

Using photointerpretation and publicly available software
to assess revegetation ground cover on a shaded hillside

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Abstract

This project examined the potential of three plant species, *Heuchera micrantha*, *Polystichum acrostichoides* and *Pachysandra procumbens* individually and in various combinations as potential ground cover for a heavily shaded north-facing slope on the Maymont Estate in Richmond, Virginia. Digital photographs were taken of the planting sites. Two software applications were used to make quantitative evaluations of ground cover for the test plantings: the USDA's point sampling application SamplePoint, and NIH's image analysis application ImageJ. GNU's Image Manipulation Program was used to edit the digital images as needed to prepare them for interpretation and OpenOffice.org was used to analyze data. Limiting factors for plant growth on these sites included topography and a dense tree canopy, which obstructed sunlight (May – September) and produced mats of leaf litter (October – March) which hindered quantification of plant growth. In order to compare the two image evaluation methods, individual plant species' ground cover averages recorded by ImageJ were summed to compute overall ground cover, and they were compared to the overall ground cover recorded in SamplePoint. The two ground cover evaluation methods gave similar results. The SamplePoint method can be applied by users with less technical training. However, due to consistent image quality and appropriate algorithms, ImageJ has great potential as a vegetation quantifier. SamplePoint results from August to May indicated *H. micrantha* initially covered an average of 6% in its quadrats in August 2009. May 2010 showed the average area had declined to 2%, while *P. procumbens* ground cover increased by from 3 to 4.5% and *P. acrostichoides* cover increased from 11 to 16.5%, making it the most effective species. Based on this study, *P. acrostichoides* will be used to revegetate the area, perhaps in combination with *P. procumbens*.

Key Words

SamplePoint, ImageJ, image analysis, vegetation monitoring, ground cover, Maymont

Introduction

In 1925, the Maymont Estate in Richmond, Virginia, (Latitude= 37.5360191157835, Longitude= -77.48028516769409) was opened to the public as an arboretum and park. Maymont's original 100 acres are intact and retain many of the architectural and landscape features in place at the time of death by the last surviving owner, Mrs. Dooley (Figure 1). The Maymont Foundation is working to stabilize the condition of the original woody plants collection.



Figure 1. An aerial view of the test site with the Maymont Estate in Richmond, VA

The Maymont Foundation's Director of Horticulture and the Associate Executive Director had several areas within the property slated for rehabilitation. Erosion mitigation and invasive species control were recurring concerns. Of these areas, a very steep north-facing hillside that had been covered with English Ivy (*Hedera helix*), an exotic invasive vine, was selected as a test site (Figure 2). The Foundation wanted to reestablish native ground cover on the area before *H. helix* could take over again. Three potential native Mid-Atlantic plant varieties were selected for testing: Hairy alumroot (*Heuchera micrantha* - Hm), Christmas fern (*Polystichum acrostichoides* - Pa) and Allegheny spurge (*Pachysandra procumbens* - Pp). Each species was selected based on acid soil preference and shade tolerance, characteristics needed to thrive on this particular site.



Figure 2. The test site after installation of test plots.

Heuchera micrantha is often found on hillsides and cliffs in well-drained soils. It does not spread by stolons or rhizomes, but rather grows larger through a constantly expanding rosette. *Polystichum acrostichoides* had already become established in various locations in and around the site. The fern spreads through increasing the size of its crown. Based on the prolific growth of its Eurasian counterpart, *P. terminalis*, in similar environs, *P. procumbens* was chosen (Chazdon 1988).

Pachysandra procumbens is also a clumping plant and does not grow as quickly as *P. terminalis*, which spreads by stolons.

This project is an investigation of the possibility of successfully performing a vegetative cover assessment using publicly available materials, software and simplified techniques of quantification. This project's goal is to develop an easily adaptable method for potential use by laypersons to quantify ground cover. Other researchers have explored the possibility using widely available public domain programs in scientific research instead of commercial applications for several reasons:

1. Commercial programs are expensive
2. Commercial programs' source code and algorithms are proprietary, not public domain.
3. The operation of commercial programs is often complicated (Helma and Uhl 2000).

