USING FOREST INVENTORY PLOT DATA AND SATELLITE IMAGERY FROM MODIS AND LANDSAT-TM TO MODEL SPATIAL DISTRIBUTION PATTERNS OF HONEYSUCKLE AND PRIVET

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ABSTRACT

Forest inventory and analysis data monitor the presence and extent of certain non-native invasive species. On forestland, non-native species are considered part of the understory vegetation and can be found near canopy openings as well as and the forest edge. The objective of this study is to incorporate the presence of select non-native species into forest classification modeling procedures and determine the accuracy for producing non-native species spatial distribution classifications. A secondary objective is to compare classification accuracies of the different spatial resolution data (Landsat-TM and MODIS), which suggests that an increase in resolution provides an increase in overall accuracy. The classification results provide forest distribution combined with non-native species occurrence for honeysuckle (Lonicera spp.) and privet (Ligustrum spp.). Subsets of the plot data are used in a decision tree modeling process (See5) applied to the satellite data (Landsat-TM, MODIS), and ancillary data to classify the land cover and model privet/honeysuckle spatial distribution. Classification results show that overall classification accuracy for the percent of pixels correctly classified (%PCC) increased from 67.5% to 72.5% (privet) and from 67.5% to 70.0% (honeysuckle) when privet and honeysuckle are coded as present in the plot. Comparisons between overall classification accuracy show a 5.0% increase for privet, and 2.5% for honeysuckle. A comparison between MODIS and Landsat-TM classifications shows a 3.7% increase in accuracy when both privet and honeysuckle are coded in several categories based on their percent of participation on the plot. Classifications from Landsat-TM and MODIS models show a higher confusion in the privet/honeysuckle categories (percent privet or honeysuckle on plot), however the Landsat-TM model performed slightly better.

INTRODUCTION

Aggressive competitive behavior of non-native invasive species results in economic and environmental harm to the ecosystem through a variety of causes and effects: replacing or displacing native vegetation, reducing species diversity, producing changes in forest ground flora, depleting soil moisture, reducing quality of recreational opportunities, and suppressing forest regeneration. Humans, birds and wildlife, catastrophic events, climatic and soil factors have an important contribution in the spread of invasive species. Effective control of invasive species spread requires reliable information concerning the rate of spread, dispersal capability, soil properties, and good spatial distribution knowledge. Satellite remote sensing is an important tool for forest management and for surveying vast areas of forest and non-forest land.

Improved parametric and nonparametric classification algorithms allow ancillary data (slope, soil type, vegetation indices, merged information from sensors with different resolutions, etc.) to be incorporated into the original satellite data as new channels. Classification accuracy can be improved when the original spectral channels are combined with ancillary data that are included as additional channels in the classification process (Ricchetti, 2000; Chavez, 1986; Borry et al, 1990; Pellemans et al, 1993; Vogelmann et al 1998; Salajanu and Olson, 2001). In the last few years, classification and regression tree analyses have been implemented in several software programs and were used in many remote sensing applications (Huang and Jensen, 1997; Lawrence and Wright, 2001; Cooke and Jacobs, 2005).

Forest Inventory and Analysis collects annual measurements on a portion (20%) of all land in order to form rotating panels. Forest inventory plot data, ancillary data, and satellite images can be used in a nonparametric algorithm (See5, Cubist) to classify forest/non-forest land cover, model biomass at the national level (Blackard et. al., 2008), and classify forest types for the conterminous U.S. and Alaska (Ruefenacht et al., 2008). Invasive species information that is collected by forest inventory has some limitations since FIA does not collect data on non-forested lands. Nevertheless, forest inventory data provides important information related to invasive species presence and location.

The objective of this study is to incorporate the presence of select non-native (privet, honeysuckle) species into our forest classification modeling procedures and determine the accuracy for producing non-native species spatial-distribution classifications. A secondary objective is to compare classification accuracies of the different spatial resolution data (Landsat-TM and MODIS), which suggests that an increase in resolution (smaller pixel) provides an increase in overall accuracy. The classification results provide forest distribution patterns combined with non-native species occurrence for honeysuckle (*Lonicera spp*.) and privet (*Ligustrum spp*.).

