intervals between viewing opportunities. The SPOT 3 HRV scenes are 60 km by 60 km (3,600 km^2) in size. The Landsat and SPOT scenes used in this study were cloud-free and had been radiometrically- and geometrically-corrected (Level 1B data) by the vendor. A subscene representing the areal coverage of the Reynolds Creek Watershed (RCEW) was extracted from each scene using an image processing software package (PCI, Richmond Hill, Ontario, Canada). These subscenes were precision-corrected (georectified) using ground control points located with a GPS but were not terrain-corrected.

[1]Mention of manufactures or trade names is for the convenience of the reader only and implies no endorsement on the part of the authors, USDA, or University of Idaho.

Plant Community Classification

The primary objective of image classification is to place all pixels in an image into discrete vegetation cover classes. Vegetation cover classification is based on recognition of spatial, temporal, or spectral patterns in multispectral imagery. Spectral pattern recognition is the most commonly used form. Different vegetation cover types have different combinations of spectral reflectance and emittance properties. These spectral patterns are captured on multispectral imagery and manifested as different combinations of digital numbers (DN), thus, providing a numerical basis for vegetation cover type classification (Lillesand and Kiefer 1994).

There are 2 spectral pattern-based methods, supervised and unsupervised classification, commonly used for vegetation cover type classification (Lillesand and Kiefer 1994). In the supervised approach, the vegetation cover types to be mapped as classes are specified initially. Spectral signatures for each of these classes are generated from spectral information acquired from imagery pixels corresponding to field sites representative of each class. These sites are called training areas. Classifier algorithms then statistically compare each image pixel to these spectral signatures and assign the pixel to the cover class it most closely resembles. In the unsupervised approach, clustering algorithms are used to aggregate image pixels into spectrally separable classes. The vegetation cover type associated with each class is determined *a posteriori* by comparing the classified image data to ground reference data.

Although rangeland vegetation can be successfully classified using either supervised or unsupervised classification (Tueller 1989), both involve a certain amount of trial and error before a satisfactory result is obtained. An approach which combines both classification methods can often be more efficient. Range managers are typically aware of the dominant vegetation cover types on a landscape of interest and would include these as classes in a supervised classification. Failure to recognize and include other spectrally-separable cover classes will, however, inflate the number of unclassified or misclassified pixels resulting from a supervised classification. By initially applying an unsupervised classification to the imagery data set, these other cover classes can be identified and included in a subsequent supervised classification.

In this study, an unsupervised classification (K-means clustering) was initially applied to the Landsat and SPOT subscenes. Although the spectral classes generated by the initial run of K-means clustering procedure did not exhibit an obvious spatial relationship with the native plant communities or cultivated grass hay fields known to be present in the Reynolds Creek Watershed, application of this unsupervised classification identified the need to include the burned and seeded area as a separate class in the supervised classification described below.

Classifier training areas were established in the 9 dominant plant communities, including 7 native communities (salt desert shrub, Wyoming big sagebrush, big sagebrush/bitterbrush, low sagebrush, mountain big sagebrush, aspen, and mixed-conifer) and 2 non-native communities (cultivated grass hay and Siberian wheatgrass), occurring in the Watershed. Selection of these 9 communities was based on information gathered from field survey, existing vegetation maps of the Reynolds Creek Watershed, and rangeland cover type descriptions published in Shiflet (1994). Riparian, mountain meadow and other plant communities of small spatial extent were not included in order to simplify the analysis and reduce classification errors associated with mixed pixels (see discussion below). To ensure the training areas were representative of the vegetation on the Watershed, 4 to 5 training areas were established in each plant community. These training areas were located on relatively flat terrain to minimize topography-induced effects on the reflectance values of the imagery. Training areas were established within large patches of relatively homogenous vegetation from each respective plant community. Inclusion of non-target cover types within the training areas was avoided. A Global Positioning System (GPS) with a horizontal accuracy of ± 2 m was used to establish the training area perimeter ≥ 30 m (i.e., a Landsat pixel width) interior to the edge of the patch. This 30-m buffer zone around each training area helped minimize inclusion of mixed pixels (pixels which span more than 1 plant community). Each training area was at least 5.4 ha in size or large enough to contain at least sixty, 30-m pixels. This minimum size criteria for training areas is based on the following equation:

$$P = (5(n^2 + n)) \quad \textbf{(1)}$$

where P is the minimum number of image pixels required per training area and n is the number of spectral bands to be used in the classification (PCI 1998). In this case, 3 spectral bands were used (see below). A training area of adequate size could not be established in the salt desert shrub community, however, without obtaining some inclusions of the Wyoming big sagebrush community. Impure salt desert shrub training areas probably contributed to classification errors between this community and the Wyoming big sagebrush community.

