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Using photographic image analysis to assess ground cover: a case study of forest road cutbanks

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Abstract Road prisms, including cutbanks, road surfaces, and fillslopes, can be important contributors of sediment to streams in forested watersheds. Following road construction, cutbanks and fillslopes are often seeded, mulched, and sometimes fertilized to limit erosion and sedimentation. Assessing the success of vegetation establishment on cutbanks and fillslopes is a common task of forested land managers. This study developed and applied a photographic image analysis method to assess percent ground cover along an entire cutbank of a cut-and-fill haul road in the Monongahela National Forest in Tucker County, West Virginia. Variable-sized sections were employed to quantify the vegetative cover. Measurements obtained by this technique were similar to more commonly applied fixed-area plots, and it proved to be a useful tool for land managers who require a more repeatable quantification of ground cover than is possible through visual assessments. Cutbank slope and aspect also were analyzed to determine their potential impact on cutbank vegetation establishment. Slope was not a significant variable in explaining differences in vegetation cover; however, aspect did affect vegetation establishment. South-facing aspects had significantly lower percent vegetation cover than northeast, east, northwest, and north northwest aspects after the first year following seeding and throughout the entire study. Mean percent cover on the south-facing cutbanks was 32% over all time periods, compared to 60% to 73% for the other represented aspects. This result was expected since south-facing slopes generally are drier in the growing season and are subject to more freeze–thaw cycles in the winter. Timber felled onto the cutbank also decreased vegetative cover in the short term on north and north northwest aspects, but vegetation quickly became reestablished on these aspects with their favorable growing conditions.

Keywords Aspect · Cut slope · Best management practices · Road prism · Revegetation · Variable-sized sampling areas

Introduction

Road prisms (top of the cutbank to the base of the fillslope) are the major sources of sediment in managed forests, in part because they are the

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largest sources of exposed soil, which makes them highly susceptible to erosion. Consequently, one of the major road-related best management practices in forestry is covering soil quickly to improve stabilization. Soil covering usually takes the form of placement of gravel or other type of aggregate on the driving surface and seeding the remaining exposed soil on the fillslopes and cutbanks. Liming, fertilizing, and/or mulching can accompany the application of seed to promote and accelerate revegetation.

Within the road prism, fillslopes often have lower total erosion than cutbanks (Swift 1984; Bochet and García-Fayos 2004). The former tend to revegetate more quickly and completely because fillslopes are constructed of unconsolidated sidecast soil, and the sidecast material can contain fertile topsoil (Bochet and García-Fayos 2004) removed from the excavated portion of the road prism. Conversely, cutbanks provide some of the least conducive conditions for revegetation, unless they are gently sloping (Bochet and García-Fayos 2004). Cutbanks are composed of residual subsoil that may be more compacted than surface soils, and the more-fertile top soil has been removed during road excavation. Seed and mulch are susceptible to washing off of steep cutbanks during rain events or to dry ravel by gravity (Burroughs and King 1989; García-Fayos and Cerdà 1997). Cutbank soils and vegetation also are susceptible to frost heaving (Swift 1984; Burroughs and King 1989; Rowe 2001; Takeda et al. 2002), making permanent root establishment difficult (Hursh 1949). Moist surfaces from intercepted subsurface flow also promote repeated slumping (Burroughs and King 1989), thereby retarding revegetation.

Because of the difficulty in establishing vegetation, particularly on cutbanks, many agencies, industries, and states have “catch and cover” thresholds for reseeding. That is, minimum vegetation establishment levels are set, and if vegetation does not meet those levels, reseeding and/or other actions follow to achieve at least that minimum cover requirement. Whether formally or informally defined, a level of 50% to 60% cover often is used as the minimum threshold, because erosion is greatly reduced once vegetative cover reaches these levels (Quinton et al. 1997; Loch 2000).