STUDY AREA

The geographic location for this study includes the portion of Landsat scene path 17, row 37 within the state of South Carolina. It includes small portions of the USGS mapping zones 54 and 58, and portions or whole pieces of the nineteen counties in South Carolina. The study area consists of diverse landforms and land cover/use types such as forests, agricultural lands, open spaces, urban areas, low populated rural areas, bodies of water, and wetlands. Southern conifer forests are the dominant forest type followed by the mixed conifer-hardwood and hardwoods. Hardwoods forests consist of mixed broadleaf species throughout the area. The study area is approximately 70-75% forest and includes 806 FIA plot locations

FOREST INVENTORY PLOTS

The national forest inventory field plot design consists of four subplots approximately 1/24 acres in size, for collecting data on forest trees with a diameter at breast height of 5 inches or greater (Figure 1). Each subplot contains a microplot of approximately 1/300 acre in size for collecting information on seedlings and saplings.

Geographic coordinates are recorded for every forested plot using a Global Positioning System (GPS) receiver at the center of subplot 1 and labeled plot center (PC). For this study, a set of 806 plots (592 forested, 205 non-forested, and 9 water) was extracted from a complete 5-panel dataset in South Carolina. This set includes all of the 100% forested and 100% non-forested plots, as well as mixed plots that can have a mixture of forest, non-forest and water condition within the same plot. The 806 plots in the set include 79 plots with privet, and 192 plots containing honeysuckle. The privet plots consist of 74 plots having the plot center in the forest, and 5 plots with plot center in non-forest, while the honeysuckle plots have 179 plot centers in the forest and 13 in non-forest. This study area set was further used to create four subsets. The first subset consisted of forest inventory plots coded as forest, non-forest, water, and forested plots with privet. The second subset consists of forested non-forested, water, and forested plots with honeysuckle. In the next two subsets forested plots with privet and those with honeysuckle from the first two subsets were further divided into several classes, and coded based on the percent of privet or honeysuckle presence on the plot (trace< 1%, 1 – 10%, 11 – 50%, and 51 – 90%). These subsets were used to model privet and honeysuckle invasive species spatial distribution.

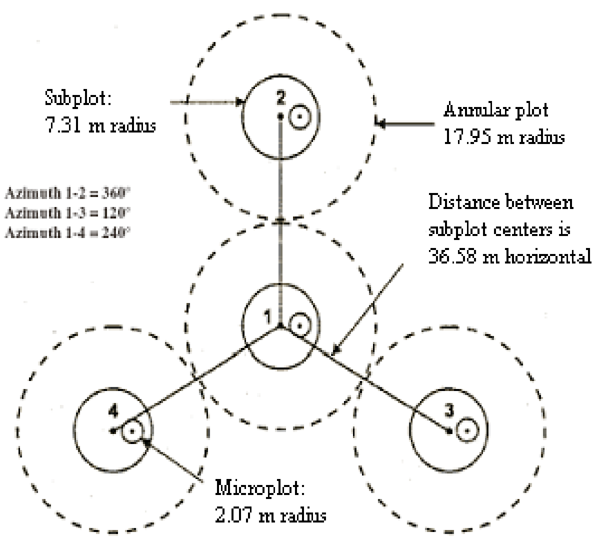


Figure 1. FIA field plot design.

DATA BASE DESCRIPTION

Satellite images with mid and high spatial resolution from two different satellite sensors, Landsat-TM, and MODIS were selected to model spatial forest distribution of privet and honeysuckle invasive species throughout the study area. The study area database consists of raster and vector data that fall within portions of the USGS mapping zones 54 and 58 and geographically intersect the portion of TM scene Path/Row 17/37 that falls within South Carolina. The study area data have been resampled as two different sets of data at 250 and 30-meter resolution. One data set contains 269 layers of data (49 are MODIS): a large number of ancillary and remote sensing layers re-sampled to a spatial resolution of 250 meters and projected to the Albers Equal Area projection. Multitemporal MODIS satellite data have been acquired for spring, summer, and fall of 2001, 2002, and 2003, while Landsat-TM is a single scene acquired in 1999. The second set contains 220 layers of data (six are Landsat-TM). The six Landsat-TM layers replaced the MODIS layers that were in the first data set. Landsat-TM layers were projected to the Albers Equal Area projection and the ancillary layers have been re-sampled to 30 meters spatial resolution. These data sets were used to classify/model privet and honeysuckle spatial distribution. Table 1 shows a small portion of the 269 layers that make up the first geo-spatial database.