A bitmap image mask of each training area was generated with an image-processing software package (PCI, Richmond Hill, Ontario, Canada) using the perimeter coordinates obtained from the GPS survey. Four sets of spectral signatures for each training area were developed (1 for each satellite system/date combination) using green, red, and near-infrared reflectance data from image pixels located under the corresponding image masks. The green, red, and near-infrared combination was used because preliminary experimentation with different band combinations indicated this combination would provide the best image classification for these data sets. To ensure good statistical representation of the spectral characteristics of each plant community, spectral signatures from 2 to 3 training areas per community were merged to form a single signature per community.

Selection of the spectral signatures to be merged was based on their separability from signatures of other plant communities. Signature separability was analyzed using a transformed divergence procedure (Swain and Davis 1978). Transformed divergence values theoretically range from 0 to 2. A value of 0 indicates the spectral signatures from a pair of classes are completely inseparable and a value of 2 indicates complete separability. Transformed divergence values below 1.9 tend to be poorly separable. The signature separability between the salt desert shrub and Wyoming big sagebrush plant communities was very poor for all training areas. Transformed divergence values comparing the spectral signatures of these 2 communities ranged from 1.09 to 1.76 depending on which of the 4 date/system image combinations was used. Consequently, the salt desert shrub community was not treated as a separate class in successive analyses. Merged signatures were generated from all 4 satellite images using the same training area combinations for the 8 remaining plant communities.

The Gaussian maximum likelihood classifier was used to classify the pixels from each subscene into 8 plant community classes based on their spectral signatures. The maximum likelihood classifier typically provides higher classification accuracy than the other 2 commonly used supervised classification techniques; minimum-distance-to-means and parallelepiped. Although the maximum likelihood classifier is much more computationally complex than the other 2 classifiers, recent advances in computer hardware have essentially nullified this disadvantage.

Initial evaluation of the 4 resultant classification maps revealed that some high elevation pixels had been classified as cultivated land. Cultivated land in the study area was actually localized around the lower reaches of Reynolds Creek and its larger tributaries. The classifier appeared to be confusing aspen stands and mountain meadows at high elevations with cultivated land. A simple correction model was applied to the maps, reassigning cultivated land pixels of greater than a threshold elevation to the aspen class. Mountain meadows were not mapped as a separate class because they occupied only an extremely small fraction of the study area.

Accuracy Assessment

There are several measures commonly used to assess vegetation cover type classification accuracy. Overall accuracy is a percentage of reference pixels from all cover types which were correctly classified. Overall accuracy is essentially a weighted mean of all individual cover type accuracies. Producer accuracy is a percentage of reference pixels representing a specific cover type which were correctly classified to that cover type. Errors of omission (exclusion) decrease producer accuracy. Producer accuracy is commonly used as an indicator of training area quality during map product development (Lillesand and Kiefer 1994). User accuracy indicates the percentage of pixels classified to a specific cover type when they truly represent that cover type. Errors of commission (inclusion) decrease user accuracy. When a range manager identifies a feature mapped as a specific cover type, the user accuracy indicates the likelihood that feature truly has the same cover type in the field. Consequently, user accuracy is commonly used to express the accuracy of cover type map products. Accuracy comparisons in this study were based on user accuracy values.

Two ground truth data sets were collected to assess the accuracy of the 4 vegetation maps (Fig. 2 to 5). An initial map accuracy assessment was performed using a 1 by 2-km grid of reference points established across the Watershed by field visits with a GPS. This grid contained a total of 146 points. Of those, 46 points were discarded either because they were located on small patches (< 3 by 3 pixels) of a target plant community or on a plant community we were not evaluating (e.g., Juniper Woodland). The remaining 100 points provided data representative of the areal extent of those plant communities found in the Watershed. This data set was used to evaluate acquisition date and satellite system effects on vegetation map accuracy. Because of small sample sizes in some plant communities, this initial accuracy comparison between maps was limited to the 4 plant communities having the greatest land cover in the Watershed: (1) Wyoming big sagebrush, (2) low sagebrush, (3) big sagebrush/bitterbrush, and (4) mountain big sagebrush.

The second ground truth data set was developed so that the classification accuracy for all 8 plant communities investigated in the Watershed could be assessed. Thirty sample points from each of the 8 communities were randomly selected from the map exhibiting the highest initial accuracy. Each of these 240 sample points was classified to a reference plant community by interpretation of 1:12,000 scale color-

Table 1. Main effects and interactions, with their respective p-values, for user accuracy of plant community maps created using Landsat 5 TM and SPOT 3 HRV multispectral data acquired during peak vegetation growth (June) and late summer dry-down (August) in the Reynolds Creek Experimental Watershed in southwestern Idaho.

