Quantifying Forest Ground Flora Biomass Using Close-range Remote Sensing

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Abstract.—Close-range remote sensing was used to estimate biomass of forest ground flora in Arkansas. Digital images of a series of 1-m^2 plots were taken using Kodak DCS760 and Kodak DCS420CIR digital cameras. ESRI ArcGIS™ and ERDAS Imagine® software was used to calculate the Normalized Difference Vegetation Index (NDVI) and the Average Visible Reflectance (AVR) index for each plot. Regressions, developed to estimate green and dry biomass from the NDVI and/or AVR values, explained 30-40 percent of the variation. A vegetation mask and/or different independent variables are needed to improve the regression models.

Many forest research projects estimate forest ground flora biomass via the labor-intensive technique of clipping, drying, and weighing vegetation samples (Brower *et al.* 1990). When combined with species identification, such work is used to report various diversity measures (Elzinga *et al.* 1998, Foti and Devall 1994, Magurran 1988) used in ecosystem studies and reporting. Such information is also used when assessing wildlife habitat (National Wildlife Research Center 2000).

Satellite imagery combined with computer algorithms has been used to estimate forest biomass (Ahern *et al.* 1991, Baret *et al.* 1989), but this imagery cannot be used to estimate forest ground flora biomass because of canopy blockage and scale. Our pilot project sought to determine whether techniques used to estimate forest biomass from satellite imagery can be used to estimate forest ground flora biomass using close-range, remotely sensed imagery. Photoplots have been used in ecological research for change detection (Schwegman 1986, Windas 1986). This project combines the use of photoplots with the techniques of satellite imagery to estimate forest ground flora aboveground biomass.

Equipment

Two digital cameras were used in conjunction on this project: A Kodak DCS760 camera with a Nikon F5 body was used to take color digital images at a 6 million pixel (3038 x 2028) resolution; a Kodak DCS420CIR camera with a Nikon F90 body camera operating at a 1.5 million pixel (1524 x 1020) resolution was used to take the color infrared images. Twenty mm auto-focus lenses were used on both cameras, and an Omega Optical band pass filter (500-900 nm) was used in conjunction with the DCS420CIR camera to block blue light.

An aluminum stand was constructed to frame the 1-m^2 plot and mount the cameras. (The actual frame size was 0.966 m^2 but will be referred to as 1 m^2 in this manuscript.) The cell size for the imagery was 0.1015 cm. Black and white bands were painted onto the frame to calibrate images from 0 to 255 to take into account variations in illuminations. Cross hairs (or tick marks) were drawn onto the frame to develop a local coordinate system for image comparisons. ESRI ArcGIS™ 8.x and ERDAS Imagine® 8.5 software was used to process the imagery and calculate the vegetative indices used herein.

Methods

Collecting Images and Vegetation

A series of 1-m^2 plots were randomly established on the University Forest at the University of Arkansas-Monticello for the initial analysis. Once a plot was located, the aluminum camera stand was set up and vegetation overlapping or extending beyond the border of the frame was removed to ensure only vegetation within the plot would appear in the images. Each camera was then mounted on the frame separately and raised to the appropriate level. Three pictures were taken per camera to be sure at least one usable image was captured. After the images were taken, the vegetation on the plots was clipped at

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ground level, sorted by species, and placed into labeled plastic bags and sealed for laboratory analysis.

Mass Determination

The green mass of the contents of each bag was determined immediately upon return to the laboratory. The contents of each plastic bag were then transferred to labeled paper sacks and placed in a drying oven at 60ºC for 3 to 4 days. After drying, the dry mass of the contents of each bag was measured.

Image Registration and Standardization

The camera stand used in this study had seven tick marks on its frame. These tick marks were measured to within 0.025 cm and placed in a shapefile to represent a local coordinate system for the camera stand. Each collected image was then registered to that coordinate system within ArcGIS™ ArcMap™ using the georeferencing extension. The referencing was done by lining up the measured tick marks with the marks seen on the image; this ensured that all images would line up exactly with each other and could be compared.

Because the amount of solar energy incident on the plots can change, the camera stand also had black and white painted regions on it so the illumination of images could be standardized. To ensure that the digital values represented the same color from one image to the next, a GER2600 spectroradiometer determined the reflectance of the painted regions for four bands (Near Infrared[NIR], Red[R], Green[G], and Blue[B]) and represented the extremes of the range of colors present in any image for any band. A simple linear regression was created per band per image to convert the range of values present within a given band/image combination to the range defined via the spectral radiometer. The regressions were used to calibrate each image.

Images were then subsetted by creating areas of interest (AOI's) manually in Imagine®. The AOI's contained only that portion of each image that was inside the borders of the camera stand and were used for all subsequent analyses.

When applying the regression models to the areas of interest for each band/image combination, any values in the output grid less than 0 were reset to equal 0 (negative values can disrupt calculation of certain vegetation indices). The final output grid was a six-band image consisting of standardized NIR, red and green bands from the color infrared image, and the red, green, and blue bands from the color image.