In this project, the researcher is developing and applying an easy-to-use, efficient system for quantifying ground cover using public domain software. Independent researchers, volunteers and students with limited budgets can make use of the software and techniques described in this paper. Two potential uses include on-site measurement of meadow seed germination rates and assessment of vegetative reclamation attempts of eroded soils.

Objectives

The primary goal of the project is to evaluate and compare growth rates of test ground cover species in various combinations on a shaded, North-facing slope at the Maymont estate. This assessment will be made using publicly-available, open source graphics editing programs. Specifically, we focused on three objectives:

1. **Photo interpretation & analysis:** Develop an inexpensive method of ground cover quantification using public domain, open source software.
2. **Data Analysis:** Estimate the percentage of ground covered by test plantings at various stages during the first year of growth.
3. **Data Comparison:** Evaluate the test plantings to select the most effective method to revegetate the north-facing slope with native plant species.

Method

Planting Sites

Two adjacent sites were chosen for their relative lack of existing native vegetation, exposed rock; and tree roots. A soil sample was collected in early 2009 and sent to the Virginia Tech soil testing lab

for analysis. Notable was a pH of nearly 4.9. Soils within the area are mapped as Wateree-Wedowee-Rock outcrop complex by the National Cooperative Soil Survey (Soil Survey Staff 2009). Wateree-Wedowee-Rock outcrop complex is described as a mixture of predominately strongly acid, sandy loam soils. Large sections of tree roots have been exposed in the area due to erosion of the topsoil. Dense shade was created by a canopy of *Acer rubrum*, *Liriodendron tulipifera*, *Quercus alba* and *Carya glabra*. Remaining light was filtered through an understory of *Rhododendron* sp., and *Cornus florida*.

Test Plantings

In each area six quadrats were established for a total of twelve quadrats. A third replication was established in a separate location but was lost to heavy rains soon after planting. The remaining two areas were established in combinations within each set of quadrats (Table 1, Figure 3):

Quadrat 1	14 equally spaced <i>P. acrostichoides</i> (Pa●)
Quadrat 2	14 equally spaced <i>H. micrantha</i> (Hm●)
Quadrat 3	9 evenly spaced <i>P. procumbens</i> (Pp●)
Quadrat 4	Interplanting- 3 Pa, 2 Pp, 3 Pa, 2 Pp, 3 Pa
Quadrat 5	5 Pa, 5 Hm, 5 Pp
Quadrat 6	Alternating rows- 3 Hm, 2 Pp, 3 Hm, 2 Pp, 3 Hm

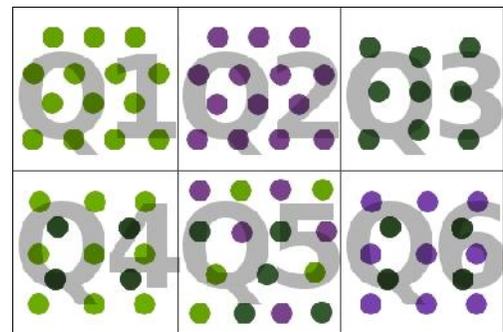


Table 1. Planting plans for each of the six quadrats.

Figure 3. Diagrams representing planting layout.

The test plantings were established in April 2009. *Huchera micrantha* and *P. acrostichoides* were established as plugs and the *P. procumbens* as bare root plants. Ample rains during April and May helped to establish plantings.

Image Capture

A Canon PowerShot SX110 IS 9.0 megapixel camera and a camera stand with a 1 m² base, 1.5 m in height constructed for photographing ground cover on a slope were used (Figure 4). The stand was constructed with one inch PVC tubing, 6 elbow joints, and 4 T-connectors. A quarter-inch 20 thread eye-bolt was used to mount the camera. To prevent sliding on hillsides, an exposed nail was attached to the bottom of the base. Each of the 12 quadrats was photographed on five occasions over a period extending from August 2009 through May 2010. From November 2009 through February 2010 photography was suspended until soil temperatures approached 12°C, when plant growth resumes.