Main Effects and Interactions	Degrees of Freedom	P-Values
S[1,2]	1	0.4816
D[2]	1	**0.0450**[3]
C	3	0.3545
S*D[2]	1	0.1672
S*C	3	0.1750
D*C	3	0.3123

[1]S = Satellite system, D = Acquisition date, and C = Plant community (Wyoming big sagebrush, big sagebrush/bitterbrush, low sagebrush, and mountain big sagebrush).
[2]Effects of satellite system, acquisition date and their interaction were calculated based on means which were weighted by sample size while plant community effects and interactions were calculated based on unweighted means.
[3]P-values < 0.05 are printed in bold face

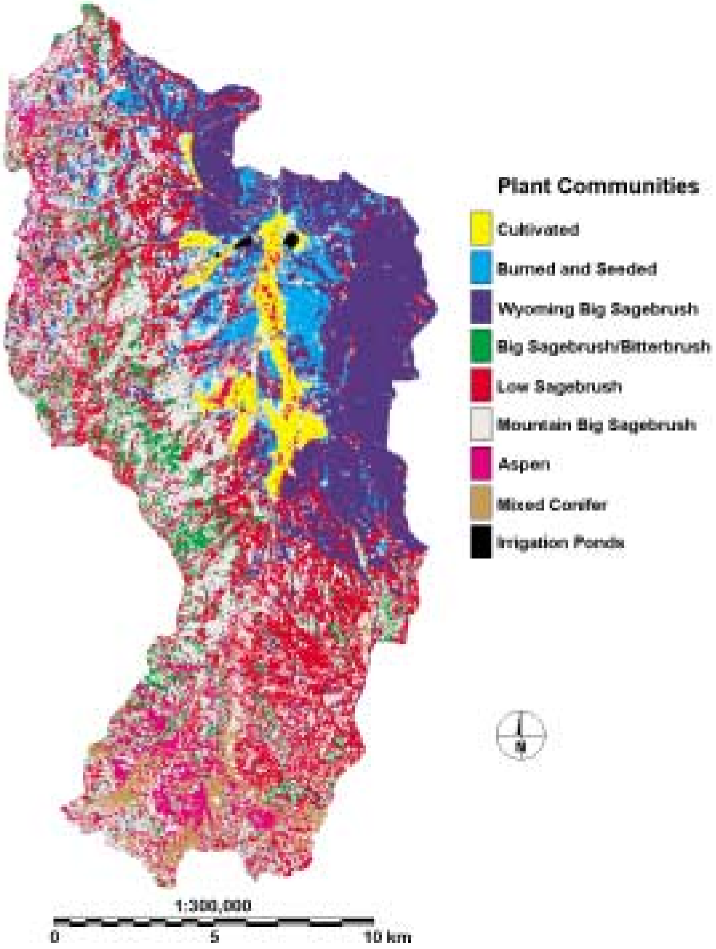

Fig. 2. Plant community map of Reynolds Creek Experimental Watershed in southwestern Idaho created by maximum likelihood classification of a Landsat 5 TM image acquired 6 June 1996.

infrared aerial photography acquired 1 August 1987. Accuracy of the aerial photograph interpretation was assumed to be 100%. Field visits to a 10% sample of reference points from each class confirmed this assumption. This type of intensive accuracy assessment was only applied to the map with the highest initial accuracy because it was not logistically feasible to establish a new set of 240 reference points for each of the other 3 maps.

Statistical Analysis

The effects of acquisition date, satellite system, and their interaction were examined using a weighted General Linear Model (GLM) procedure (SAS 1988) (Table 1). Weighting allowed calculation of mean overall accuracies for the acquisition date and satellite system comparisons. Weighting was based on the number of reference points located in each plant community class. The effect of plant community and its interactions with acquisition date and/or satellite system were analyzed using an unweighted GLM procedure. Where significant effects were detected, Fisher's Least Significant Difference (LSD) procedure was used for mean separations at a 5% level of significance. The scope of inference for this study is limited to the Reynolds Creek Experimental Watershed.

