Development of a MODIS tree cover validation data set for Western Province, Zambia

M.C. Hansen, R.S. DeFries, J.R.G. Townshend, L. Marufu, R. Sohlberg

Abstract

One of the annual land cover products to be made from Moderate Resolution Imaging Spectroradiometer (MODIS) data is the vegetation continuous fields layers. Of these fields, one is a global percent tree cover map. Using field measurements, IKONOS data, Enhanced Thematic Mapper Plus (ETM+) data, and ancillary map sources, a tree cover map was made and validated for two WRS path/rows in Western Province, Zambia. This map will be used in validating the 500-m global MODIS tree cover product. The map was made at the 30-m Enhanced Thematic Mapper Plus (ETM+) resolution and also scaled up to 250- and 500-m resolutions. Five IKONOS images were classified into crown cover/no crown cover maps at 4-m resolution. These maps were aggregated to 30 m to create a continuous training data set of percent crown cover. Three dates of ETM+ data were acquired to predict percent crown cover using a regression tree algorithm. Comparisons of training accuracies and field data to ETM+ tree estimates yielded root mean square errors (rmse) of ~ 10% crown cover. When aggregating the 30-m map to 250- and 500-m MODIS cell sizes, the training errors are more than halved. The final 250-m map was assessed using a structural vegetation map of the area and an overall rmse of 8.5% is estimated. The 250-m map was sampled and used to derive a tree cover continuous field product using 3 Level 1B MODIS time slices, approximating the acquisitions of the ETM+ data. The results are promising as an overall root mean square error between the ETM+ derived tree crown cover map and an aggregated MODIS 500-m map was 5.2%. Results from this test in Zambia show that the MODIS 250-m bands should allow for improved depictions of percent tree cover.

1. Introduction

Global land cover maps are needed to aid researchers in earth systems science. Satellite imagery provides a data source for creating such global maps (Townshend et al., 1994). While a number of products have been created (DeFries et al., 2000; DeFries, Hansen, Townshend, & Sohlberg, 1998; DeFries & Townshend, 1994; Hansen, DeFries, Townshend, & Sohlberg, 2000; Loveland et al., 2000), only the International Geosphere Biosphere Programme’s DISCover product (Loveland et al., 2000) has been validated. This effort relied on regional experts to interpret high-resolution Enhanced Thematic Mapper Plus (ETM+) data and assign sites land cover labels. Difficulties associated with performing such a validation are many (Scepan, Menz, & Hansen, 1999). The strength of the DISCover validation was that it was based on a random sample, while a weakness was its reliance on regional interpreters. Using more precise data sources, such as very high-resolution imagery and in-situ data, would result in a better validation data test bed (Cohen & Justice, 1999). However, such an approach within a global random sampling scheme is, at present, impractical due to costs and access to sites. In lieu of a global sample, sites can be chosen for dominant biomes across the globe where access and data exist. These sites can then be used to evaluate and improve coarse resolution land cover products such as those produced with Moderate Resolution Imaging Spectroradiometer (MODIS) data.

This paper describes an effort to use high-resolution satellite data in conjunction with field measurements and ancillary map sources to create a validation data set for use with the MODIS 500-m tree cover continuous field. This initial foray is a test of the feasibility of combining these
various spatial scales of data for validating coarse resolution maps. The Southern African Research Initiative (SAFARI) 2000 (Swap & Privette, 1999) program afforded an opportunity to test mapping tree cover in a tropical woodland setting. In addition to its use in validating MODIS products, the map derived in this exercise will eventually be expanded to cover the area of the Kalahari transect (Scholes & Parsons, 1997) for use by ecosystem modelers and others who need cover information on fuel loads of annual biomass burning and other applications.