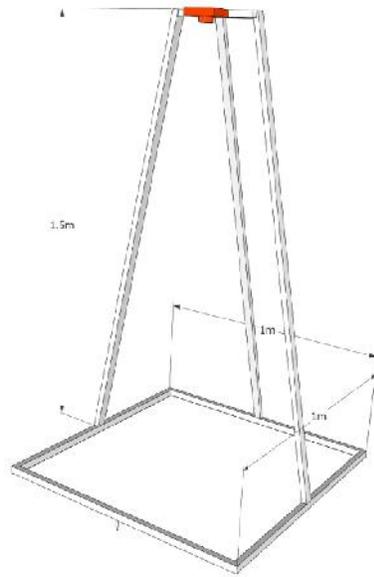


Figure 4. Camera stand final design

Photo interpretation & analysis

Two methods were used to interpret and analyze the images for the purpose of quantifying ground cover. The first method used spatial analysis of digital images and the program SamplePoint (Booth, et al. 2006a) for software-assisted ocular examination. We were able to measure the area covered by the selected species, miscellaneous species and leaf litter.

The second method used a more technical process. It reduced the entire spectrum of green pixels to black and converted all non-green pixels to white. A macro program written for NIH's ImageJ (Burger and Burge 2009) provides a ratio of black to white pixels in the image giving us a percentage of area covered by the growing plants represented by the black pixels.

Image Pre-processing using GNU Image Manipulation Program (GIMP)

The program used to create and edit photos is an open-source application referred as GIMP. UC Berkeley students Spencer Kimball and Peter Mattis developed the original program in 1995 and its development has been continued by volunteers (Burgess 1998). Before viewing the images in SamplePoint and ImageJ, the digital images were cropped to 1728 x 1728 pixels, rotated when necessary, arranged in proper sequence and saved as JPEGs. These images were then analyzed using the methods described.

Photo Interpretation using SamplePoint

SamplePoint is a manual image-analysis program designed in the programming language, C Sharp, by researchers for USDA to facilitate vegetation cover measurements from nadir digital images of any scale. The software operates essentially as a digital point frame, loading images, placing classification points on the image, and storing the data to a database as the user classifies each point (Booth et al. 2006b). 100 points represented by single pixels were evenly distributed across each image in grid formations a means of sampling the image pixels. User created buttons were used to assign each of the 100 points a label: *P. acrostichoides*, *H. micrantha*, *P. procumbens*, Root (exposed tree roots), Soil, Invasive (self-propagated non-native plant species), or Volunteer (encroaching native plant species). The results from each set of images were saved to a database.

Image Analysis using ImageJ

ImageJ was developed using the Java programming language by Wayne Rasband at the U.S. National Institutes for Health. Its key features include a set of interactive tools for creating, editing, processing, analyzing, loading, and storing images, with support for several common file formats. This is complemented by a simple plugin/macro mechanism allowing users to extend the functionality of the program by writing small pieces of Java code (Burger and Burge 2009). The program's primary purpose is medical research, but as public domain, open source software any user has the four essential freedoms defined by the Richard Stallman (1986), the founder of GNU:

1. The freedom to run the program, for any purpose.
2. The freedom to study how the program works, and change it to make it do what you wish.
3. The freedom to redistribute copies so you can help your neighbor.
4. The freedom to improve the program, and release your improvements to the public, so that the whole community benefits.

Green plants were isolated in the image by adjusting hue selection levels (Richardson et al. 2001, Goodwin and Hsiang 2010) in GIMP for each quadrat manually to select only the green pixels. (Enough green was present in the normally purple *H. micrantha* for those pixels to also be selected. Species with foliage other than green can be selected by adjusting the selection levels accordingly.) The saturation and lightness for the yellow and green channels were reduced to -100 which converts all green hues to a dark gray. The saturation for all other colors was also set to -100 while the lightness was set at +100, converting the non-green pixels to shades of light gray. A thresholding function was

then used to force the dark pixels, representing plant matter to black and the lighter remaining pixels to white (Johnson 2003) (Figure 5). Any non-green plant elements still visible in the image such as leaf-litter or roots were digitally removed. This black and white image was then saved as an 8bit grayscale TIF file (Figure 6). Following this, a macro-program, B/W Ratio, developed for ImageJ was used to assess the ratio of black pixels (representing green plants) to white pixels (representing soil, leaf litter, roots, etc.) within the photographed quadrat. The data were then transferred to a spreadsheet.