Results and Discussion

Plant Community Map Accuracy

Maximum likelihood classification of Landsat data acquired during dry-down (1 August 1993) produced a highly accurate map (73.6% overall accuracy) of the Wyoming big sagebrush, big sagebrush/bitterbrush, low sagebrush, and mountain big sagebrush communities in the Watershed (Fig. 3, Table 2). The low sage community (82.6% user accuracy) tended to be the most accurately mapped while the big sagebrush/bitterbrush community (64.3% user accuracy) tended to be the least accurately mapped of these 4 plant communities. Low sagebrush and mountain big sagebrush communities were often misclassified as the big sagebrush/bitterbrush community in maps from all 4 date/system combinations, particularly in the SPOT 17 June 1993 map (Fig. 4, Table 3). The spectral separability between low sagebrush and big sagebrush/bitterbrush was poor to very poor. Transformed divergence values comparing the spectral signatures of these 2 communities ranged from 1.38 to 1.89 depending on which of the 4 date/system image combinations was used. Mountain big sagebrush and big sagebrush/bitterbrush exhibited poor separability (TD value = 1.83) when the 1 August 1993 Landsat data were used. In the Watershed, bitterbrush can occur as widely-scattered plants within low sagebrush and mountain sagebrush communities, particularly on ecotone sites. Bitterbrush may have a dominate spectral signature which confuses the classifier even when bitterbrush cover is very low.

Based on this initial accuracy assessment, the most accurate map (1 August 1993 Landsat map) was selected for the more intensive accuracy assessment involving all 8 plant communities. The

Table 2. Percentage overall user accuracy and user accuracy by plant community for maps of 4 sagebrush communities created by maximum likelihood classification of Landsat 5 TM and SPOT 3 HRV imagery acquired during peak greenness (June) and dry down (August) at Reynolds Creek Experimental Watershed in southwestern Idaho based on 79 points from 100-point reference grid.

Satellite Imagery[1]	Overall User Accuracy[2]	User Accuracy by Plant Community: Wyoming B. Sagebrush	B. Sagebrush Bitterbrush	Low Sagebrush	Mountain B. Sagebrush
	--%				
LSAT 6_96	45.7	67.9	75.0	48.0	12.5
SPOT 6_93	63.3	70.0	36.4	68.0	61.5
LSAT 8_93	73.6	75.0	64.3	82.6	66.7
SPOT 8_94	67.4	60.0	50.0	85.7	76.9

[1]LSAT 6_96 = Landsat 5 TM image acquired June 6, 1996, SPOT 6_93 = SPOT 3 HRV image acquired 17 June 1993, LSAT 8_93 = Landsat 5 TM image acquired 1 Aug. 1993, and SPOT 8_94 = SPOT 3 HRV image acquired16 Aug. 1994.
[2]Weighted mean user accuracy

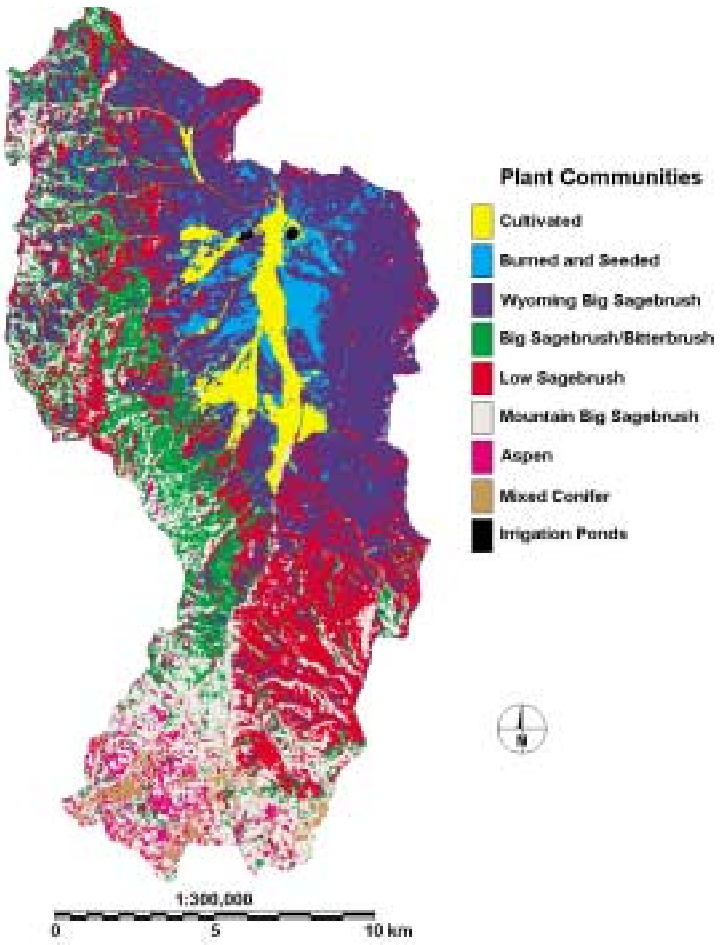

Fig. 3. Plant community map of Reynolds Creek Experimental Watershed in southwestern Idaho created by maximum likelihood classification of a Landsat 5 TM image acquired 1 August 1993.