An excellent source of validation data is very high resolution satellite imagery (1–4 m), which have only recently become commercially available (Tanaka & Sugimura, 1999). While still an expensive option compared to other, coarser data, they afford the user a fine-scale tool for mapping without reliance on dated imagery. Table 1 outlines the general characteristics of the sensor. The work described here employed IKONOS data to map tree cover. Tree cover characterizations at very high resolutions have more frequently employed photo-interpretation methods to delineate cover such as in Miller et al. (1995) and Turner, Wong, Chew, and Ibrahim (1996). Manual methods are limited in their application due to a lack of objectivity and prohibitive time requirements. More automated approaches have used image processing techniques to map tree cover using digital aerial photographs (Gougeon, 1995; Kadmon & Harari-Kremer, 1999). Automated approaches are the more practical choice for mapping, especially since one goal of this work is to develop a repeatable procedure which could be used at various sites globally.

In this study, the IKONOS data are used to create a 30-m training data set for use in characterizing ETM+ imagery. The result is a 30-m continuous tree cover map, which is then aggregated to MODIS resolutions for use in testing and validation of MODIS products. To measure the success of the approach, in-situ tree cover measurements as well as ancillary maps are employed to evaluate the final map product.

2. Data

2.1. IKONOS imagery

Five IKONOS images were acquired for use in developing a percent tree crown cover training data set. Table 2 shows the scene centers and associated vegetation cover types for these footprints. In addition to the individual bands listed in Table 1, simple average, standard deviation, and average standard deviation texture measures were created using 3 × 3 and 5 × 5 pixel kernels. Normalized Difference Vegetation Index (NDVI) was also calculated as well as NDVI texture measures like those in the individual bands. The total number of image layers used to classify crown

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<td><strong>IKONOS specifications for images used in this study</strong></td>
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<tr>
<td>Scene footprint</td>
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<tr>
<td><strong>IKONOS site locations and dominant vegetative covers from “Landscapes and Grasslands of Western Province, Zambia” (Jeanes, 1991)</strong></td>
</tr>
<tr>
<td>IKONOS site</td>
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<td>-----------------------------------------------</td>
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<tr>
<td>West of Kahoma, Liande, Zambia</td>
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<td>East of Luuku, Kanoti, Zambia</td>
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<td>South of Mongu Namushakende, Zambia</td>
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<td>North of Senanga, Itufa, Zambia</td>
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<td>Near Maziba, Zambia</td>
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Fig. 1. Enhanced Thematic Mapper Plus false-color composites for WRS path/rows 175/070–071: (a) April 4, 2000 with crosses marking centers of IKONOS acquisitions; (b) June 29, 2000; (c) August 16, 2000.
cover was 35. At the IKONOS resolution, identifying many
tree canopies is aided by including local variability measures.
The measures here are similar to those of Coop and Catling
(1997) where the spatial resolution is not successively
degraded, but kept at the original 4-m cell size. Coop and
Catling found that in keeping the original resolution, the
local variance does not fall substantially, much like a semi-
variogram. The $5 \times 5$ window was chosen as the maximum
filter size by inspection of the images and that the typical
object size, or crown size, was captured at this scale.

2.2. Enhanced Thematic Mapper Plus imagery

Three ETM+ images were used to estimate percent tree
cover. A wet season image dated April 4, 2000 was the
clearest peak greenness image available in the ETM+
archive for path/rows 175/070–071. Peak greenness con-
dition imagery is necessary for mapping tree cover, as many
seasonal tree types such as drought deciduous formations
become difficult to map during off-peak conditions. Multi-
temporal imagery is needed to improve differentiating tree

dard

![Graphical plot](https://example.com/plot.png)

Fig. 2. Graphical plot adapted from Jeanes (1991) for the map “Landscapes and Grasslands of Western Province, Zambia.” The class names and descriptions are from the map and the tree cover ranges associated with each are shown. The mean value for each class is taken as the tree cover validation value for comparison with the 250-m ETM+ derived crown cover map.
cover from other cover types which may be confused in a single image. Thus, two other images which captured the transition to the dry season were also used. These images date from June 29, 2000 and August 16, 2000. The three images, along with IKONOS acquisition sites, are shown in Fig. 1. Clouds were present in ~20% of the April image and mapping these areas required special attention because of the presence of clouds and their shadows. Additionally, imagery was used for reference in the field and archival Landsat 5 Thematic Mapper (TM) data were obtained for the area.