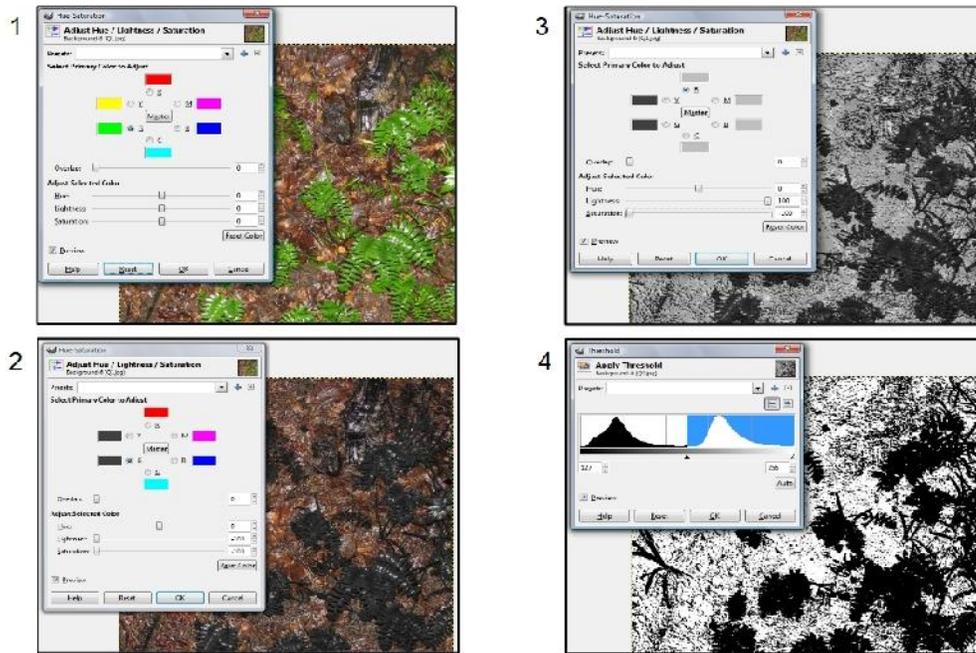


Figure 5. GIMP process for preparing image for ImageJ

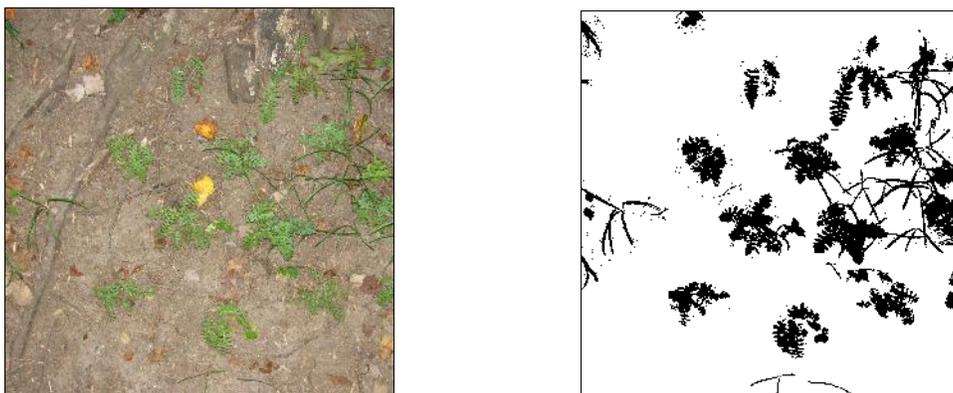


Figure 6. An example of the Quadrat 1 cropped image and an example of the image created for ImageJ

Results

Data Analysis & Comparison

Using ImageJ, *P. acrostichoides* and other plants sharing the quadrats were shown to cover an average of 10.4% of the quadrat in August 2009. May 2010 showed the average area covered to be 20.4%, an increase of almost double. The area covered by *P. procumbens* and the other plant species in those quadrats nearly tripled from 4.9 to 14% of the 1 x 1m quadrat area. *H. micrantha* & additional plants in those quadrats increased by 4.6%, from 8 to 8.4% of the area covered.