While there are a variety of well-established quantitative procedures to determine vegetative cover (Sykes et al. 1983; Floyd and Anderson 1987; Gregoire and Valentine 2008), few of these are actually used to evaluate cover on cutbanks, probably due to the time involved and the difficulty in estimating cover on steep slopes. Instead, cover typically is estimated visually and qualitatively during site inspection, so the accuracy of those estimates depends upon the experience of the inspector. However, there may be situations where vegetation establishment must be ensured and perhaps even documented without risking the potential damage to established vegetation that can occur by physically walking or standing on steep cutbanks. Toward this end, we developed a procedure that is suitable for use by land managers to quantify vegetative cover along entire lengths of road cutbanks, from the top of the bank to the base, using image analysis of photographs taken from the road. This procedure eliminates concerns related to obtaining sufficient measurements from plots and errors associated with ensuring the measured sample areas are representative of the entire cutbank length. We tracked the cover over several years, including a period when the bank was damaged by harvesting trees upslope of the road, to obtain information about vegetation establishment on cutbanks and illustrate the utility of this method.

Materials and methods

Background

The study area was a forested watershed in the Cheat District of the Monongahela National Forest in Tucker County, West Virginia (Fig. 1). Within this watershed, 918 m of a cut-and-fill type haul road (Forest Service Road 973) was constructed for a timber sale. The road was pioneered in 2002 and completed by late summer 2003. The entire cutbank length was open to sunlight due to the relatively wide road right-of-way and steep hillslopes.

In October 2002, a slurry of a seed mixture (applied at a rate of 40 kg ha^{-1}) including Kentucky 31 fescue (*Festuca arundinacea*; 63%),

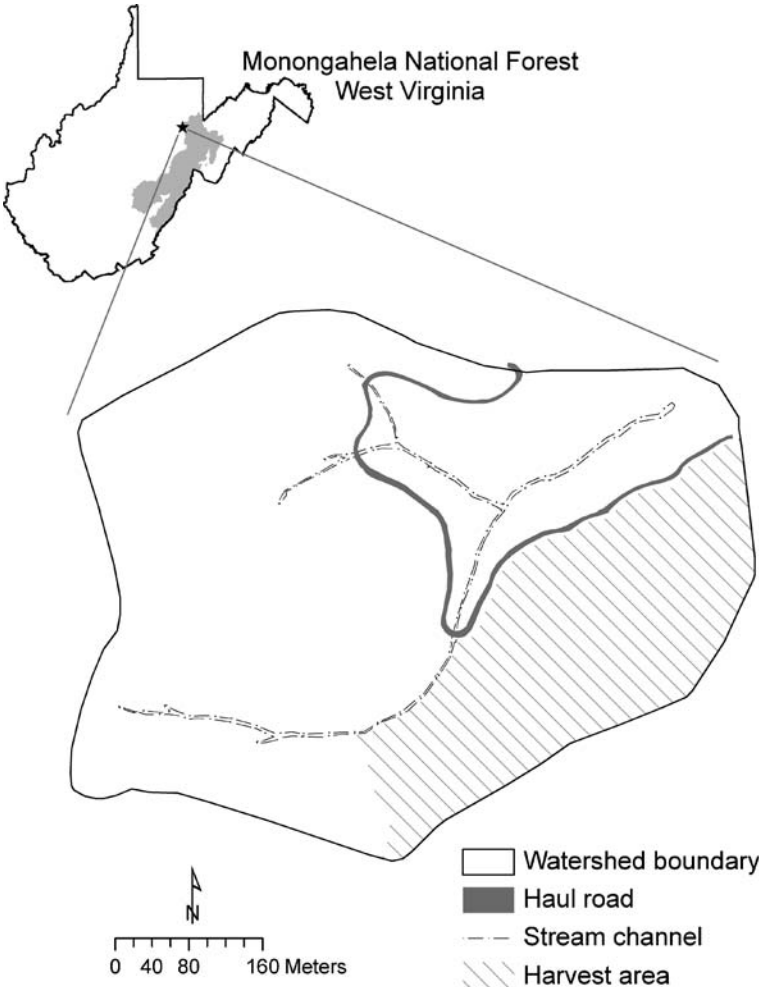


Fig. 1 Location of the study watershed in the Cheat District of the Monongahela National Forest, Tucker County, West Virginia