2.3. Field data

Field surveys of tree cover were conducted on March 7–19, 2000. Work was performed in 4 TM path/rows (174/071, 174/072, 175/070, 175/071) which cover over 80% of Western Province Zambia. Over 40 sites were visited, 21 of which fall within the area covered in this analysis. Cloud-free imagery for the ETM+ sensor during the growing season has not yet been acquired for path/rows 174/071–072. This area will be added to the data set upon acquisition and analysis of these images. The cover types measured ranged from dense Cryptosepalum exfoliatum evergreen forest to Brachystegia spiciformis woodlands on Kalahari sand and Burkea africana open woodlands. Two grassland sites were also recorded. Baikea plurijuga (teak) forests are absent here but were visited in the adjacent TM imagery of WRS 174071/072. A number of the sites exhibited degradation from human disturbance, but since the data acquisitions are coincident with the field work, land cover change should not impact this analysis.

Two orthogonal transects were traversed at each site. Each transect measured 90 × 10 m and was centered on a 3 × 3 pixel array. A total of 105 observations of the presence or absence of crown and canopy (foliar or overstory) closure were taken for each site using a visible laser aimed orthogonally at the sky. In this instance, a tree was measured as any woody vegetation at least 5 m in height. The laser was set at 1.5 m, and any vegetation with a height of 2–5 m was also measured for interception by the laser and recorded. A clinometer was used to measure tree heights. Tree crown cover is defined as the percent of ground covered by crowns, including skylight, of trees greater than 5 m in height. Tree canopy cover is taken as the percent of skylight orthogonal to the surface which is intercepted by trees of at least 5 m in height (crown cover = canopy cover + within crown skylight).

2.4. Ancillary map sources

Two maps were used as validation databases, both of which referenced aerial photos and field visits to map vegetation types in western Zambia. The primary one used was “Landscapes and Grasslands of Western Province, Zambia” (Jeanes, 1991). This map has a detailed description of woody cover and a useable estimate of tree cover could be obtained from it. Fig. 2 shows the tree cover categories and the mean estimates used as validation for this work. A small portion of the imagery in the south occurs outside of Zambia in Angola for which there was no ancillary data available. Another portion in the north occurs outside the primary Western Province map, and another country-wide vegetation map, “Vegetation Map of Zambia”, (Edmonds, 1976) was used to analyze pixels in this area. The Western Province map was preferred over the Edmonds map as it has a greater number of cover classes, including disturbance classes which are absent in the Edmonds map.

2.5. MODIS data

Three 250-m and 500-m images of MODIS level 1B data were georectified to the ETM+ data. These raw data were chosen based on the need to have a peak greenness image in the study. The best available growing season image found in the browse files was for day 140. This predates any of the thorough processing of the global MODIS archive. All seven bands along with derived NDVI were used for three dates which approximated the timing of the ETM+ images. The MODIS daily browse imagery were examined and the 1B data which had the best view geometry and least clouds were chosen. The dates of these images were May 20, June 25, and July 27, 2000.

3. Methods

The procedure used is outlined in Fig. 3. An example of the progression of product derivation through resolutions is shown for one of the IKONOS acquisitions in Fig. 4. IKONOS data were classified into crown and no crown classes and aggregated to proportions of tree crown cover within 30-m cells. Typically, the imagery used to map crown cover at very fine scales is near or less than 1 m (St-Orange & Cavayas, 1995), but only using the 1-m panchromatic band was deemed impractical. Advanced methods of characterization using a single band in conjunction with texture measures such as semi-variograms are beyond the scope of this work. Much of this kind of work has been performed at the single stand level with intensive field measurements (Cohen & Spies, 1990; Levesque & King, 1999). A possibly less robust but simpler approach is used in this analysis, where crown cover is directly classified using the multi-spectral 4-m IKONOS bands and indices described earlier. The panchromatic band was used as a visual aid in interpreting the 4-m data.

