A COMPARISON OF COVERTYPE DELINEATIONS FROM AUTOMATED IMAGE SEGMENTATION OF INDEPENDENT AND MERGED IRS AND LANDSAT TM IMAGE-BASED DATA SETS

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ABSTRACT

Existing image segmentation algorithms have recently been ported to the widely used ERDAS Imagine graphical user interface. Within the USDA Forest Service Region 5 Remote Sensing Lab these algorithms have traditionally been applied to Landsat TM data for the purpose of landscape delineation. A less confining image processing environment, combined with the wide availability of finer resolution data sets, has lead to the possibility of multi-scale delineation of various orders of landscape features from diverse spectral categories. A comparison of image segmentation output is made for five meter IRS panchromatic, thirty meter Landsat TM multispectral, and a merged data set. The merging of satellite imagery is commonly used to generate a product that has enhanced complimentary characteristics. The method introduced consists of performing image segmentation on spatially and spectrally merged data sets. The results indicate segment delineations using a merged data set for mid and fine scale landscape mapping efforts as a marked improvement over conventional image segmentation procedures.

INTRODUCTION

Detailed stand based mapping of floristic composition and stand structure is important for developing and using forest vegetation inventories, landscape assessments and monitoring, and land management planning. Developing these maps from remotely sensed data using the traditional approach of pixel level image classification results in a limited ability to spatially define vegetation characteristics that are a function of the vegetation stand or patch. Attempts to delineate vegetation stands post-facto classification often results in imprecise boundaries and allows erroneous thematic data to affect stand boundary delineation. Image segmentation has been proven effective for segregating an image into multiple polygonal components that relate to unique stands of vegetation. Precise delineation of unique vegetation stands or patches enables the characterization of vegetation communities and vegetation stand structure that may otherwise be depicted by a spatially ambiguous group of pixels. Furthermore, spatially identifiable stands feasibly allow for ground and photo verification during the mapping process.

The process of image segmentation involves the delineation of an image into spectrally and spatially related partitions. These partitions can subsequently be labeled as to basic covertype, e.g. shrub, hardwood, conifer, agriculture, urban, water, and species-level vegetation types. Essentially, the process of segmentation computes differential boundaries around spectrally homogenous landscape units, which can, in turn, be labeled. Due to the dominant species level classification required by the USDA Forest Service, Region 5 Remote Sensing Lab (R5RSL), standard image classification tools available within ERDAS Imagine do not provide the means for continuous delineation of homogeneous spectral pattern. This method of segmentation processing for regionalization (populating the segmented partitions with an identifying label) has been in use since 1993.

Two major processes are associated with the methodology of this study; these are data merging and segmentation.

For vegetation mapping purposes, the process of segmentation is twofold: 1) image segmentation and 2) segment regionalization or labeling. Image segmentation relies on spectral pattern and spatial arrangement of the image data to define patches of homogenous and continuous landcover condition. The image analyst controls the spectral variance, shape and size of the resulting image segments or 'regions' through the definition of spectral and spatial threshold parameters. The desired segmentation output is a continuous set of regions that meet or exceed the required minimum map unit, delineate unique land cover conditions and separate homogenous from highly variant conditions within similar land cover types. Naturally, generating the desired segmentation outputs is dependent on the ability of the source image to resolve land cover conditions.

The second component of the segmentation process in land cover mapping is the thematic attribution of unlabeled regions. The image is processed using a hybrid approach – an unsupervised image classification followed by a supervised classification. The classified image is used to populate the delineated regions in the segmented image, thereby providing a generalized basic land cover label, which can be subsequently reviewed and corrected for anomalous classification error. Labeling rules that reflect the land cover classification system, determine the region label based on the membership of pixels by class within each region. Labeled regions represent both the spatial and thematic foundation of existing vegetation maps and in the mapping process are used to stratify map areas for the hierarchical development of greater floristic and structural detail.

For several years the R5RSL has used thirty-meter multispectral Landsat TM imagery for segmentation and classification. Recently, IRS imagery was introduced into the process. This five-meter panchromatic imagery is a logical compliment to the TM image sets. The high spatial resolution of the IRS imagery affords the ability to resolve spatial and textural details to a greater level of precision while the high spectral resolution of the TM imagery allows for differentiation of land cover types.

The goal of this paper is to develop an approach for assessing the precision of a Landsat TM and IRS merged data set for segmentation. With the determination of greater precision in spatial land cover delineations, it is presumed that there will be potential for improved thematic map accuracy. Furthermore, user confidence in subsequent map products, which often lags due to perceived delineation inaccuracy, is likely to increase. Our approach is intended to give insight, not only to the effectiveness of higher resolution data sets for land cover delineation, but also to make a preliminary determination of the feasibility of integrating higher precision feature delineations into the Regional land cover mapping and monitoring program.

STUDY SITE

The study site is located in Napa County (Figure 1). This area was selected for its diverse land cover types, including forest, shrub, and agriculture.