Using SamplePoint, data from the three mixed-species quadrats showed a greater increase of ground covered than the three quadrats that were initially established as single species. The *Pa/Pp* quadrat showed an almost 2x increase from 10.5% of the area covered to 20%. *Pa/Pp/Hm* showed a 3.5x increase from 5 to 17.5%. *Pp/Hm* showed a .64x increase from 8.5 to 14%.

Software Comparison

The Black/White Ratio macro in ImageJ was only capable of measuring nonspecific plant cover. Invasives and seedlings were included in the pixel counts. In contrast, the original SamplePoint data represented only the planted species (Tables 2, 3 and 4). In order to compare the two methods, the invasive and volunteer plant counts were added to the planted species count in their respective quadrats in SamplePoint. When charted, a correlation was evident between the two method's data. The data generated by SamplePoint and ImageJ for *P. procumbens* and the miscellaneous plants in its quadrats are especially similar.

Plant Species Comparison

A consistent rise in leaf litter obscured the plant growth occurring between August 2009 and March 2010. Despite the thick mat of leaf litter, data generated by SamplePoint solely for the planted species from August to May indicated *P. acrostichoides* initially covered an average of 11% of the quadrat in August 2009. May 2010 showed the average area covered to be 16.5%, an increase of 50%. The area covered by *P. procumbens* also increased by 50% from 3 to 4.5% of the 1 x 1m area covered. *H. micrantha* decreased by a factor of 3, from 6 to 2% of the quadrat covered.

<i>P. acrostichoides</i> & misc.	SamplePoint	ImageJ
Aug	15.5	10.4
Sep	12	9.9
Oct	13	9.9
Mar	10.5	6.4
May	22.5	20.4
Increase from August	45.2%	95.5%
<i>H. micrantha</i> & misc.	SamplePoint	ImageJ
Aug	10.5	8.0
Sep	7.5	4.4
Oct	3	4.4
Mar	5.5	4.2
May	9.5	8.4
Increase from August	-9.5%	4.6%
<i>P. procumbens</i> & misc.	SamplePoint	ImageJ
Aug	5.5	4.9
Sep	5.5	5.9
Oct	5.5	5.9
Mar	8.5	8.7
May	15	14.0
Increase from August	172.7%	188.5%

TABLE 2
Total ground cover and ground cover increase, August 2009 to May 2010 for the initially single species groups.

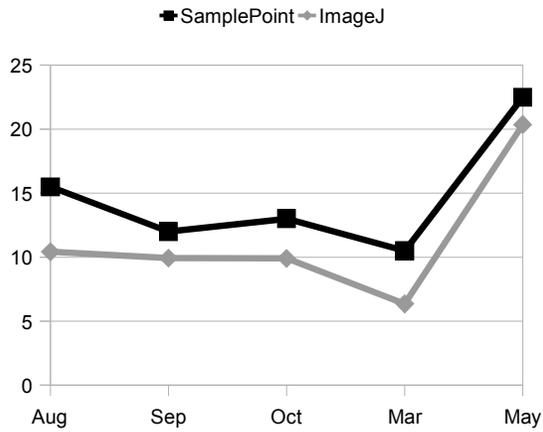
<i>Pa/Pp</i>	SamplePoint	ImageJ
Aug	10.5	8.0
Sep	12.5	8.0
Oct	14	10.0
Mar	4.5	3.9
May	24	20.4
Increase from August	128.6%	154.5%
<i>Pa/Pp/Hm</i>	SamplePoint	ImageJ
Aug	5	7.8
Sep	6	7.1
Oct	7	6.5
Mar	4.5	3.3
May	17.5	16.3
Increase from August	250.0%	108.2%
<i>Pp/Hm</i>	SamplePoint	ImageJ
Aug	8.5	4.5
Sep	6	4.3
Oct	6	3.9
Mar	4.5	4.2
May	14	9.9
Increase from August	64.7%	119.8%

TABLE 3
Total ground cover and ground cover increase, August 2009 to May 2010 for the mixed species groups.