The layers in the database either existed as 250-meter resolution data or were re-sampled to 250-meters and projected to Albers Equal Area projection by personnel at the USFS Remote Sensing Applications Center in Salt Lake City (RSAC). The database contains continuous and categorical variables.

Table 1. List of Layers Used to Map Forest, Non-forest and Forest Biomass**.**

Database Layers Description
MODIS 32 day composite imagery between 2001 and 2003 Conus MODIS32-2001097 - Bands 1 to 7 Conus MODIS32-2001193 - Bands 1 to 7 Conus MODIS32-2002129 - Bands 1 to 7 Conus MODIS32-2002225 - Bands 1 to 7 Conus MODIS32-2002257 - Bands 1 to 7 Conus MODIS32-2002321 - Bands 1 to 7 Conus MODIS32-2003161 - Bands 1 to 7 Conus Bailey's Ecoregions image layer MODIS Vegetation Indices Layers Conus EVI- 2002097 image Conus EVI- 2002321 image Conus NDVI- 2002097 image Conus NDVI- 2002225 image MODIS Vegetation Layer: MODIS –percent tree cover image Reflectance layers from spring, summer and fall of 2002 Conus Reflectance – 2002097 – Bands 1 to 7 Conus Reflectance – 2002225 – Bands 1 to 7 Conus Reflectance – 2002321 – Bands 1 to 7 NLCD layers; Conus NLCD – Percent conifer forest image Conus NLCD – Percent deciduous forest image Conus NLCD – Percent mixed forest image Terrain information; Conus dominant aspect, Conus mean elevation, stream density Conus MODIS fire points from 2001 and 2002 Soil data layers; available water capacity, permeability, soil bulk density, soil ph, soil plasticity, soil porosity, rock volume and soil texture. USGS mapping zone images Precipitation – annual and for each month Temperature layers – averages, minimum and maximum temperatures. …..

CUBIST AND SEE5

Cubist and See5 are regression tree software modules that are used to create decision tree classifications models (forest/non-forest) and models for modeling invasive species spatial distribution. See5 was used to classify/model the categorical variables, of forest, non-forest, water, and forest with privet or honeysuckle. Two files are essential for running Cubist or See5, and several others are optional. The first essential file is the names file that lists the names and describes the classes and attributes/predictors, as shown in Table 2.

Table 2. Names File Description**.**

```
FNF
FNF: 1, 2, 3, 4.
awc-250m.img-band1: continuous.
bdgrid-250m.img-band1: continuous.
conus-dvi-2002225.img: continuous.
conus-evi-2002097.img: continuous.
conus-modis32-2001097-albers.img-band1: continuous.
us_ppt01_jan.img: continuous.
us_ppt02_feb.img: continuous.
us_ppt03_mar.img: continuous.
us_tavg301_albers.img: continuous.
us_tavg302_albers.img: continuous.
us_tavg303_albers.img: continuous.
usgs_mapping_zones.img: 0, 54, 58, 59.
ustmax01_albers.img: continuous.
ustmax02_albers.img: continuous.
:
:
attributes excluded:
conus_modis32_2001097_albers.img_band5.
conus_modis32_2001193_albers.img_band5.
```

The first row/entry in the names file is the attribute (forest/non-forest, privet or honeysuckle) that contains the target value to be classified/modeled based on values of the other predictors. Predictors contained in the name file are continuous or defined by numeric values. The final entry in the names file specifies a list of predictor attributes that will be excluded from the classifier/model. The second essential file is the data file, which provides information on the training data used to construct the decision tree model. The entry for each case consists of one or more lines that provide values for all the predictors. A comma separates each values and each entry terminates with a period (http://www.rulequest.com). The test file is optional, and it is used to evaluate the performance of the classifier/model. There are several ways for assessing model predictive ability such as; collection of new data to check the model and its predictive ability, comparison of results with earlier empirical results, or the use of a holdout sample when a data set is large enough to check the model performance. In this study FIA, plot data have been split randomly 90% and 10% into data training and test files, respectively.