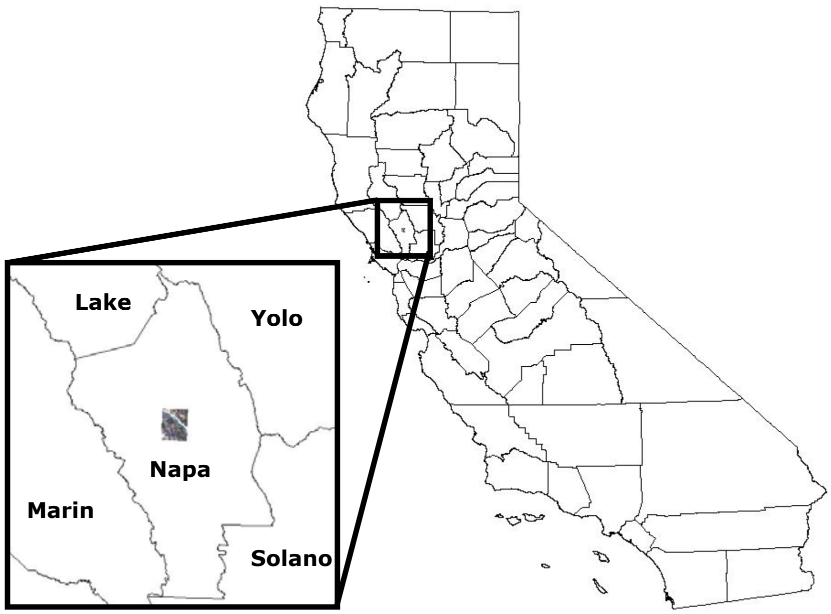


Figure 1. The study site is located in central Napa County. The area is approximately 6km x 7.5km (11,700 acres/ 4700 hectares).

METHODS AND MATERIALS

Landsat TM Preprocessing

Spatial enhancements of remotely sensed imagery are often employed for classification routines.

The Landsat TM imagery is subjected to two preprocessing transformations prior to merging with the IRS imagery. These are resampling and convolution. Both processes are critical to the effective merging of spatial and spectral resolutions of the component imagery.

After georectification requirements are met, the Landsat TM data must be resampled to the 5-meter spatial resolution of the IRS imagery. This is accomplished using an affine transformation. This transformation is equivalent to a first order polynomial transformation and is used to handle all linear transformations as well as translation (From ERDAS IMAGINE On-Line Help Copyright (c) 1982-1999 ERDAS, Inc.)

The output cell size multiplier number can be determined by with the following equation:

$$\frac{IRS\ cellsize\ (meters)}{TM\ \ cellsize\ (meters)} = output\ cellsize\ multiplier,\ i.e. \frac{5}{30} = 0.166666667$$

In order to resample the TM data to 5 meters, 0.166666667 must multiply the output cell sizes. This effectively reduces the size of the 30-meter TM cell to five meters.

Spatial frequency is a parameter of remotely sensed imagery that describes tonal variations over a known distance on the image (Jensen). These variations may be enhanced or subdued through spatial convolution filtering, which is applied in a convoluted masking or “kernel” concept. The low-pass filter applied to the 5-meter resampled TM imagery de-emphasizes high in spatial frequencies in the image. The filter evaluates a particular pixel brightness of the input pixel and outputs a new brightness value based on the mean of this convolution. The kernels available in ERDAS Imagine are 3x3, 5x5, and 7x7. The 7x7 low-pass filter calculates the greatest convolution; this filter showed the best results in the merging process.

Image Merging

It is assumed that the TM and IRS data have been geographically registered and radiometrically corrected prior to the merging process. It may be necessary to co-register the TM and IRS data sets. Prior to merging two critical criteria must be fulfilled; 1) the IRS and TM data must be precisely geographically co-registered and 2) The image extents must match. All preprocessing can be done in ERDAS Imagine. It is recommended to use the more geographically accurate of the two images to be co-registered as the reference. Preprocessing TM imagery was critical to eliminating the 30m pixel footprint (Figure 2). Refer to Figure 3 for merging process flow.