The IKONOS-derived 30-m training data were used in the regression tree analysis to produce the ETM+ percent tree cover layer. But first, a cloud and cloud shadow mask for the April image was created using a combination of tree classification and photointerpretation techniques. The mask was then buffered for three pixels on all sides in order to
assure that almost all clouds and shadows were eliminated. Two regression trees were then produced, one using three dates and one using two dates for cloud-affected April pixels. Percent crown cover was the dependent variable in a regression tree analysis of the ETM+ bands 1–5 and 7 from the three/two image dates.

Regression tree analysis has been used with remotely sensed data (DeFries et al., 1997; Michaelson, Schimel, Friedl, Davis, & Dubayah, 1994; Prince & Steininger, 1999). It is a flexible, nonlinear tool for predicting a continuous variable such as tree cover. For this study, 10% of the available training was used to grow the regression trees. Another 10% was then run through that existing tree object in order to prune it to an appropriate size. Trees typically overfit the data and a tree pruning exercise is required to produce a more generalized model. The additional 10% sample is used to give an indication as to where the overfitting begins. These data were run down the tree until a point was reached where the sum of squares were no longer being reduced within nodes, but actually beginning to increase. The decision to prune the tree for this work was made where an additional node added less than 0.01% additional explanation in reducing the sum of squares as compared to the data’s overall sum of squares in the root node. The method parallels the approach for the operational MODIS continuous field algorithm and includes the use of a stepwise regression at each node to fine-tune the regression tree result.

Assessments were undertaken at each step of the analysis to measure the procedure’s robustness. First, training accuracies were determined. Training accuracy here means testing the algorithm’s ability to reproduce the training values. This would typically require having a portion of the training sites set aside for testing. For this work, all of the training, the 10/10% sample was randomly generated. Since subsequent comparisons are performed at aggregated cell sizes, where pixels from the original sample are mixed with pixels not used in training, it was deemed that using all of the IKONOS-derived training would allow for a reasonable comparison of training accuracies across scales.

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The IKONOS data do not represent a random sample of the study area. Deriving an overall map accuracy using the IKONOS data is not possible. Even if a cross-validation approach to test training sites was used, the underlying problem of not having a random sample remains. The primary use of training accuracies for this exercise is to yield an indication of the separability of the sites used and to say whether or not an efficiency is created via resampling to a coarser grid. This can give a good indication on the

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Fig. 3. Flow diagram of procedure in multi-resolution approach to mapping crown cover.
Fig. 4. Example of progression from IKONOS to MODIS for the Senanga IKONOS acquisition. (a) False-color infrared composite of IKONOS bands 4-3-2; (b) crown/no crown classified map; (c) percent crown cover training from IKONOS aggregated to 30-m cells; (d) result of ETM+ characterization of percent crown cover; (e) ETM+ result aggregated to 250-m MODIS resolution cells; (f) crown cover map made from MODIS data using data from ETM+ aggregated 250-m map.
Fig. 5. ETM+ and MODIS NDVI composites. (a) ETM+ NDVI overlay for following dates—red = April 4, 2000, green = June 29, 2000, and blue = August 16, 2000. (b) MODIS NDVI overlay for following dates—red = May 20, 2000, green = June 25, 2000, and blue = July 27, 2000. Blue-green colors in the Bulozi floodplain show the lack of green vegetation due to inundation in April and May. Red in the south shows the onset of the dry season and burning for June to August which result in low NDVI values. White in the northeast reveals the high NDVI values for all months and the evergreen nature of the *C. exfoliatum* woodlands located there.
improvements in accuracy gained by resampling the fine-scale map output to coarser grid cell sizes.

The second assessment consisted of comparisons with field data. The two major problems with the field data are (1) indeterminate exact geolocation and (2) the lack of a spatially random sample, as with the training data. The field sites were chosen in a way to ensure homogeneous cover by examining texture images of the archival TM data and evaluating homogeneity on the ground. This field work was performed before the elimination of selective availability, an introduced error which resulted in displacements of up to 100 m for global positioning satellite receivers (Langley, 1997). As a result, errors associated with the ETM+ sensor blurring sharp boundaries are not quantified. A benefit of the field data is that it can be used to test the measure of agreement between the output map product and a sample of in-situ measured field sites chosen to represent the various tree cover strata present in the imagery. Another benefit of the field data is that it allows us to take the interpreted variable from the IKONOS imagery, that of crown cover, and derive a relationship between it and the other variable of interest, canopy cover.