orchard grass (*Dactylis glomerata*; 31%), and ladino clover (*Trifolium repens*; 6%) combined with fertilizer (10–20–20; applied at the rate of 567 kg ha^{-1}), cellulose fiber mulch (applied at the rate of 1700 kg ha^{-1}), and lime (applied at the rate of 4.55 metric ton ha^{-1}) was applied to the cutbanks and fillslopes via hydroseeding at and immediately adjacent to three stream crossings (Fig. 1). The mulch application was very thin and did not appear to be effective at holding the seed in place. According to Forest Service records, the contractor applied temporary seed and mulch to the remaining cutbank and fillslope lengths in November 2002, but this application was at the end of the allowable seeding period and there was snow on the ground at the time of application. Consequently, this application had little effect on vegetation establishment.

Because of the lack of cover on the cutbanks and fillslopes and visible sediment delivery to the stream (Stedman 2008), in May 2003, the same seed mixture was applied again at a rate of 80 kg ha^{-1} along with the previous rates of lime, fertilizer, and cellulose mulch to the fillslopes and cutbanks at the three stream crossings. The remaining lengths of the watershed's cutbanks and fillslopes were seeded, fertilized, limed, and mulched in sections as the road was completed during the summer of 2003 through October 2003; the application rates were the same as those used in 2002. Vegetation on the fillslope became established fairly rapidly and completely during summer and fall 2003. By contrast, seed establishment on the cutbank was observed to be relatively unsuccessful, but no seed or other amendments were applied after 2003.

In 2005, timber harvesting occurred in a portion of the watershed just upslope from and along approximately the first 310 m of the road (Fig. 1). Approximately 46% of the total cutbank area was within the sections along that length of road. During that operation, which spanned from July 15 to the end of August, trees were felled onto the cutbank and dragged upslope off of it. As a result, the cutbank was damaged throughout that length—patches of cutbank vegetation were pulled out, and in some places, the soil was gouged deeply.

Climate and soil characteristics

The 30-year average air temperature for the area is 9.43°C, and the 22-year average precipitation is 65.31 cm year^{-1} (unpublished data). The frost-free season averages about 145 days. During the winter, temperatures can periodically fall between −23°C and −29°C (USDA Forest Service 1987). Average air temperature and precipitation for the growing season (April through September) and dormant season (October through March) of the years 2002 to 2007 are presented in Table 1.

Three soil complexes and associations exist within the watershed where the haul road was constructed: Berks, Brownsville, and Highsplint. Berks, Brownsville, and Highsplint are loamy-skeletal, mixed, active, mesic Typic Dystrudepts (USDA Natural Resources Conservation Service 1999). These soils are considered moderately erodible, except on steep slopes where they are considered moderately or highly erodible. The cutbanks in this watershed would qualify as steep slopes.

Field techniques for evaluating cutbank cover

The cutbank was divided into 24 sections in early summer 2004 (Fig. 2). Each section's boundaries were defined by the positions of water control features on the road; thus, the start and end of sections were at cross drain culverts or boundaries of broad-based dips and, in one case, a grade break in the road. This method was used simply because it provided a systematic approach for dividing the cutbank into lengths that were easily defined and generally allowed investigation into the importance of aspect on revegetation.