overall accuracy for this map was 83.8% based on the 240 references points randomly selected from the map (Table 4). The low sagebrush community was mapped with 100% user accuracy and thus was the most accurately mapped of the 8 communities. User accuracy for the big sagebrush/bitterbrush community (66.7%) was the poorest of the 8 communities. As detected in the initial accuracy assessment, low sagebrush and mountain big sagebrush were often misclassified as big sagebrush/bitterbrush by the classifier (Table 5). The classifier also had problems with the 3 high elevation communities. Aspen and mountain big sagebrush pixels were sometimes misclassified as mixed conifer. Broadleaf and conifer trees typically have similar signatures in the red and green bands but differ in the near infrared band (Lillesand and Kiefer 1994). Performing a second classification run, on areas initially mapped as broadleaf (e.g., aspen) or conifer trees, using signatures generated from only the near infrared band may improve classification accuracy for these communities.

The salt desert shrub community was not treated as a separate class because of its low spectral separation with the Wyoming big sagebrush community. It was assumed any salt desert shrub stands would be mapped as Wyoming big sagebrush. Field visits and a qualitative comparison of the 1 August 1993 Landsat map with an older plant community map, created using ground survey and photograph interpretation color aerial photographs (acquired 11 June 1961), tended to confirm this assumption. Some salt desert shrub stands delineated on the 1961 plant community map, however, occurred in an area that was prescribed burned and seeded to Siberian wheatgrass in 1984. This burned and seeded area was correctly classified by the maximum likelihood classifier.

The salt desert shrub stands in the Experimental Watershed occur in what appears to be an ecotone between the salt desert shrub and Wyoming big sagebrush communities. It may have been possible to delineate the salt desert shrub community from Wyoming big sagebrush if the salt desert shrub training areas had been established in more extensive, "pure" stands outside of the Watershed.

Acquisition Date and Satellite System Effects

Imagery acquisition date significantly influenced overall user accuracy of maps delineating the Wyoming big sagebrush, big sagebrush/bitterbrush, low sagebrush, and mountain big sagebrush communities within the Reynolds Creek Watershed (Table 1, Fig. 2 to 5). Landsat and SPOT data acquired during dry-down (early August) produced more accurate plant community maps ($\bar{x}$ = 70.5% overall accuracy) than data acquired during peak growth (early June) ($\bar{x}$ = 54.4% overall accuracy). Overall accuracy of maps generated by Landsat ($\bar{x}$ = 60.1%) and SPOT ($\bar{x}$ = 65.5%) were statistically similar. No significant plant community main effect or interactions with acquisition date or satellite system were detected (Table 1).

Similar to our results, Jakubauskas et al. (1998) reported the separability of spectral

Table 3. Maximum likelihood classifier performance for 4 sagebrush communities in Reynolds Creek Experimental Watershed in southwestern Idaho using SPOT 3 HRV imagery acquired 17 June 1993 and based on 79 points from a 100-point reference grid.

	Classifier Output (y) Native Sagebrush Communities[1]				
True Class (x)	WYMSG	SGBIT	LOWSG	MNTSG	Total pixels in each true class
WYMSG	21[2]	1	5	2	29
SGBIT	1	4	1	2	8
LOWSG	8	4	17	1	30
MNTSG		2	2	8	12
Total pixels in each output class	30	11	25	13	79

[1]Native sagebrush communities where, WYMSG = Wyoming big sagebrush community, SGBIT = big sagebrush/bitterbrush community, LOWSG = low sagebrush community, and MNTSG = mountain big sagebrush community
[2]Each entry indicates the number of pixels the classifier has placed in each respective class y, when in fact they belong to true class x.