The third assessment was a statistical sample of existing structural vegetation maps for comparison with the map product. This exercise is meant to provide a reliable accuracy estimate for the 250-m ETM+ derived map. The “Landscapes and Grasslands of Western Province, Zambia” and “Vegetation of Zambia” maps use a similar classification scheme as the one for the continuous fields. For example, the maps define trees as 5-m-tall woody plants and a sequence of tree canopy cover strata from forest to woodland to savanna to grassland is defined based on this definition. The maps also allow for a statistically random spatial sample to be taken for assessing the overall and per stratum accuracies of the map output. The major limitation of this approach is that the canopy cover estimates are made based on class labels as the map itself is not a depiction of a continuously varying tree cover. The primary map, “Landscapes and Grasslands of Western Province, Zambia,” was scanned and georegistered. This map has a scale of 1:500,000, meaning that a 250-m² area is represented as a 0.5-mm² on the map, approaching a point in practical terms. A cursor of this size was used with the scanned map to locate sample points.

The 250-m map, created by aggregating the ETM+ data, was divided into five strata which represent general tree cover classes provided by the Global Observations of Forest Cover (GOFC) framework (Ahern et al., 1999). The strata were 0–10%, 11–25%, 26–40%, 41–60%, and >60% tree canopy cover. Each stratum had 25 sites randomly selected from the 250-m map. The latitude and longitude coordinates for these sites were then plotted on the Western Province map. Based on Fig. 2, each point was assigned a single class cover value. Out of the 125 points, 28 were along or near the boundaries of two classes, but only a single class was taken for each point. None of the sites fell outside of the map boundaries in Angola. Thirteen were located in Northwest Province, outside of the Western Province map. For these points, the “Vegetation Map of Zambia” (Edmonds, 1976) was referenced and numbers assigned by crosswalking the Edmonds class to one from the Western Province map.

Three MODIS images were georegistered to the aggregated 250-m data for use in a test of the ability to use MODIS to map percent tree crown cover. Fig. 5 shows three overlain NDVI time planes for the ETM+ and MODIS 1B data. The dates are slightly different as are the enhancements, however, the general phenological variation is comparable. The colors clearly show the fluctuation of water in the Bulolo Plain, the onset of burning and senescence in the south, and the evergreen foliage of the forests in the northeast. From the 250-m map, a 10% sample was taken to grow a regression tree, and another 10% taken to prune the grown tree. The approach mirrors that of the ETM+ map production. After the map was made, the output was aggregated to 500 and 250 m, and 500-m comparisons were made.

4. Results

4.1. Classifying IKONOS data

The final IKONOS classifications were compared to the traced training areas. The average training accuracy for all five IKONOS images was 86.7%. The texture indices were of great use in separating crowns, particularly the variability of the near-infrared (NIR). In the classification trees created for each IKONOS image, texture measures dominate as high local variability due to illuminated and shadowed areas of crowns is characteristic of trees. Local variance values of the NIR were found to relate to forest structure variables by Coop and Catling (1999). Of course, some stands are of such a continuous, smooth structure that high local variance values are not useful and metrics other than NIR local variance are used.