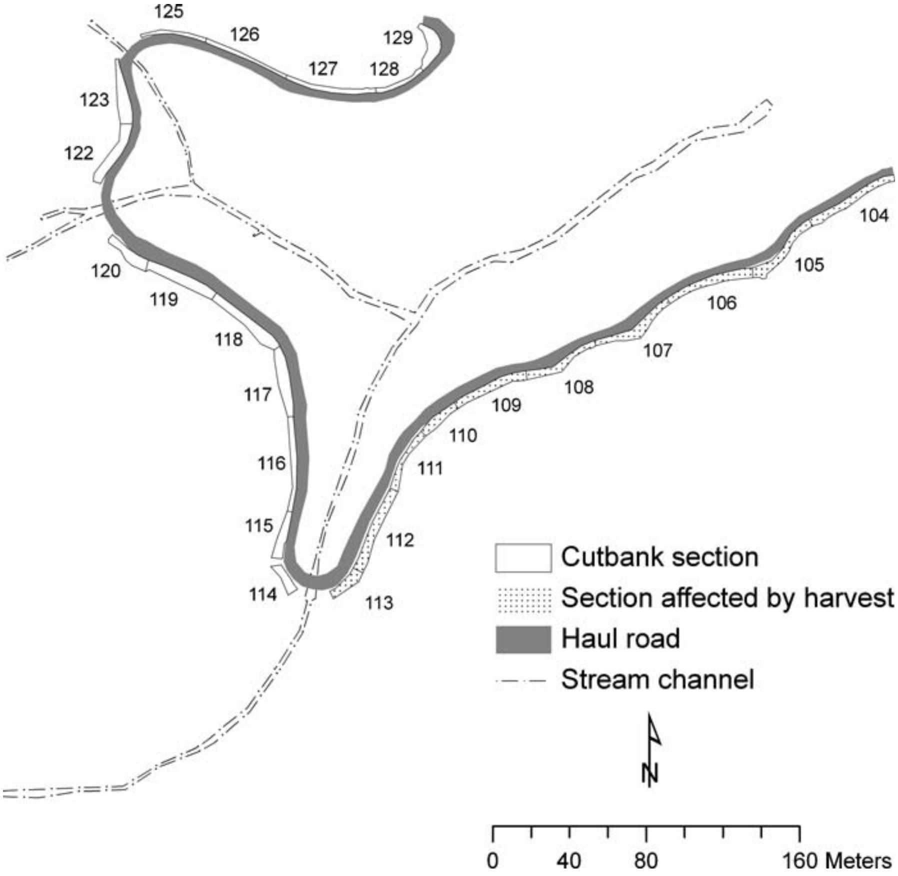
The beginning and ending boundaries of each section were delineated with reinforcing bar (rebar), which was hammered into the ground along the top of the cutbank. A metal tag with the section number was affixed to each rebar. Section numbers were sequential from 104 to 129 (Fig. 2). Section designations began from where the road entered the watershed to where it exited it, moving from low to high elevation; for example, section 104 was the area between section tags 104 and 105. Sections were not delineated at the stream crossings. No section demarcation was made along the base of the cutbank because there was a concern that markers would be knocked out or moved during road maintenance, or tires would be damaged if vehicles drove too close to the cutbank.

The percent vegetative cover within each section was analyzed from 2004 through 2007 using digital photographs. Because entire cutbank sections were too long to be photographed in a single frame, each section was divided into

Table 1 Mean air temperatures and total precipitation for the growing season (April through September) and dormant season (October through March) for the years before, during, and after cutbank seeding

Year	Air temperature		Precipitation	
	Growing	Dormant	Growing	Dormant
	°C		cm	
2002	17.56	0.17	79.6	90.4
2003	14.57	0.52	111.7	92.0
2004	15.40	1.38	94.2	85.3
2005	15.53	0.57	63.2	82.7
2006	15.43	1.98	91.3	77.2
2007	16.72	2.20	86.0	94.0

Fig. 2 Map of the study area showing cutbank sections along the Forest Service haul road



subsections, which were photographed in succession. Two-centimeter diameter polyvinyl chloride (PVC) pipe was placed vertically on the cutbank at approximately 3- to 4-m intervals to define the subsections. Thus, a given piece of pipe denoted both the right edge of one subsection and the left edge of the next subsection, and the pipe was not moved until both subsections had been photographed. Subsection divisions were not marked permanently and were not consistent widths or areas from year to year, but this was not a problem since the annual results were calculated as percent of the total area covered by vegetation. For areas of the cutbank that were too tall for a single 3-m-long section of PVC pipe, additional sections were attached using joint connectors. Generally, two cutbank subsections each year were too tall to include the entire height of the subsection in a single camera frame. Consequently, these subsections were divided into upper and lower parts, with PVC pipe also laid horizontally on the cutbank.