FOREST NON-FOREST INVASIVE SPECIES CLASSIFICATION

In this study, a See5 decision tree algorithm is used to model spatial patterns of the non-native invasive species, privet and honeysuckle, in association with forest cover. The classification model also includes forest, non-forest, and water. The geographic extent covers portions of USGS mapping zones 54 and 58 in South Carolina that fall within TM scene path 17, row37. A set of 806 forest inventory plots from a complete 5-year cycle of FIA data can be found in the geographic area. Attributes selected for these plots include forested/non-forested plots and plots containing privet or honeysuckle. Attributes in the study dataset generates four subsets, each containing all 806 plots. The first pair of subsets is for modeling privet and consists of inventory plots that are forested, non-forested, water plots, and plots containing privet. One subset is coded with a single class/category for presence of privet. The other subset is coded in several classes based on the categorical percent of privet on the plot. The second pair of subsets is similar to the first pair, except honeysuckle is coded as the single class variable for presence, and categorical class values based on the percent of honeysuckle present on the plot. Each of the four subsets is placed through two different trials (4 for each trial) to model separately, the spatial distribution of privet and honeysuckle.

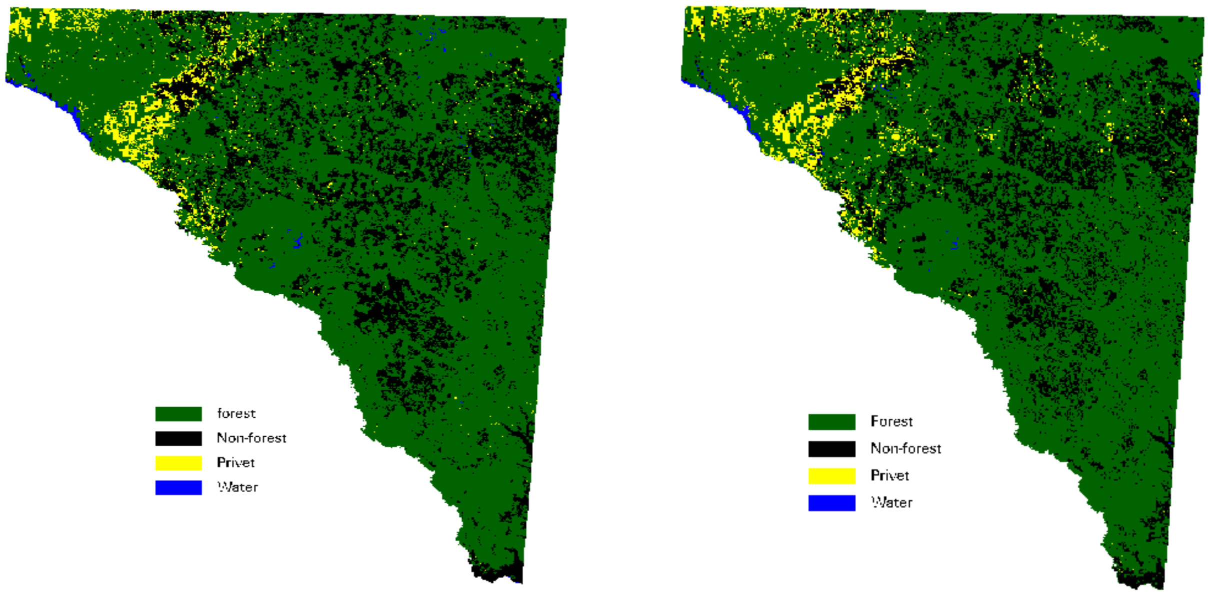
The four subsets and two trials produce an output of eight geo-spatial datasets. The first four output datasets are 30-meter resolution as applied to the Landsat-TM satellite data, and the second four outputs are 250-meter resolution, associated with the original data layer stacks for the MODIS satellite data. Output variables are the same as previously described for the input variable datasets. Separately, an iterative decision tree modeling process is applied to each of the eight output datasets to classify the land cover into forest, non-forest, water, and invasive species (privet and honeysuckle). Prior to the data mining process, the remote sensing and GIS data layers (satellite, ancillary and plot data) for each dataset are converted into See5 and Cubist data file formats through the use of ERDAS Imagine tool modules developed at the Remote Sensing Applications Center (Prepare FIA Data for See5 and Cubist, Apply See5 Results Spatially).