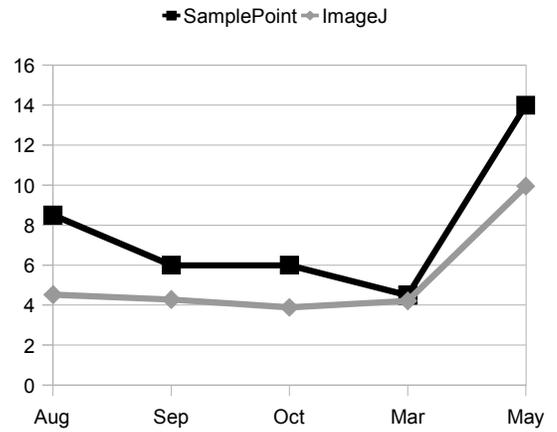
Plant Species	Aug. 2009 Plant Cover	May 2010 Plant Cover	Increase / Decrease
<i>P. acrostichoides</i>	11	16.5	50.00%
<i>H. micrantha</i>	6	2	-67.00%
<i>P. procumbens</i>	3	4.5	50.00%

TABLE 4
Ground cover change as recorded by SamplePoint, August 2009 to May 2010 for planted species

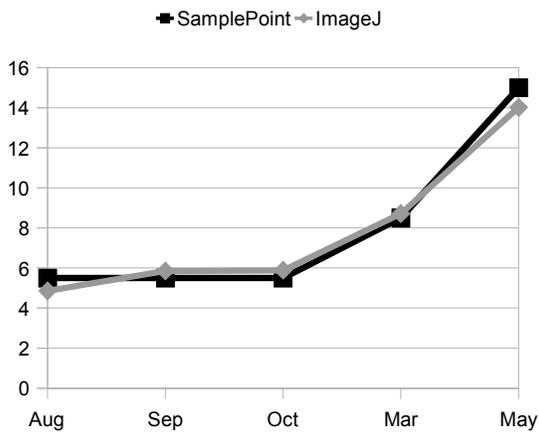
***P. acrostichoides* & miscellaneous plants**



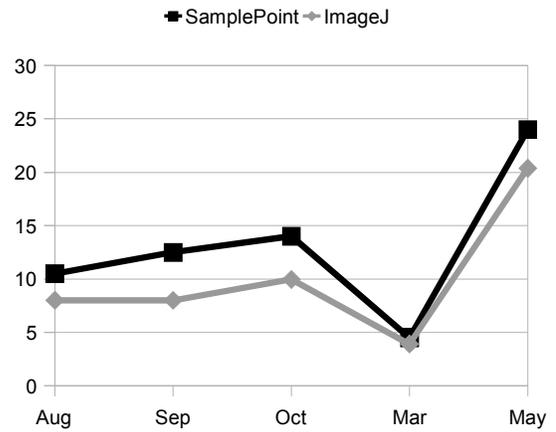
P. procumbens* & *H. micrantha



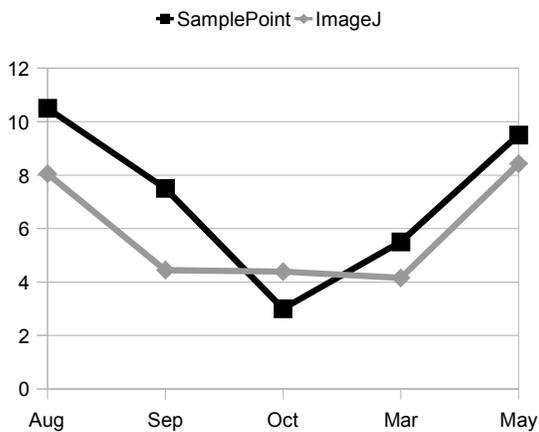
***P. procumbens* & miscellaneous plants**