A Canon PowerShot G2™ 4.0-megapixel digital camera was used to photograph each subsection. Pictures were taken by standing on a bed-mounted tool box in a pickup truck. The truck was driven to approximately the center of each subsection for each photograph, and the camera was held above the photographer, approximately parallel to the cutbank surface to reduce displacement between the top and bottom of the photograph. The tiltable liquid crystal display on the camera allowed the cutbank image to be viewed while the camera was held in the air. Each photograph included both the left and right subsection PVC pipe dividers. Section and subsection information and corresponding photograph numbers were recorded in a field notebook for reference during subsequent image analysis.

Five sets of photographs were taken from 2004 to 2007. In 2004, 2006, and 2007, the cutbank was photographed in July. In 2005, photographs were taken in mid-June to ensure that the cutbank could be photographed fully before logging began and road access within the watershed would become limited. When logging damage to the cutbank between sections 104 and 113 was observed, a second set of photographs of only those sections was taken in early September 2005. Data for sections 114 and 129 were not available for all years because of modifications to the cutbanks so those sections were excluded from the analyses.

Because there is tilt and topographic displacement associated with the photographs as they moved away from the isocenter and nadir (University of California, Santa Barbara 2008) and vegetative cover estimates may be affected as a result of that displacement, we evaluated those effects on the quantification of percent vegetative cover. This was done on six subsections of cutbank: two of these were well vegetated, two were moderately well vegetated, and two were poorly vegetated. Five 0.61 × 0.61-m squares constructed of 2-cm-diameter PVC pipe were placed on each of the six subsections, with one square approximately in the middle, two near the top of the cutbank on the right and left sides of the subsection, and two near the bottom of the cutbank on the right and left sides of the subsection. With the five squares in place, a photograph of each of the six subsections was taken from the truck using the same procedures as for the rest of the study. The two well-vegetated and moderately well-vegetated subsections were relatively tall, so the photographs were taken in portrait layout, whereas the poorly vegetated subsections were taken in landscape layout since they were relatively short. Portrait orientation also was used for tall subsections and landscape for short subsections during the main part of the study.

Immediately after taking the full subsection photographs, a photograph of each square was taken while standing on the cutbank. The camera was attached to a camera mount on a prism pole set at 1.8 m and positioned at the edge of and directly over each square at the approximate angle of the cutbank to make the camera parallel to the ground surface. These paired sets of photographs were used to compare the effects of displacement on vegetative cover by comparing the percent cover within the squares from the photographs taken from the truck (i.e., where displacement was greatest) to those taken directly above the squares (i.e., where displacement was least). The test data set contained subsampled areas from the three different cover classes taken from the truck ($n = 30$) and from directly above the squares ($n = 30$).

Photographic image processing

ArcGIS™ 9.1 and extension software XTools Pro™ were used to create a boundary shapefile for each subsection. Points were inserted along the upper and lower cutbank boundaries and both vertical pieces of PVC pipe to create the boundary shapefile (Fig. 3a). There was some subjectivity in identifying the top and bottom boundaries, especially when the cutbanks became better vegetated, because the borders were not defined in the field. To aid in defining the boundaries, photographs from adjacent sections and previous year(s) were used to define them more consistently.

Vegetation in each photograph was identified using the supervised multispectral classification process in ERDAS IMAGINE® 8.7. First, a signature file containing two cover classes, “vegetation” and “other”, was developed from a subset of images deemed representative of all cover conditions on the cutbank. Next, a second randomly selected group of images was classified with the signature file. These images were checked for accuracy in ArcMap™ by overlaying a semi-transparent classified image produced in ERDAS IMAGINE® over the corresponding original image (Fig. 3b). If there was a significant amount of vegetation that was not classified as vegetation, the signature file was adjusted and tested again. After the signature file satisfactorily classified the test image subset, it was used to classify all of the images.

The classified image files were converted to cover shapefiles using the extension Image Analysis™ for ArcGIS raster-to-feature data conversion tool. Next, each cover shapefile was clipped using its boundary shapefile. The end result of the image processing was a thematic shapefile for each subsection that contained polygons coded as either “vegetation” or “other”. Total area (in square pixels) by cover class was summed and recorded for each subsection.