The greatest difficulty in mapping the IKONOS data was defining shadowed areas as crown or no crown. Even in the 1-m data, these distinctions were not easily made. Fig. 6 shows a training site from one of the IKONOS images. This is a marginally successful depiction with an overall agreement of 75%. The root mean square errors (rmse) of the IKONOS training to the IKONOS predicted at 30 m for this site is 9.64%. The rmse of the ETM+ result to both the IKONOS training and classification result is 13.81% and 13.05%, respectively. The total crown cover for the 300 × 300 m training site is 57.9% for the IKONOS training data, 56.2 for the IKONOS classification result, and 57.6 for the ETM+ crown cover depiction. Two facts are important to note from this figure. First, even though the rmse between the three depictions is near or greater than 10% crown cover, the total crown cover for the area, about the size of a
Fig. 6. IKONOS training site from Kahoma acquisition. (a) One-meter panchromatic band; (b) 4-3-2 composite; (c) training and classification results: green = crown agreement, yellow = no crown agreement, blue = omission error, red = commission error; (d) IKONOS training aggregated to 30 m; (e) IKONOS classification result aggregated to 30 m; (f) ETM+ 30-m characterization from regression tree analysis.
MODIS pixel, is almost identical. Second, the ETM+ imagery exhibits adjacency effects which preclude the sharp delineation of tree cover seen in the IKONOS image. Both the high and low ends of the data are smoothed out in this case. The functional resolution of the ETM+ is greater than 30 m when sensor modulation transfer and point spread functions (MTF and PSF) are included. Townshend et al. (2000) tested these effects and warn data users to beware making per pixel characterizations. It appears that the ETM+ pixels should be either deconvolved or resampled to a coarser scale to reduce the impact this blurring has on boundary delineation. This could also be done by resampling the product to a coarser scale, as was done in this study.

The high end of crown cover in the IKONOS imagery proved somewhat problematic. When crowns begin to touch and overlap, the mixing of shadow, canopy, and ground leads to some difficulty in accurately estimating crown cover. Small gaps are indistinguishable and even larger gaps and shorter trees can be obscured in shadow. Field measurements for forest sites, including B. plurijuga and C. exfoliatum forests, had crown cover values around 80%. Based on this fact, the high end of the 30-m aggregated IKONOS training was scaled. Values from 60% to 100% crown cover were scaled to 60% to 80% crown cover.

### 4.2. Characterizing and aggregating ETM+ data

A comparison of the final 30-m ETM+ predicted tree cover versus training values for all of the IKONOS interpreted sites yielded an rmse of 10.97% crown cover and an $R^2$ of 0.70. The median error was ±8%, while fully 10% of pixels were in excess of 27% error. The larger errors are associated with two aspects of the imagery. First, as shown in Fig. 6, the loss of clarity in the ETM+ imagery leads to

<table>
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<th>Map resolution (m)</th>
<th>Overall rmse</th>
<th>0–10%</th>
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<td>30</td>
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Fig. 7. Root mean square error comparing field measured crown cover to ETM+ predicted crown cover (square symbols), and for comparing field measured canopy cover to ETM+ predicted canopy cover (diamond symbols). The ETM+ values for comparison are associated with the individual pixel for the center of the field site and averages of 30-m pixel kernels of shown configurations.

Fig. 8. Plot of field measured crown cover versus ETM+ predicted crown cover for pixel where center of site was located. Solid line is the 1:1 line. Dotted line is derived relationship, describing the reduced major axis. Bold squares represent the class boundaries of GOFC tree cover strata.

Fig. 9. Plot of field measured crown versus canopy cover.

Fig. 10. Plot of field measured % crown cover versus ETM+ predicted crown cover for center pixel.
many errors where there are sharp tree cover boundaries. Secondly, in the spectral domain, there are isolated pixels which are inseparable, even given three dates and six bands of ETM+ data (see the center of the upper left dambo in Fig. 4d).

A test of the predicted crown cover for the three date analysis versus the two date analysis yielded an rmse of \(9\%\) crown cover with a median error of \(5\%.\) The larger errors were almost exclusively associated with the flooded grassland formations. The two date products could not accurately delineate the grasslands. The use of only the June and August images caused difficulties in mapping the grasslands of the Bulozi Plain and some dambos. The April image has dramatically different signatures for many grasslands which for that time are inundated. Not having those signatures leads to some errors in the cloud masked area.

Resampling both the training data and the map output to a 250-m grid increases the \(R^2\) to 0.88 and the rmse falls to 5.88\% and the median error to \(\pm 5\%\) of the predicted value. Only 10\% of the pixels have errors in excess of 13\% crown cover. Table 3 shows these results and those of a 500-m comparison. The benefits of resampling to a coarser grid are obvious as both the ETM+ and training pixels are blurred and per pixel sensor limitations are partially overcome. Also, the last few inseparable spectral signatures between very different canopy cover classes can be washed out or minimized via aggregating.