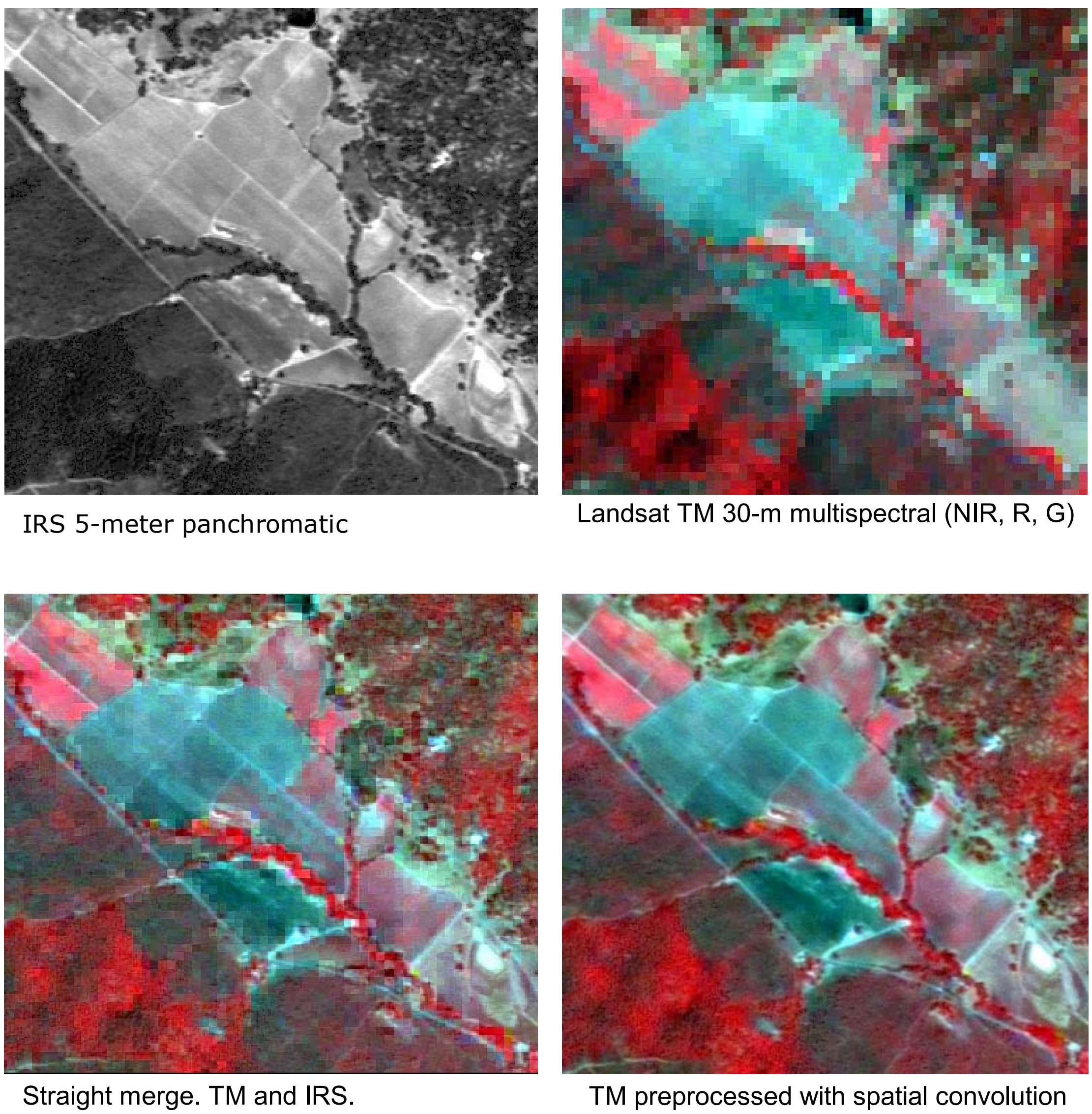


Figure 2. (Clockwise from upper left). 5m IRS panchromatic, 30m TM, preprocessed TM, and straight merge. Note the obvious TM footprint on the straight merge product.

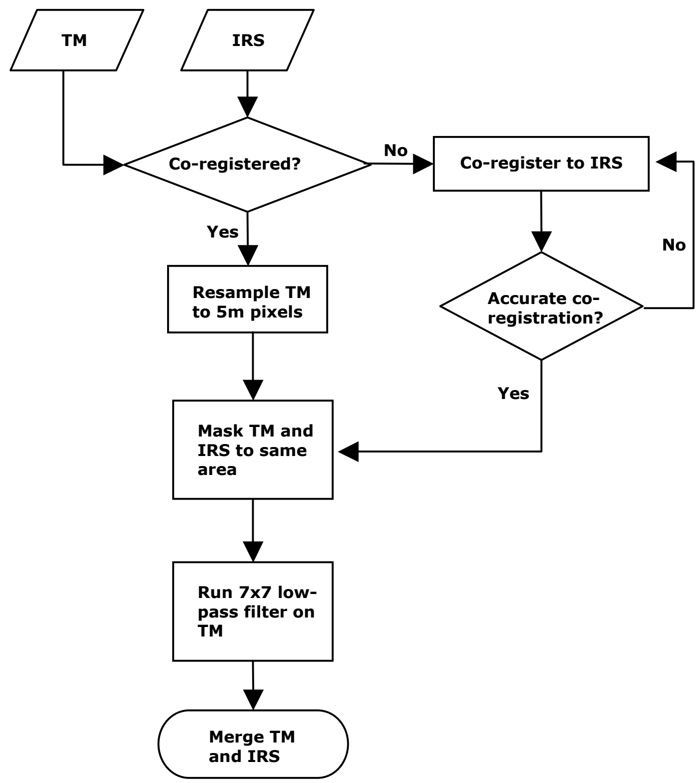


Figure 3. Process flow for image merging.