Because the photograph of each sequential subsection was a different scale due to the way

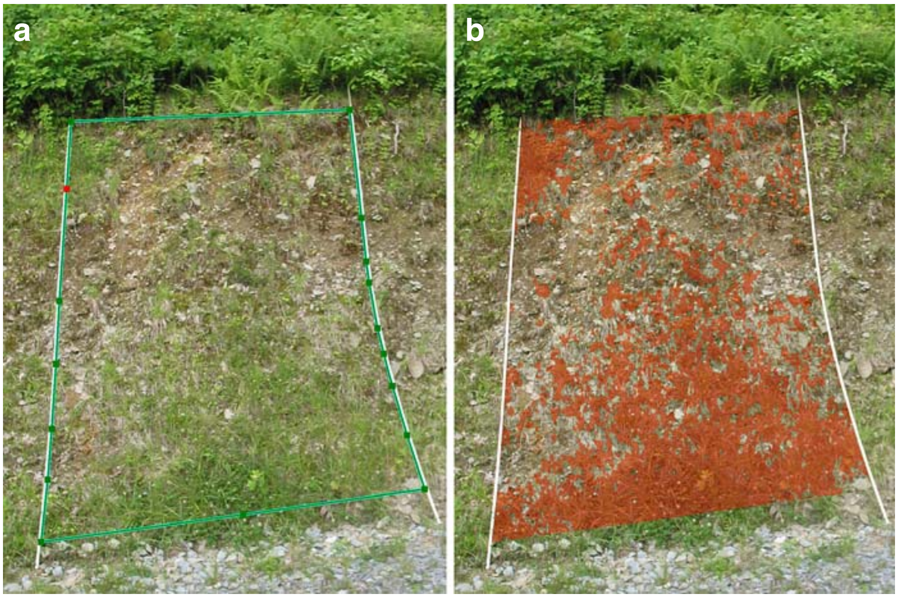


Fig. 3 **a** A boundary shapefile was created for the subsection in each photograph and then used to extract the subsection area from the classified image. **b** Results from the classification process are displayed over the original photograph with pixels classified as "vegetation" given a *red tint*

each picture was taken in the field—that is, as the pickup truck moved from one subsection to another, the distance between the camera and the cutbank was not the same—all subsection areas within each cutbank section were adjusted to a common scale. The scale factor between subsection photographs could be determined in one dimension and then squared before it was used to adjust the areas because the underlying unit of measure was square (i.e., a square pixel). Adjacent subsections always had a vertical PVC pipe in common, so height was the dimension chosen for scaling.

ArcMap™ was used to measure the height of each subsection boundary shapefile at its right and left edges with the first subsection in each section used as the base scale. A scale factor was calculated between each sequential pair of subsections (beginning at the left-most subsection and moving to the right) by dividing the right edge height of the first subsection by the left edge height of the second subsection. Next, adjusted edge heights were calculated for the second subsection using the scale factor. The process then was repeated for the second and third subsections and so on until a scale factor had been calculated for each sequential pair of subsections. An adjusted area was calculated for each cover class in each subsection by multiplying the area recorded above by the subsection's squared scale factor. Percent "vegetation" and "other" for each section were calculated by summing all adjusted areas by category from each subsection and dividing the category total by the total area of that section (i.e., the sum of "vegetation" and "other" areas) and multiplying by 100. To test for topographic displacement effects on vegetative cover results, the photographs of the squares taken from the truck and from the individual photographs for the six test subsections were processed as described above, except that no scale factors were needed.

Other variables

Mean azimuth and slope data for each section were calculated using ArcGIS™ 3D Analyst. Elevation points at the top and bottom of the cutbank sections had been collected using a total station during other research activities in the watershed, and these were used to construct a triangular irregular network (TIN) of each cutbank section. Azimuth (degrees) and slope (percent) grids were derived from each TIN, and then mean azimuth and mean slope were calculated for each section as area-weighted averages.