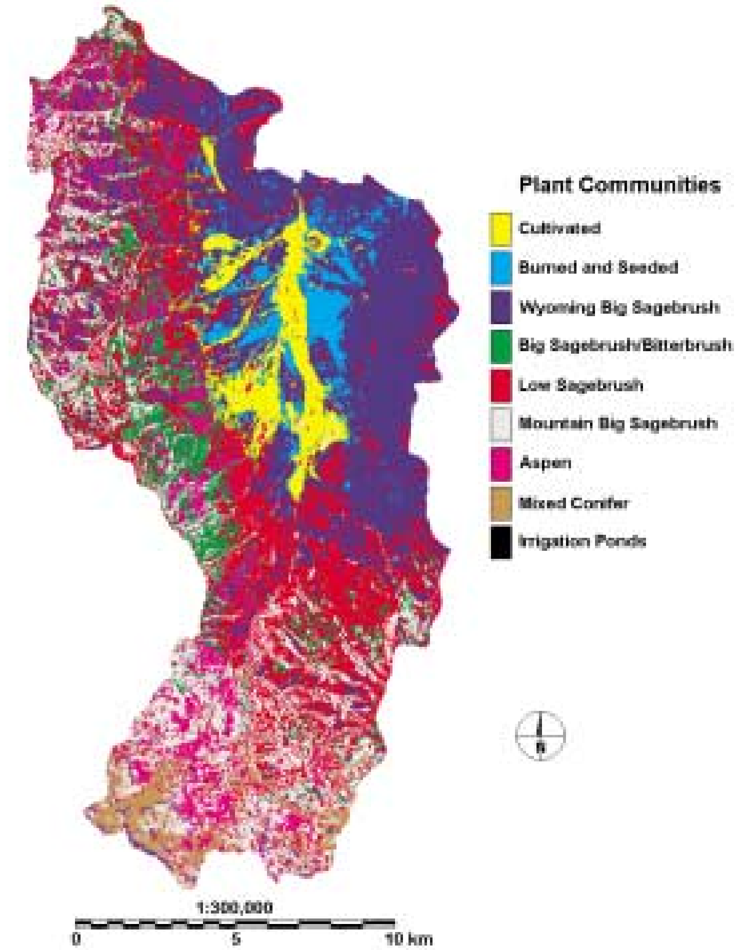

Fig. 4. Plant community map of Reynolds Creek Experimental Watershed in southwestern Idaho created by maximum likelihood classification of a SPOT 3 HRV image acquired 17 June 1993.

signatures generated from Indian IRS LISS-II multispectral data for 4 sagebrush steppe communities was poor during peak greenness in June and greatest in August and decreased in October as plants became completely senescent. Extensive differences exist in the phenologies of the major plant species in the sagebrush steppe (Blaisdell 1958). Phenological development affects the spectral characteristics of plants (Huete and Jackson 1987). These phenological effects vary among species and growth forms (Duncan et al. 1993, Franklin et al. 1993, Bork et al. 1998). Phenological differences probably affect the spectral characteristics of plants most during the late season (August) when some plants are still green or have ephemeral leaves intact, some are drying down or dropping leaves, and some are already completely senescent. Consequently, the spectral combinations forming individual cover type signatures would be more complex in August than in June, and this could result in greater spectral separability for some cover types in August. Additionally, because precipitation in the Intermountain West is typically higher in June, wet soil surfaces are more common in June than August. Spectral signatures of wet soils are less separable from sagebrush steppe vegetation than dry soils (Bork et al. 1998), effectively simplifying the spectral signatures of sagebrush communities in June and possibly reducing the spectral separation between these communities.

Sources of Classification Error

There are several important sources of classification error than should be considered when developing a plant community mapping project using satellite imagery. Poor georegistration of imagery can produce considerable classification error, particularly for communities which occur as small patches. If only the scene corner and center coordinates (provided in the scene header by the vendor) are used to georectify system-corrected imagery (Level 1-B), the horizontal accuracy would be ± 250 m. On relatively flat areas, horizontal accuracy can be substantially increased with inclusion of additional ground control points in the georectification process. In more rugged areas, however, it is unlikely additional ground control points will correct terrain-induced displacements which can produce considerable classification error (Dymond 1988, 1992) and reduce map accuracy. A digital elevation model and additional ground control points are required to correct for terrain displacement. Imagery used in this study was not terrain-corrected and misclassification of some reference pixels was clearly due to inadequate georectification. Where the relief is greater than 500 m, terrain-corrected imagery is recommended for accurate mapping.

Poor spectral separability between plant communities classes can lead to poor classification accuracy. Selection of training

Table 4. Accuracy Statistics for Maximum Likelihood Classification of 8 plant communities in Reynolds Creek Experimental Watershed in southwestern Idaho using Landsat 5 TM multispectral imagery acquired 1 August 1993 based on an accuracy assessment using 240 randomly located reference points.