Segmentation

Image segmentation took shape in the Region 5 Remote Sensing lab in 1992 when a team of researchers from Boston University configured unix-based Image Processing Workbench (IPW) on the existing computer system (Woodcock et al). IPW was used as a stand-alone image segmentation package until 2001, when the IPW algorithms were successfully ported to an ERDAS Imagine interface.

Image segmentation is a non-traditional method of classifying an image that consists of subdividing the images spectral components into separate delineations (Figure 5). These delineations are not related. Refer to Figure 6 for an overview of the segmentation process flow. The input parameters for image segmentation are explained in detail below:

-t -n Nabsmin, Nnormin, Nviable, Nmax, Nabsmax

-t represents the spectral Euclidean distance threshold

-n represents the spatial parameters of segmentation outputs

$$Nabs\min = \left(\frac{4046.856\ \ m^2}{cellsize\ (m^2)} \right) = number\ of\ \ square\ cells\ in\ one\ acre$$

Where:

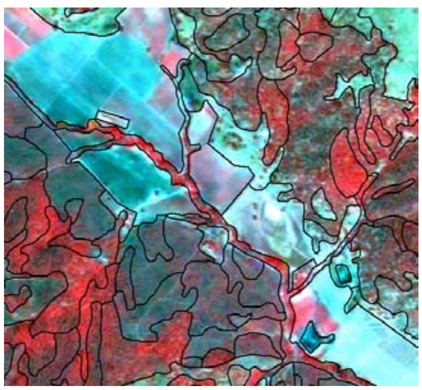
Nabsmin = absolute minimum mapping unit in acres (auxillary output)
4046.856 m^2 = number of square meters in one acre
cellsize = pixel dimension of raster-based imagery

Nnormin = minimum mapping unit in acres
Nviable = Spatial control measure. As soon as a region in an image achieves viable size, it is no longer available for merging/segmentation
Nmax = maximum mapping unit
Nabsmax = absolute maximum mapping unit in auxillary output

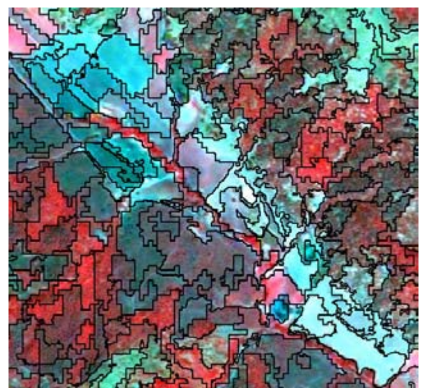
$$Nabs\min = \left(\frac{4046.856\, m^2}{900\, m^2}\right) * (1\ acre) = 4.5\ thirty\ meter\ square\ cells\ in\ one\ acre$$

Parameters for 2.5 acre mmu:
For 30m TM: -t 6 -n 11,11,30,100,1000
For 5m Merge: -t 6 -n 405,405,1110,3700,37000

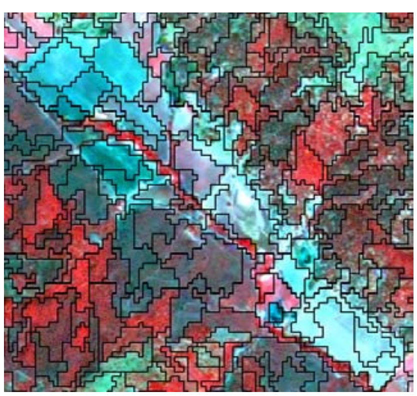
Parameters for 1.0 acre mmu:
For 5m Merge: -t 6 -n 162,162,440,1500,15000



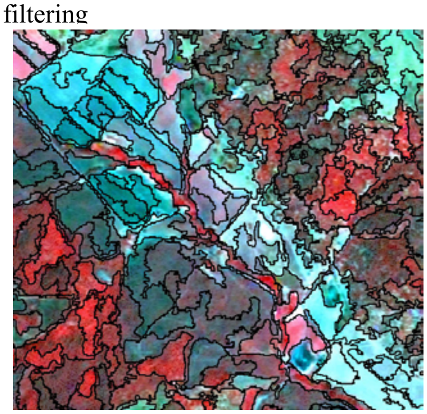
Hand-delineated polygons. NO mmu.



NIR, Red, NIR texture band stack based on 5m merge with NO TM filtering



NIR, Red, NIR texture band stack based on 30 TM imagery.



SWIR, NIR, Red band stack based on merge with TM filtering.

Figure 5. Image segmentation based on four techniques. The background image, a color IR representation, is used only for segmentation display purposes. With the exception of the hand-delineated polygons, all segmentations use a 2.5 acre minimum mapping unit (mmu).