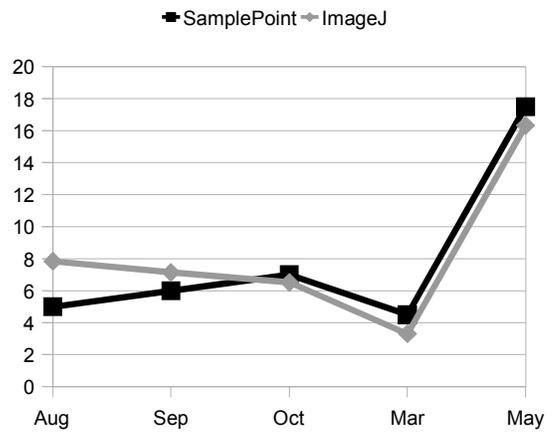
P. acrostichoides* & *P. procumbens



***H. micrantha* & miscellaneous plants**



P. acros./ P. proc / H. micrantha



Discussion

Inaccurate interpretation was a problem with early SamplePoint data. In a preliminary analysis, several non-plant pixels located directly adjacent to plant pixels had been marked as living plants. The SamplePoint data corresponded much more closely to the ImageJ results when the exact single pixel centered in the marker was recorded. Limiting the introduction of human error into the SamplePoint data could be accomplished with the addition of several different users, with each analyzing the images and then using an average of their findings as project results (Booth et al. 2006a).

With ImageJ, maintaining consistent image interpretations was a problem when attempting to analyze photos taken under varying conditions. A solution that can be applied during image capture is to create diffuse lighting by surrounding the quadrat with translucent plastic sheeting (Rotz et al. 2008). This technique equalizes image color yielding more consistent images regardless of the lighting on the days when individual photos are taken. In research conducted in 2005 by other researchers, lighting differences were digitally adjusted after image capture. Histograms for all images were adjusted using the autoequalize algorithm in Corel Photo Paint, normalizing color among all images to cancel the differences caused by light intensity and color temperature (Booth et al. 2005). I did not use these methods in this research but in retrospect, that or a similar technique might have been helpful.

VegMeasure, a vegetation measurement program developed at Oregon State University, gives the user the option of processing each image with its own threshold value (Johnson 2003). This technique was also used in our research, but without an algorithm or guidelines for the RGB values representing productive plants the potential for bias exists. Another concern with ImageJ involved “noise” in the photographic images which registered as plant cover. A 1m² image of uncovered soil produced 5.6% black pixels representing plant growth, even though no plants were present.

Wet leaves were another problem for the ImageJ software. Glare in the May images resulted in the omission of the highlighted parts of the plant when selecting for green pixels. Polarizing camera lens filters were suggested as a potential solution in previous research (Rotz et al., 2008). Waiting for the leaves to dry is also a viable solution when time allows.

Although ImageJ was unable to differentiate various plant species, regular plant maintenance and integrated pest management would limit the amount of non-target species in the assessment plots. With periodic maintenance of the plots, ImageJ would be able to quantify the target species more accurately.

Conclusion

In searching for a less expensive, quicker way of quantifying ground cover, I found value in the use of methodical algorithm creation, strict adherence to the rules of image assessment and careful image capture with regard to lighting and precipitation. Expensive, commercial quantification software packages come with these and other capabilities built-in. Both public domain software packages tested here have the potential for use in ground cover assessment with an acceptable level of agreement. To achieve this, the researcher using these methods must have cursory knowledge of both software and plant materials, and should be prepared to perform mathematical calculations.

Project results indicate *P. acrostichoides* as the planted species showing the most horizontal growth, resulting in increased percent ground cover. The researcher's interpretation of these results is that *P. acrostichoides* is the best suited species used to revegetate the area. When used alone and in combination with *P. procumbens*, *P. acrostichoides* provided a relatively high level of ground cover early in the plantings' second growing season. It appears that with careful management, any of these plant species could become established on the hillside. When using a hands-off approach, however, *P. acrostichoides* adapts most readily to the environment.

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