Overall Accuracy: 83.8% 95% Confidence Interval: 78.9–88.6%
Overall Kappa Statistic: 0.814% Overall Kappa Variance: 0.001%

Class	Producer Accuracy	95% Confidence Interval	User Accuracy	95% Confidence Interval	Kappa Statistic
	--------	--------	%-	--------	--------
CULTV[1]	96.6	88.2 –104.9	93.3	82.7 – 103.9	0.92
BURND	100.0	98.0 – 102.0	83.3	68.3 – 98.3	0.81
WYMSG	84.4	70.2 – 98.5	90.0	77.6 – 102.4	0.88
SGBIT	90.9	76.6 – 105.2	66.7	48.1 – 85.2	0.63
LOWSG	63.8	49.0 – 78.6	100.0	98.3 – 101.7	1.00
MNTSG	75.0	58.4 – 91.6	80.0	64.0 – 96.0	0.77
ASPEN	85.7	71.0 – 100.5	80.0	64.0 – 96.0	0.77
CONIF	92.0	79.4 – 104.6	76.7	59.9 – 93.5	0.74

[1]CULTV = cultivated land, BURND = rangeland burned and reseeded to Siberian wheatgrass, WYMSG = Wyoming big sagebrush community, SGBIT = big sagebrush/bitterbrush community, LOWSG = low sagebrush community, MNTSG = mountain sagebrush community, ASPEN = aspen community, and CONIF = mixed conifer community.

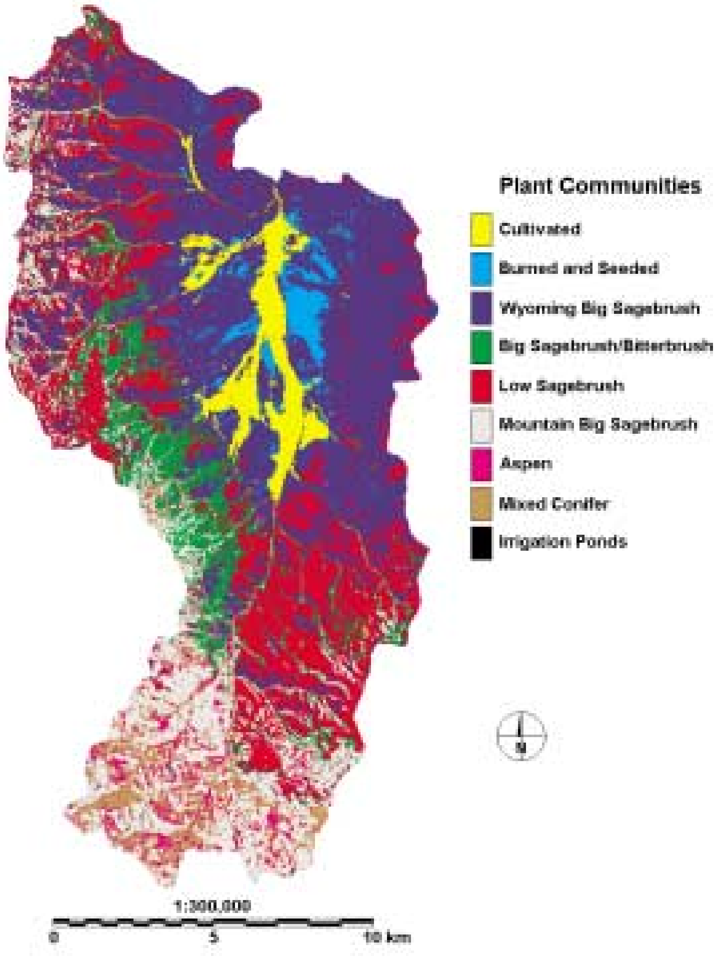

Fig. 5. Plant community map of Reynolds Creek Experimental Watershed in southwestern Idaho created by maximum likelihood classification of a SPOT 3 HRV image acquired 16 August 1994.

areas with more homogenous cover may improve class separability. Improvement of classification accuracy, however, may require combining of poorly separable classes into a single class as was done with the Wyoming big sagebrush and salt desert shrub communities.

Mixed pixels can also contribute to classification error. Mixed pixels are common along distinct patch boundaries. Riparian areas are good examples of where classification errors due to mixed pixels may occur. In arid and semi-arid rangeland there is typically a distinct boundary between low productivity vegetation in the uplands and higher productivity vegetation in the riparian areas. Riparian areas of rangeland streams are typically narrow, often narrower than a Landsat or SPOT image pixel. Imagery of the riparian areas, consequently, will nearly always have pixels which contain spectral information from a combination of both riparian and adjacent upland vegetation. Because of this mixture of spectral information, the classifier may misclassify these pixels to a third class which may be completely out of place both, spatially or ecologically. The presence of spatially-broad ecotones and unclassified intermediate cover types can also result in mapping errors. As in conventional mapping techniques, cover types which grade into each other across a broad area make it difficult to delineate boundary lines.