4.3. Comparison of 30-m map with field data

The field data sites were tabulated and plotted against various kernels of the ETM+ tree cover output. Fig. 7 shows the various kernel arrangements along with results comparing the estimated crown cover to the field measured crown cover. There is no significant variability seen between kernel figurations and this is taken as evidence that in general, the geolocation problem was minimized by selecting homogeneous sites. Individual sites could still exhibit signature extension problems, but for these sites no such problems are evident. A plot of the center pixel ETM+ crown cover prediction versus the field measurements is shown in Fig. 8.

All misses within the boundaries of tree crowns were noted and a strong relationship between field measured crown and canopy cover was found (\(R^2 = 0.98\)). The plot of canopy versus crown cover can be seen in Fig. 9. This allowed for an adjustment of the crown cover to predict
Fig. 12. Comparison of crown cover estimates for (a) ETM+ derived map aggregated to 250 m, and (b) 250-m MODIS crown cover map produced by sampling 20% of (a).
canopy cover (canopy = 0.76*crown). The field canopy cover values are plotted against the ETM+ canopy cover estimates in Fig. 10. The field data for canopy cover compared to the scaled ETM+ canopy cover map resulted in an average error for the ETM+ kernel configurations of 8.1% canopy cover.

4.4. Comparison of 250-m map with ancillary map sources

The data from the 250-m resampled ETM+ map and the validation values from the maps are plotted in Fig. 11. The overall area weighted average error was 8.5%. The errors are further explained in Table 4. While this approach is inexact given the categorical depiction of tree cover in the Western Province map, the numbers provide an indication that the typical range of errors for this map are within the range of traditional tree cover classes such as those of the five strata used here. The least accurate stratum in this comparison is the open woodland class. This reveals the predominance of the woodland class in both the Western Province and Zambia maps. The range of cover for this class is 30–80% for the Western Province map and 40–60% for Edmonds’ Zambia map. We feel that the continuous field approach, where training is created on actual intermediate cover pixels, yields explicit results for this entire range and should be an improvement over the existing maps for this area. The use of broad categories over large canopy cover ranges is unable to capture the actual variability of cover which is present in the satellite signal. The evaluations undertaken here show that it is possible to capture this variability and map it in a continuous fashion.

5. Experimental mapping with MODIS data

The final part of the analysis involved using actual MODIS data in mapping the area of study. Ultimately, a global MODIS product will be used for comparison. As that has yet to be generated, a map using level 1b MODIS data was made. The map was generated using a 20% sample of the validation data set. Since the training sites for the MODIS data come directly from the validation data set, this is not a true validation example. It represents a test of MODIS data in mapping the area of study. Ultimately, a map using level 1b MODIS data can be scaled using this relationship to estimate canopy cover. Performing such an adjustment assumes that this relationship exists across the region or biome. Certainly, different species of trees have different canopy cover values. However, each of these transects represents an integrated measure of tree stands of various composition and range from C. exfoliatum-dominated broadleaf evergreen forests to more seasonal B. spiciformis, B. africana, and Guibourtia coleosperma woodlands and savannas. While making such an adjustment could take a more complex form, where various stands each had their own adjustment function, the evidence for this area shows that a simple approach may be possible at this resolution. A more intensive effort where a species or ecoregion-based adjustment is sought is beyond the scope and resources of this work.

The comparison of the 250-m aggregated map to the Western Province map resulted in an rmse which indicates the 250-m data to be an accurate portrayal of tree cover. Congalton and Green (1999) point out the limitations when using existing map sources for validation. First, there is the difficulty in comparing different legends. The adjustment of a map legend to conform to the new map’s legend is inexact. Second, existing maps are older and some have likely changed. Third, the errors of the source map are unknown and disagreements are labeled errors in the new map. These potential errors tend to cause an unknown overestimation of the errors in the satellite-derived products.