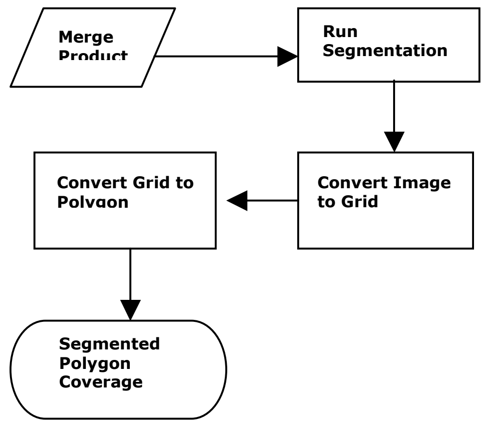


Figure 6. Segmentation process flow.

RESULTS

Image Merging

The TM footprint was essentially eliminated in the merged data set (Figure 7). This was critical to the segmentation process, as the ghosting of 30 m cells greatly minimized segment precision and delineation across the landscape, i.e. confusion resulted where 30 m pixels were spectrally and spatially obvious on the merged data set. The results of the image merging process introduced in this paper are summarized below:

• Multispectral merged image set is significantly larger in file size than the raw 30m TM.

• Permits more precise segmentation due to higher spatial resolution combined with spectral characteristics.

• More readily interpretable and resolvable image both spatially and texturally.

The process used to combine IRS and TM data in a spatial and spectral resolution fusion resulted in spectral data smoothing -- a reduction in digital number variance – thereby reducing the number of segment outputs. Subsequently, a smaller spectral data range corresponds to a smaller segment output. This is attributed to a combination of 7x7 lowpass filtering and 5-bit IRS data. While the output exhibited increased spatial resolution, it also exhibited reduced spectral range. This side effect of reduction in spectral variance and reduction in possible number of segment delineations was considered of no critical significance in the resultant segmented product.

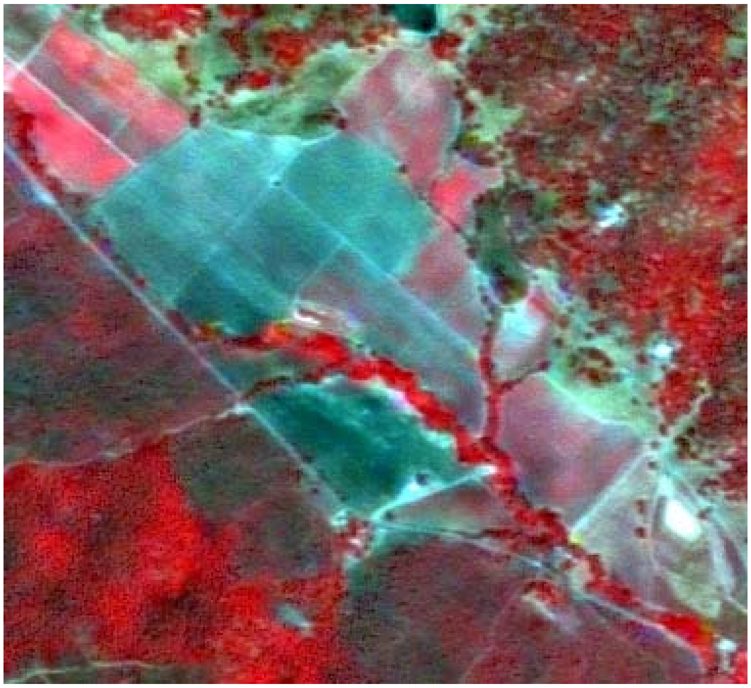


Figure 7. Final merged image. This multispectral image, displayed in a color infrared band combination, is a result of fusing 30m multispectral Landsat TM with 5m panchromatic IRS satellite imagery. Note the absence of the 30m pixel TM footprint.

RESULTS

Segmentation

All segmentation results are based on entirety of the study site with a 2.5 acre minimum mapping unit and comparable segmentation performance parameters. Both a visual and statistical analysis were performed on resultant segmentation of three image types:

1) **5m_434t_25p.** 5m merged data set with NIR,R,NIR texture band stack and 2.5 acre mmu.
2) **Photo Delineation.** On-screen hand-delineation over DOQQs with analyst consideration of ecological conditions.
3) **30m_434t_25p.** 5m merged data set with NIR,R,NIR texture band stack and 2.5 acre mmu.

Visual Evaluation

The initial assessment was a subjective evaluation of the segmentation outputs as they related to the edge of significantly contrasting features, i.e. shrub/agriculture, shrub/conifer, hardwood/agriculture. In addition to edge delineation, outputs were also evaluated for their correlation with significant landscape and vegetated features. Of particular interest were riparian vegetation stringers commonly composed of scattered overstory hardwood species and dense understory woody shrub species. These stringers occur in a spatial pattern that has traditionally been difficult to delineate with 30 meter LANDSAT TM data. Riparian stringers are often less than 60 meters wide, the minimum width possibly delineated on Landsat TM data with the segmentation algorithm employed.