Practical Considerations

Landsat TM and SPOT HRV scenes acquired in August proved useful for accurately mapping Intermountain plant communities within the Reynold Creek Watershed. Although the probability of obtaining a cloud-free image of Intermountain rangeland is likely better during August than any other month of the year, it still may be difficult to obtain a cloud-free Landsat image during that time period because the 16-day orbit cycle of the Landsat system limits opportunities. If a current-year scene is desired (e.g., to map plant communities following a wildfire), the pointable optics of the SPOT system provide more opportunities to obtain a cloud-free August scene than Landsat. For example, a point at 45° latitude can have as many as 11 viewing opportunities within the 26-day SPOT orbit cycle via off-nadir viewing (Lillesand and Kiefer 1994). Use of SPOT imagery acquired through

Table 5. Maximum Likelihood classifier performance for 8 plant communities in Reynolds Creek Experimental Watershed in southwestern Idaho using Landsat 5 TM multispectral imagery acquired 1 August 1993 based on an accuracy assessment using 240 randomly located reference points.

	Classifier Output (y)								
True Class (x)	CULTV	BURND	WYMSG	SGBIT	LOWSG	MNTSG	ASPEN	CONIF	Total pixels in each true class
CULTV[1]	28[2]					1			29
BURND		25							25
WYMSG	2	3	27						32
SGBIT		1		20		1			22
LOWSG		1	3	6	30	2	4	1	47
MNTSG				4		24	1	3	32
ASPEN						1	24	3	28
CONIF						1	1	23	25
Total pixels in each output class	30	30	30	30	30	30	30	30	240

[1]CULTV = cultivated land, BURND = rangeland burned and reseeded to Siberian wheatgrass, WYMSG = Wyoming big sagebrush community, SGBIT = big sagebrush/bitterbrush community, LOWSG = low sagebrush community, MNTSG = mountain big sagebrush community, ASPEN = aspen community, and CONIF = mixed conifer community.
[2]Each entry indicates the number of pixels the classifier has placed in each respective class y, when in fact they belong to true class x.

off-nadir viewing, however, increases the complexity and potential for problems in image correction and calibration (Royer et al. 1985, Gerstl and Simmer 1986, Moran et al. 1990, Franklin and Giles 1995) and may decrease classification accuracy (Foody 1988).

Landsat data may be more economical than SPOT for resource management applications, particularly for U.S. federal agencies. Landsat scenes are much larger than SPOT scenes (31,450 km^2 compared 3,600 km^2, respectively), thus, an area of interest is more likely to be completely covered on a single Landsat scene than on a single SPOT scene. At the time of this writing, systematic-, precision-, and terrain-corrected SPOT scenes were available from SPOT Image Corp. (Reston, Virg.). System-, precision-, and terrain-corrected Landsat scenes were commercially available from Space Imaging Corp. (Thornton, Colorado) and cost less per km^2 than comparable SPOT scenes. System-corrected Landsat scenes acquired prior to or on 28 October 1992 could be purchased by the public from USGS Earth Resources Observation Systems (EROS) Data Center (Sioux Falls, S.D,) at substantially lower cost than from the commercial vendor. For U.S. federal agencies only, the USGS EROS Data Center also provided precision- and terrain-corrected Landsat scenes for much lower than the commercial cost.

Landsat 7 ETM+ was launched 15 April 1999 to continue the missions of the highly successful Landsat 4 and 5 TM sensors. Landsat 7 ETM+ samples essentially the same 7 bandwidths as Landsat 4 and 5, however, a panchromatic band product (15 m) was also provided. Landsat 7 ETM+ systematic-, precision-, and terrain-corrected scenes were available to the public from the USGS EROS Data Center in Sioux Fall, S.D. A principle objective of the Landsat 7 project was to provide satellite data products to users at cost, a considerable savings over the commercial price for other current Landsat products.

Conclusions

Although the scope of inference for this study was limited to the Reynolds Creek Experimental Watershed, these results suggest both Landsat 5 TM and SPOT 3 HRV provide multispectral data range managers can use to accurately classify and map plant communities on Intermountain rangelands similar to the Reynolds Creek Watershed. Imagery data acquired during dry-down (early August) will likely produce more accurate plant community maps than data acquired during peak growth (early June). Classification of Landsat or SPOT imagery can be a practical and economic means of mapping extensive areas (e.g., grazing allotments, large ranches, watersheds, parks and preserves, and other resource management units) common to the Intermountain West.

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