Examining the few pixels which have the greatest disagreement, some educated guesses can be made about the sources of the errors. First, it appears that B. plurijuga (teak) forests are overestimated in the ancillary map. Only one sample point was located within the teak forests in the ancillary map, and the predicted tree cover for that site was 18%. Interpretation of the imagery afterward showed there to be fewer and smaller areas of dense tree cover within the teak areas than indicated on the maps.

Three samples were characterized in the ancillary map as degraded woodland and bushland thicket. For these sites, the 250-m map overestimated tree cover. It is probable that consistently mapping woody cover at the 5-m height threshold is unreliable. It cannot be expected that dense woody cover of 4 m in height will be distinguished from the same formation at 6 m in height. While height cannot be directly measured using multi-spectral imagery, tall, dense stands can largely be discriminated from other covers. While in any given scene at a particular time, a grassland may be spectrally equivalent to a woodland, over time the phenology of the two will diverge enough for there to be a
successful discrimination. Identifying the cover types where such discrimination is not possible would be of benefit to data set users. It appears possible that the degraded woodland and bushland thicket class is one such example.

Many uses of land cover in modeling employ the land cover class as a label to attribute various biophysical parameters. The continuous field approach offers many advantages over classifications in allowing the user to define his or her own classes of interest via thresholding. However, the results here illustrate another advantage. The root mean square error allows the user to recognize whether the magnitude of errors present is acceptable in a manner more easily interpreted than a classification accuracy. For example, if the measurements from the field data are converted to the five-class scheme, an accuracy of only 65% results. However, the rmse of 11.1% reveals, as does Fig. 8, that the errors are most likely in adjacent cover classes. In other words, all errors are not equal and some may have no impact on the user’s analysis (DeFries & Los, 1999). This can be divined in a confusion matrix, but not as easily with a single value as the rmse. Errors present in Fig. 8 are not as destructive to an analysis as errors between, for example, forest and grassland. Users who could partition their biophysical properties to a continuous set of variables tied to the continuous tree cover values will further reduce the impacts of reference map errors.

A comparison made with the data from the ancillary Western Province map shows similar results. Again, the assignment of mean class cover values to the map is an oversimplification which probably underestimates map accuracy. However, when converting the continuous field to the GOFC classes and comparing to the classes in the map, an accuracy of 56% is achieved (Fig. 11). However, 90% of the sampled sites are classified correctly or in an adjacent cover class. The rmse value of 9.8% for the 125 sites provides a level of confidence much diminished when using class labels.

7. Conclusion

Multi-scale remote sensing data sets can be used to aid in large area mapping projects. The results here show that very-high resolution data sets allow for the direct interpretation of the variable of interest, while multi-temporal, coarser data sets allow for the mapping of that variable over a wide region. In situ measurements and ancillary map sources help to provide an estimate of the product’s reliability.

However, a number of issues remain to be resolved. First and foremost is the need to develop statistically rigorous sampling procedures for validating the intermediate level characterizations using the ETM+ data. Relying on ancillary map sources is not prudent, as they may not exist, or be of suspect quality. The optimal method would include enough ground sites randomly selected to provide a definitive rmse for the output map. However, access to sites is a problem almost anywhere. In Zambia, it is the lack of infrastructure that is the primary limitation. In the United States, access would be most limited by sites on private property. Costs of site access will have to be incorporated into sampling procedures. Another issue is the ability to relate the IKONOS-interpreted variable of crown cover with the in situ measured canopy cover variable. These relationships may not be so easily estimated for all biomes.

Work is ongoing to refine the approach and apply it for a number of sites representative of dominant biome types. Initial site locations are in the conterminous United States and will cover 2–3 ETM+ footprints as the Zambia prototype did. Current work is focused on maximizing field data collection efficiency, including the possible use of digital cameras to quickly gather canopy data as in the MODIS Bigfoot validation project (Campbell, Burrows, Gower, & Cohen, 1999). A standard procedure of in-situ data collection such as that of Bigfoot could allow for a globally reproducible, standardized validation technique. This would remove the need for relying on ancillary data sets for validation.

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