The "Prepare FIA Data for Cubist/See5" tool extracts geospatial data information using FIA plot locations. The process creates three data files for See5 (data file, name file, and test file), and randomly selects a dataset (10% for this study) to be set aside for accuracy assessment. The See5 program creates decision tree models. To create classification decision trees the boosting option is set to ten trials, and is the only selection used for this study. Each decision tree tries to correct the prediction error from the previous decision tree. This process continues for a pre-determined number of trials. Data file from each dataset (with TM and MODIS) is processed in See5 to create forest/non-forest, and invasive species (privet, honeysuckle) decision tree models. A sample of the output file from the See5 software program (Table 3) reports classification errors based on a confusion matrix produced for both training and test datasets.

Table 3: Sample of the See5 output showing the misclassifications from Landsat-TM**.**

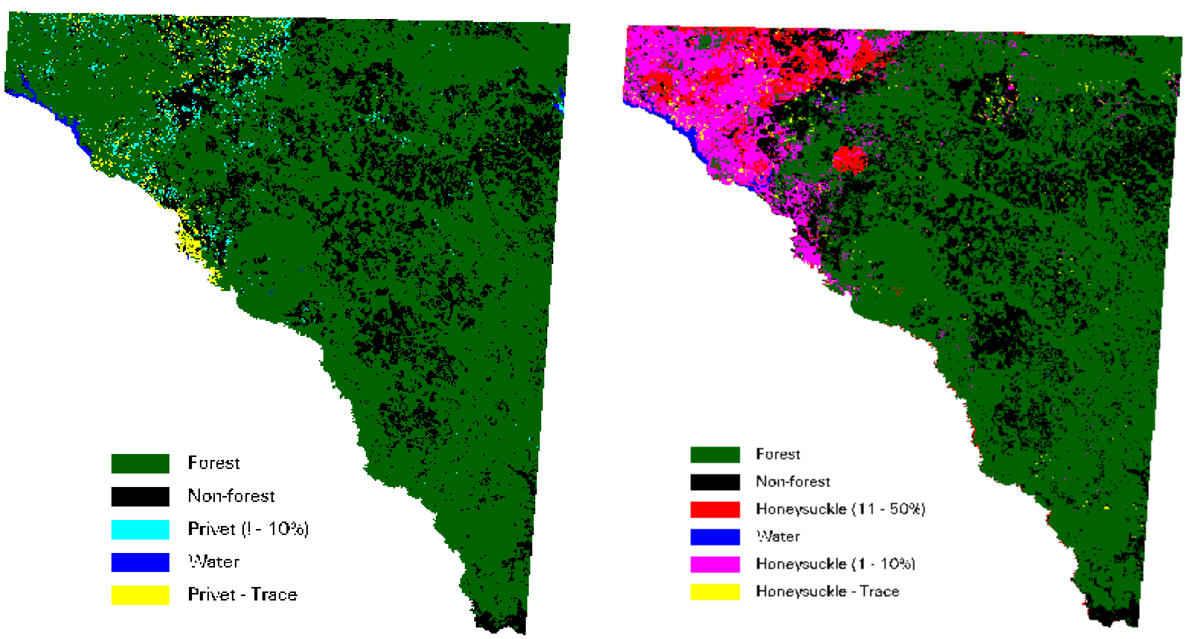
```
Options:
      10 boosting trials
Class specified by attribute `fnf'
Trial 9:  Decision tree:
SubTree [S1]
conus_tm6_albers.img_band6 <= 1: 4 (9.1)
conus_tm6_albers.img_band6 > 1:
:...conus_tm3_albers.img_band3 <= 14:
SubTree [S2]
conus_reflectance_2002321.img_band4 > 507:
conus_reflectance_2002321.img_band4 <= 507: 1 (254.9/22.2)
:...conus_modis_percent_tree_cover.img > 80.56: 2 (13.6/5.8)
   conus_modis_percent_tree_cover.img <= 80.56:
      :...us_ppt04_apr.img <=10467: 2  (36.6/11.6)
          us_ppt04_apr.img > 10467:  1  (14.5 )
  conus_tm3_albers.img_band3 > 14:
    bdgrid_30m.img_band10 > 2.64:  1  (42.3/14)
    :...conus_modis_percent_tree_cover.img > 67.852: 1 (18.4/4.3)
        conus_modis_percent_tree_cover.img <= 67.852:
Evaluation on training data (464 cases):      Evaluation on test data (308 cases):
Trial      Decision Tree                        Trial      Decision Tree
       Size      Errors                                Size     Errors
  0     98       36( 5.0%)                      0       98      37(46.3%)
  1     54      105(14.5%)                      1       54      24(30.0%)
  2     66      133(18.3%)                      2       66      26(32.5%)
  3     69       68( 9.4%)                      3       69      27(33.8%)
  4     80       88(12.1%)                      4       80      29(36.3%)
  5     68      112(15.4%)                      5       68      32(40.0%)
  6     71       79(10.9%)                      6       71      30(37.5%)
  7     87       97(13.4%)                      7       87      35(43.8%)
  8     70      107(14.7%)                      8       70      33(41.3%)
  9     69      101(13.9%)                      9       69      33(27.5%)
  boost           3(  0.4%)  <<                 boost           22(27.5%)
(a)  (b)   (c)   (d)   (e)  classified as         (a)   (b)   (c)   (d)   (e)  classified as
                            (a): class 0                                       (a): class 0
     466                    (b): class 1                 44     7     1        (b): class 1
           183              (c): class 2                  7    13     2        (c): class 2
      3          65         (d): class 3                  5           1        (d): class 3
                        9   (e): class 4                                       (e): class 4
```