Vegetation Indices and Regression Modeling

The CIR camera images were used to calculate the Normalized Difference Vegetation Index (NDVI). The Average Visible Reflectance (AVR) index was calculated using the color camera images for each pixel in each image.

$$NDVI = (NIR-R)/(NIR+R) \quad (1)$$

$$AVR = (G+R+B)/3 \quad (2)$$

The output image from this step was a two-band grid (NDVI and AVR) with a cell size of 0.1015 cm by 0.1015 cm.

Once the NDVI and AVR values for the images were calculated, they were summed and averaged for use as potential independent variables in regression equations to predict green or dry biomass.

Results and Discussion

Thirteen of the plots have been completely processed so far. Green mass of the forest floor aboveground vegetation ranged from 30 g to about 415 g and dry mass ranged from 14 g to about 200 g. Figures 1 and 2 show the relation between green and dry biomass, respectively, versus the sum of the NDVI values of the plots. A slight curvilinear pattern is apparent.

Several regression model forms were examined to fit a curve to the data appearing in figures 1 and 2. For predicting or estimating mass (green and dry, respectively) in grams, the fol-

Figure 1.—*Relationship between green mass (g) and NDVI values.*

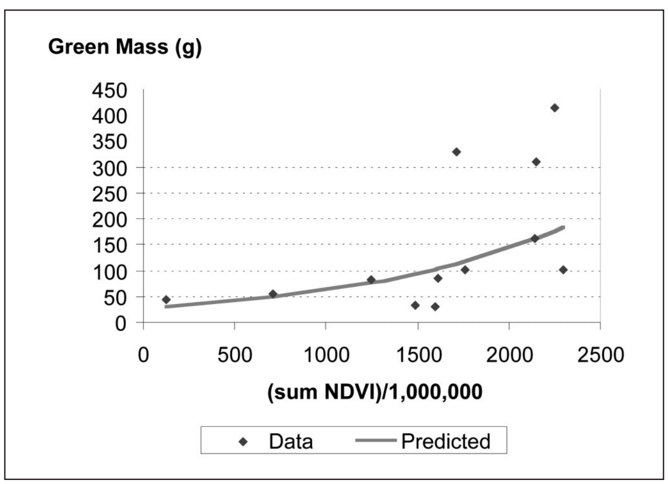
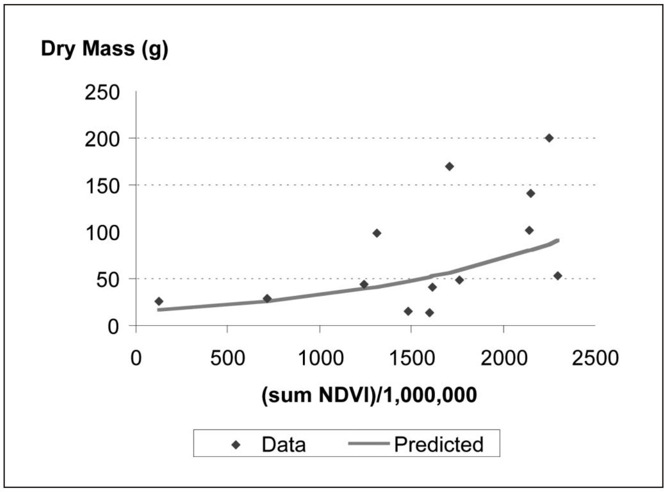


Figure 2.—*Relationship between dry mass (g) and NDVI values.*



lowing model form was most successful across the collection of images (i's):

$$\mathrm{Ln}(mass_i) = \beta_0 + \beta_1(\mathrm{sum\ NDVI}_i) + \varepsilon_i \quad (3)$$

Fit statistics for equation (3) appear in table 1.

NDVI was found to be a better independent variable than AVR. Although parameter estimates were significant, the R^2's of these initial models were fairly low. A few plots greatly impacted model performance. Visual inspection of the images of these plots indicated that a fair amount of vegetative overlap was present, which prevents the cameras from seeing the true quantity of vegetation. Vegetation overlap is definitely of concern to the researchers. If the problem persists as the data set grows, a method to account for vegetative overlap needs to be developed and included.

Other model forms/variables will be considered as the data set continues to grow. In this initial analysis, calculated vegetative indices (NDVI and AVR), not individual color bands, were used when building regression models. Use of individual color band values, especially red, may improve model performance.

A vegetation mask was not used in this initial analysis, but will be used in any future analyses. We hope a vegetation mask will further distinguish pixels that contain live vegetation from pixels that contain just the forest floor.

These preliminary results suggest the potential of handheld color and color infrared cameras for quantitative forest floor vegetation sampling by means other than clipping and weighing. This project, as it unfolds, should serve as a good first step in that direction.

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Table 1.—*Fit statistics for equation 3*

	Parameter	Estimate	Std. error	p-value	R2
Green mass	β_0	3.2934	0.5833	0.0002	37.40%
	β_1	8.3450x10^{-10}	3.4143x10^{-10}	.0346	
Dry mass	β_0	2.6745	0.6078	.0013	33.40%
	β_1	7.9650x10^{-10}	3.5574x10^{-10}	.0491	

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