In addition to comparison of segmentation outputs based on the two source image types, an independently derived cover type delineation, based on photo interpretation and on-screen digitization, was also included. This unique and more traditional form of landscape delineation was included to serve as a benchmark for human intuition. This was considered important as a means of assessing potential user confidence that is often significantly affected by visual perception of the data. The assumption applied was that, regardless of delineation accuracy, the more closely a segmentation product mimicked manually delineated features, the more likely data users were to accept subsequent map products.

In figures 1 through 3 a subset of the study area is depicted for the three delineation products. The backdrop used in this visual evaluation was the IRS/TM merged image, which biases the evaluation favorably toward the segments derived from the same source. However, the combination of spatial and spectral resolution offered a compromise between the spatial detail of digital ortho quarter quads (DOQQ) and spectral information in the TM data. Using the riparian stringer in the center of the images as a significant feature that also has clearly defined edges, the three delineations were visually assessed.

All three delineations appear to discriminate the most obvious portions of the riparian area. As expected, the ability of the 5 meter data to resolve narrower portions of the riparian area combined with a lower minimum width parameter resulted in fewer omissions of riparian edge as compared to the 30 meter data. Edge omissions on the 30 meter based segments are circled in yellow on figure 8. Neither the 5 meter based segments or the manually delineated segments appear to have significant edge omission with respect to the riparian stringer. Differences between the inductive logic of a human interpreter and the deductive process of an algorithm (red circles, figure 10) are apparent where extensions of the riparian area were obvious on the manually delineated segments but not visible on either of the image segmentation outputs. This single input form of algorithmic delineation also forgoes the ability to aggregate spectrally dissimilar units of similar cover type; something a human interpreter can more easily accomplish. This can result in ‘delineation noise’ or unnecessary segmenting of the image for land cover discrimination. While this was an observed byproduct of both segmentation outputs, it was most obvious on the 5 meter product. The most obvious example of excessive delineation, associated with general agriculture, is highlighted by the green circle in figure 9. It should be noted that excessive delineation can be controlled through post facto thematic aggregation and can be beneficial by offering greater spatial control during the mapping process.