The See5 decision tree model produced by See5 is used in the “Apply See5 Results Spatially” tool (in ERDAS Imagine) to spatially model the entire forest/non-forest area. The classification tree obtained from boosting option is used in the Apply See5 software module to model forest non-forest, water, and invasive species classes as a function of the modeling dataset for each sensor. The final product is a single layer forest/non-forest image map (predicted output image) with values representing the variables (forest/non-forest, water, privet, and honeysuckle) that were modeled (Figures 2, 3 and 4), and a confidence image. Confidence values range from zero to one. A value of or near one indicates a more confident prediction for forest area, while values near zero show a confident prediction for non-forest area. Figure 2 and 4 shows the spatial distribution of privet and honeysuckle, each modeled with MODIS and Landsat-TM data as a single category/class. Figure 3 shows the spatial distribution of privet classes modeled with MODIS data, and the spatial distribution of honeysuckle classes modeled with Landsat-TM data.



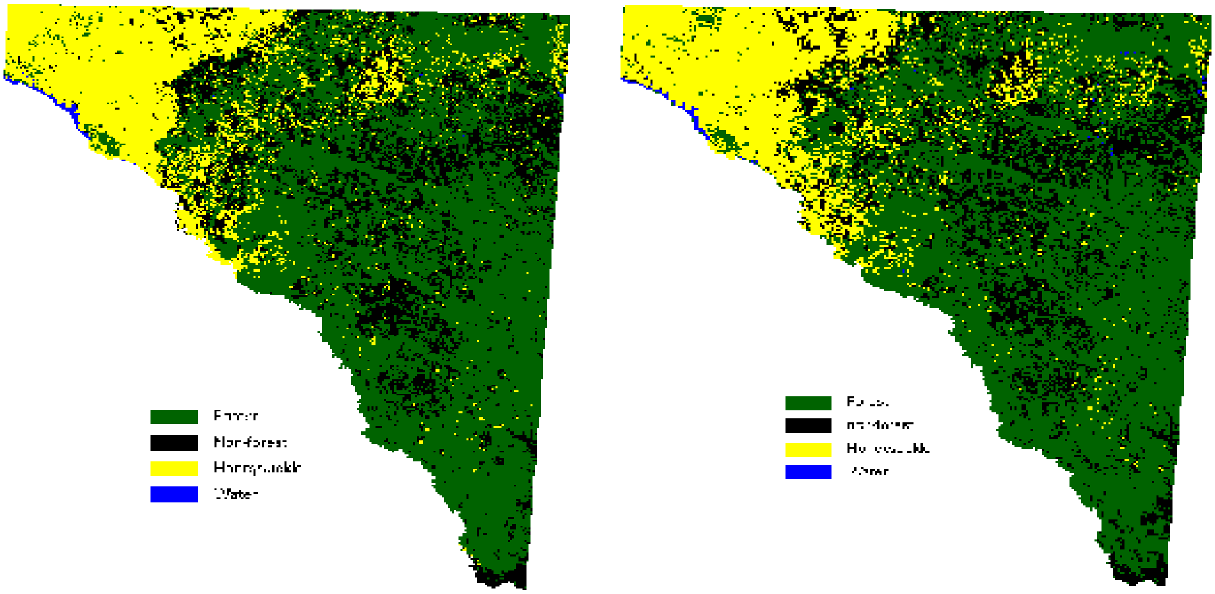
a) **b)**

Figure 2. Forest, non-forest and privet classifications from a) MODIS and b) Landsat-TM images.



c) Privet by categories **d)** Honeysuckle by categories

Figure 3. Forest non-forest and classes for a) privet from MODIS and b) honeysuckle from Landsat-TM mages.



a) b)

Figure 4. Forest, non-forest and honeysuckle classifications from a) MODIS and b) Landsat-TM images.

RESULTS AND DISCUSSIONS

Forest/non-forest, privet and honeysuckle invasive species spatial distribution models have been developed using information from two different satellite sensors (MODIS and Landsat -TM), ancillary and forest inventory data for the Southwest part of South Carolina. Two subsets of forest inventory plots with privet (single, and several classes) and two subsets of plots with honeysuckle (single, and several classes) have been used