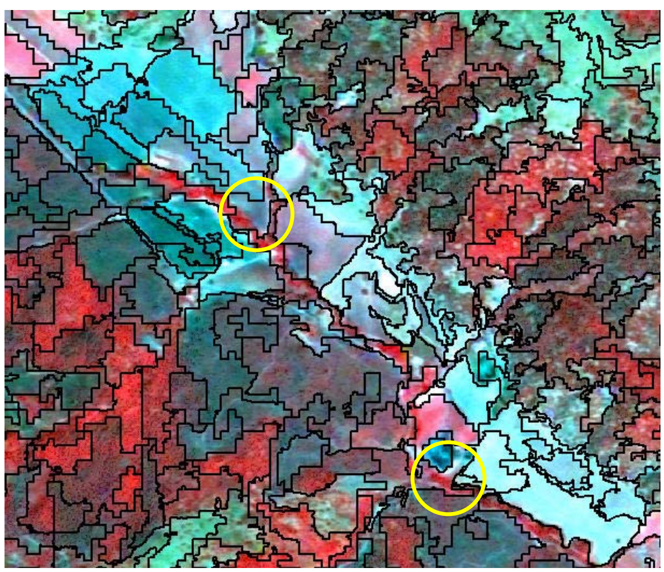


Figure 8 – LANDSAT TM Segments

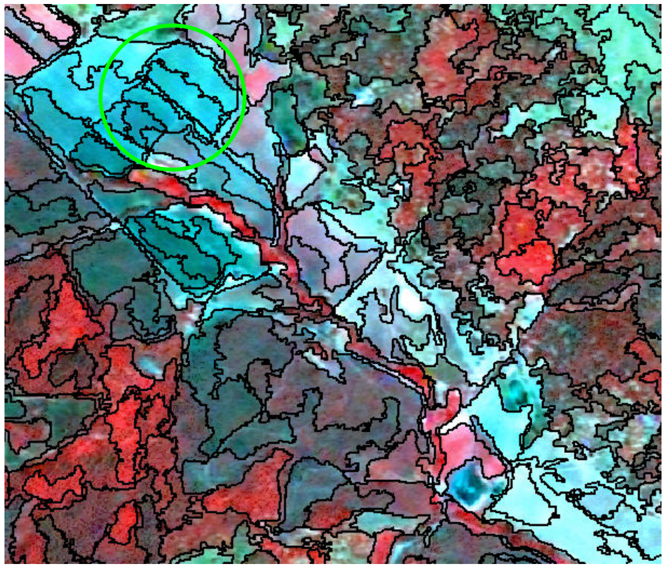


Figure 9 – IRS/TM Segments

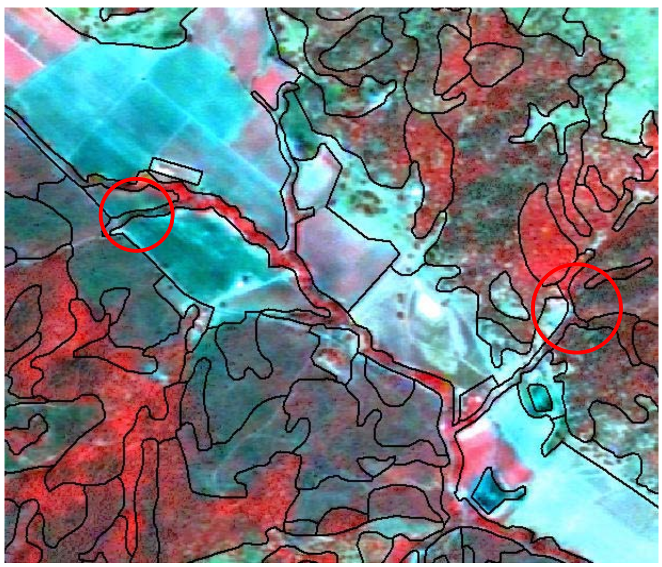


Figure 10 – DOQQ Delineations

Statistical Evaluation

A series of statistical summaries was generated using the Patch Analyst extension in Arcview to quantify the nature of each of the delineation types. Within each parameter, a relative comparison of the delineation types was depicted.

The most basic summaries determined the frequency and size of regions for each product. In all of these parameters, both the TM and IRS/TM segments performed similarly due to the spectral similarity of the source data and the function of the segmentation algorithm. Image segmentation resulted in a much higher number of regions than manual delineation with a correspondingly lower average region size. Within the 11,700 acre study area, 1613 and 1403 regions were generated for TM and IRS/TM data sets, respectively, while 694 regions were delineated manually. The differences in computer based and human interpreted delineations is clearly depicted in all of these parameters but are most obvious in the standard deviation of the region size, which is significantly higher for the manual delineations (11 vs. 2 for both TM and IRS/TM). Again, the ability of the analyst to aggregate features based on the delineation objective is inherently part of the delineation process. This would suggest that aggregation of segmentation regions, within similar cover types, should occur prior to generating a final map. Figure 11 illustrates the relative performance of each delineation product.

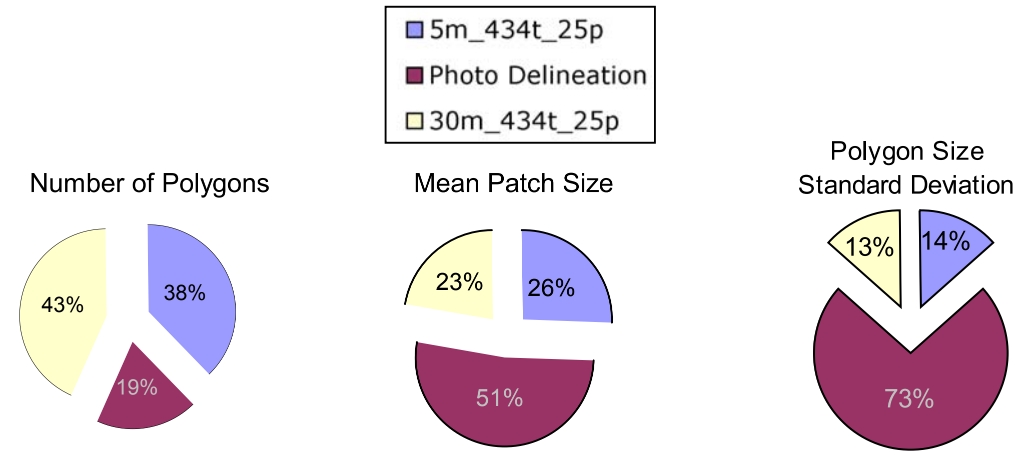


Figure 11 – Region Frequency and Size

A rigorous measurement of delineation precision was not applied in this study. However, a summary of edge area was considered to be a general indicator of delineation precision between the TM and IRS/TM segments. A comparison between the image segmentation outputs and DOQQ delineations was less reliable since land use types were aggregated as part of the delineation process, resulting in fewer total regions and correspondingly less edge. Total edge, edge density, and mean region edge were shown to be significantly higher for the 5 meter regions. When total edge was considered in conjunction with the visual analysis, it was concluded that delineation precision was indeed higher for the 5 meter segments. Figure 12 depicts relative amounts of edge for each of the delineation types.