separately with MODIS, Landsat – TM and ancillary information data in See5 with boosting option of 10 trials to classify/model the land cover into forest, non-forest, water, and privet/ honeysuckle invasive species. Results of these trials are summarized below. Classification results from See5 when privet and honeysuckle are coded as single class (present on the plot) are presented in Table 4 and 5. Overall classification accuracy (%PCC and Khat %) increased from 67.50% when MODIS (250 m) information is used in the model to 72.50% when Landsat-TM (30 m) information is used to model privet invasive species. There is also an increase in classification accuracy from 67.50% with MODIS to 70.00% when Landsat–TM is used to model honeysuckle invasive species spatial distribution (Table 5). Accuracy assessments performed are based on analysis of a contingency table produced by the See5 algorithm for the 10-percent set-aside dataset. This test is used to evaluate the predictive ability (validation) of the selected model. Overall classification accuracy shows that the Landsat-TM prediction model performs slightly better than the MODIS predictive model (Tables 4 and 5). Predictive models from both sensors perform relatively poor in detecting the non-forest land cover, but Landsat-TM does a better job. Privet is better classified by MODIS, while honeysuckle is slightly better identified by Landsat-TM. There is not water plots selected in the test file to test how good the model is, but the nine water plots in the model classified the correct area as water (Tables 4, and 5).

Table 4. Classification accuracy of forest/non-forest and privet from test data.

Sensor Type	Khat %	Overall %PCC	Producer accuracy %				User accuracy %			
			Forest	Nonforest	Water	Privet	Forest	Nonforest	Water	Privet
Landsat-TM	41.80	72.50	84.61	59.10	*	16.67	78.57	65.00	*	25.00
MODIS	25.71	67.50	88.46	27.27	*	33.33	71.88	54.54	*	40.00

Table 5. Classification accuracy of forest/non-forest and honeysuckle from test data.

Sensor Type	Khat %	Overall %PCC	Producer accuracy %				User accuracy %			
			Forest	Nonforest	Water	Honey-suckle	Forest	Nonforest	Water	Honey-suckle
Landsat-TM	48.72	70.00	83.33	50.00	*	62.50	71.43	64.71	*	71.43
MODIS	43.11	67.50	90.48	27.27	*	62.50	70.37	60.00	*	62.50

Results from MODIS and Landsat-TM classifications with privet and honeysuckle coded differently in several classes based on the average percent of privet and honeysuckle in the plot, are presented in Tables 6 and 7. The small number of plots containing privet, and the absence of water plots in the test file, makes the test unreliable for evaluating the predictive ability of the selected model. The privet models developed with Landsat-TM and MODIS misclassify the two plots in the test file, that have a trace of privet as forest without privet, while the four plots containing privet (class 1 – 10%) are misclassified as forest without privet (3 plots), and forest with a trace of privet (one plot). The Z test proposed by Cohen (1960), is used to test for significant differences between the classifications obtained from the two models. The results show that there is no significant difference between the classification accuracy of the two sensors (Table 4 and 5) at 90% confidence level (Z=1.09 <1.64 and Z=0.45 < 1.64).

Table 6. Classification accuracy of forest/non-forest and privet classes**.**

Sen-sor Type	PCC %	Producer accuracy %						User accuracy %					
		Privet %			Forest	Non forest	Water	Privet %			Forest	Non forest	Water
		Tra ce	1-10	11-50				Tra ce	1-10	11-51			
TM	72.50	*	*	*	90.38	50.00	*	*	*	*	75.81	73.33	*
MO-DIS	68.75	*	*	*	88.46	40.91	*	*	*	*	71.88	64.29	*

The Landsat-TM and MODIS models for honeysuckle invasive species provide different results regarding how well honeysuckle is identified in each class/category based on the percent of participation in the plot (Table 7). According to user, producer, and overall accuracy (Table 7) the Landsat-TM model performed slightly better than the MODIS model in modeling (classifying) each land cover class. Both producer and user accuracies show a slightly higher classification accuracy of the forest class than for non-forest, while the water class is not identified at all due to the lack of water plots in the test file. Both models have a high percent of misclassification among the honeysuckle classes, even though the Landsat-TM model performs better than the MODIS model.

Table 7. Classification accuracy of forest/non-forest and honeysuckle classes**.**

Sen-sor Type	PCC %	Producer accuracy %						User accuracy %					
		Honeysuckle %			Forest	Non forest	Water	Honeysuckle %			Forest	Non forest	Water
		Tra ce	1-10	11-50				Tra ce	1-10	11-51			
TM	58.75	*	10.0	25.0	80.43	47.06	*	*	11.1	33.3	67.27	66.67	*
MO-DIS	55.0	50.0	*	*	76.09	47.06	*	100	*	*	66.04	64.29	*

CONCLUSIONS

This dataset is a part of a product developed with the intent of using a full five-year cycle of FIA data throughout the state of South Carolina. This study covers only a portion of the state, due to the limiting extent of using only one Landsat-TM scene. Hence, accuracy of the forest/non-forest map is a very important factor when modeling the correct area for forests associated with the presence of privet or honeysuckle.

Based on the work described, Landsat-TM with its higher resolution performs slightly better than MODIS in modeling privet and honeysuckle spatial distribution. Privet and honeysuckle classifications provide information not only on their spatial distribution, but also on how privet and honeysuckle classes/categories (based on the percent cover) are spatially distributed throughout the forested area.

The spatial distribution pattern provides a visual assessment for the occurrence of high and low percent cover for these invasive species.

FIA plot information ties See5 and Cubist models to actual FIA plot measurements on the ground.

An increase in overall accuracy is associated with an increase in spatial resolution (smaller pixel size).

Low number of plots in the test file for water, privet, and honeysuckle classes makes the test less reliable in evaluating how effective the models are in modeling invasive species. There is a need to compare the final classification output from each model with the field in order to validate the model.

Results suggest that FIA plot information can be used with good results in classifying invasive species.

A recommendation is to revisit this, or a similar invasive species study, while using a statewide coverage of TM data. The expectation is that the larger amount of plot data will provide results that are more promising.

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