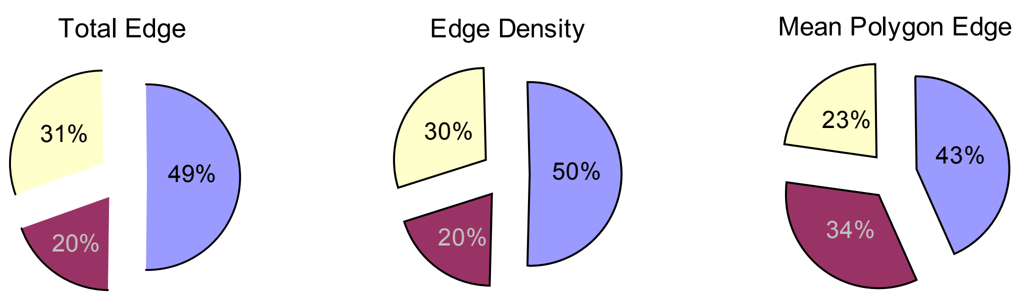


Figure 12 – Region Edge

The final set of summaries generated attempted to quantify shape complexity for each of the delineation types. Shape complexity was assumed to give an indication of the ability to delineate linear landscape features, or conversely, indicate the relative presence of delineation noise such as small spaces between trees or tracks in agricultural fields. The mean perimeter-to-area ratio (MPAR) suggests that the IRS/TM segments may have a greater shape complexity or simply a higher number of narrow regions. Alone, the MPAR did not give any indication about delineation precision versus delineation noise. When the mean region fractal dimension was considered, the shape complexity of each output appeared similar, suggesting that regions derived from the 5 meter data were delineating a higher number of small linear features. Larger, continuous and branching delineations would have resulted in a greater fractal dimension value and would potentially have less meaning in a land cover mapping context. Again when the shape complexity indicators were considered in conjunction with the visual evaluation, it was determined that 5 meter IRS/TM segments resulted in more precise land cover delineations with minor increases in delineation noise.

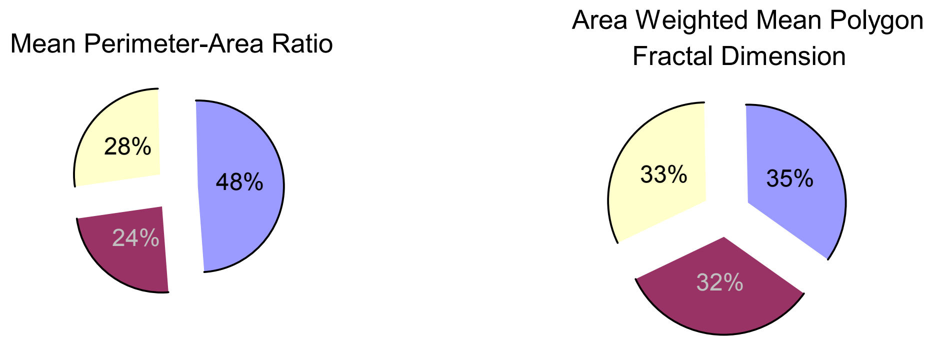


Figure 13 – Region Shape Complexity

Outlook

The apparent advantage offered by the higher spatial resolution IRS image when combined with the spectral resolution of the TM data traditionally used for land cover mapping, indicated that significant improvements can be made to the existing Regional map products. The process of landscape delineation will remain automated, consistent and repeatable while processing costs associated with image segmentation are estimated to increase only marginally. Most significantly, the ability to discern important landscape features not previously mapped will have the potential to increase map accuracy. Planning and resource staff who conjunctively use high resolution DOQQ images and mid resolution map products are also more likely to be satisfied with the map products. However, concerns remain over the cost of transitioning existing regionalized map products derived from 30 meter source data to regions based on 5 meter source data. These unknown transitional costs may become a significant barrier to implementing the processes described in this paper within the mapped portions of California.

In the initial effort to assess improvements in map quality and more precisely determine the cost of implementation, the Region 5 land cover mapping and monitoring program (LCMMP) will adopt these procedures in the southern sierra zone of California. This area is approximately 10 million acres, nearly half of which was delineated and mapped based on 30 meter LANDSAT imagery. The remaining acreage will be mapped for the first time under this program. Local Forest personnel will be given the opportunity to evaluate map regions and qualify them relative to regions in the existing maps. Accuracy assessments of the region based vegetation maps will also be conducted following map production. A cost-benefit analysis will likely determine the how much these data and procedures are used in the future of this program.

Aside from the benefits and costs to the LCMMP, the described methodology has potential for other mapping and monitoring projects. As the source image types described in this paper become widely available to USFS personnel in California, the ability to delineate smaller landscape and vegetation features than are allowable in the LCMMP map standards is significant. Specific habitat and land use concerns that may require information at the sub-acre level may benefit from a more efficient and lower cost delineation approach. More investigation will be required to determine the maximum potential of these data and evaluate procedures for collecting valuable resource assessment and monitoring information.

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