Statistical analyses

Statistical analysis of the percent vegetation in each section was performed using SAS® 9.1 (SAS Institute 2003). The percentages were tested for normality, and the results indicated that the data were not normally distributed. However, the normal probability plot showed the data were very close to being normally distributed—the exception being a slight deviation from normal in only a few sections with the highest percent cover. The typical transformation for percentage data is arcsine ($y^{0.5}$), which makes the interpretation of statistical test results extremely difficult relative to the original data (Studebaker 1985). Some initial tests of differences among sections were run on arcsine-transformed data and untransformed data, and the statistical probabilities were identical or nearly identical. Consequently, because of the near-normal distribution, initial test results, and greater ease in interpreting untransformed data, all tests were on the original untransformed percentages.

A mixed model repeated measures analysis was used to test for significant differences over time. Data were separated into 2004, 2005pre (i.e., 2005 before timber harvesting), 2005post (i.e., 2005 after timber harvesting), 2006, and 2007 data sets. Results were considered significant at $\alpha = 0.05$.

An analysis of variance (ANOVA) was used to test whether cutbank slope or azimuth affected mean percent vegetative cover. Mean slope and mean azimuth for each section were used as continuous variables. Mean cutbank slopes ranged from just above 70% to just less than 120% (Fig. 4). Cutbank sections also were grouped into aspect categories (Table 2) based on similar azimuth values, and an ANOVA was run to test for differences among aspect categories. Tukey's Studentized range (honestly significant differences) test was used for mean separation. Results were considered significant at $\alpha = 0.05$.

Nonparametric statistics were used to test for displacement effects because these data were not normally distributed. To test whether photographic displacement had a significant effect on percent cover, a Kruskal–Wallis ANOVA on ranks (SAS Institute 2003) was performed. The percent vegetation within the squares photographed from the truck was compared to the percent vegetation in the squares from photographs taken from directly above them for all of the subsections combined. Kruskal–Wallis ANOVA tests on ranks also were performed by cover class (i.e., by well-vegetated, moderately well-vegetated, and poorly vegetated subsections). Nonparametric test results also were considered significant at $\alpha = 0.05$.

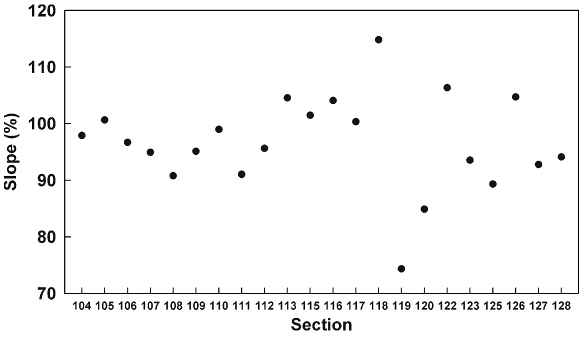


Fig. 4 Mean slope (%) for each section included in the analyses

Results and discussion

Displacement effects on percent vegetation

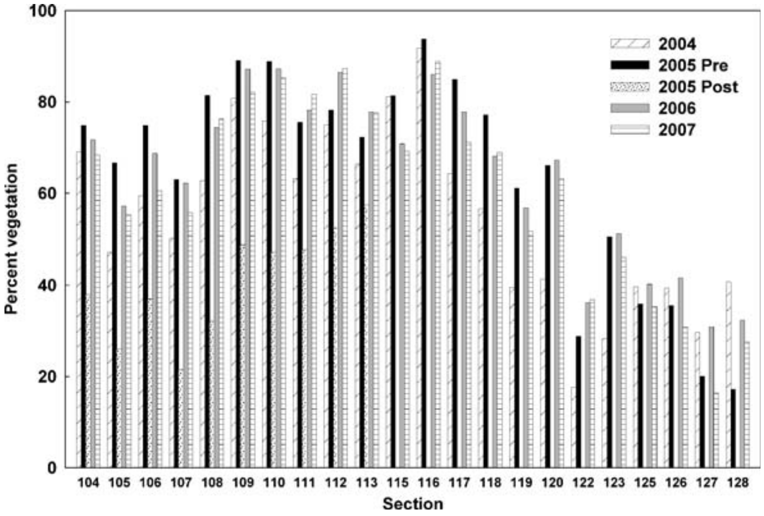
Because the overall utility of this variable-sized area approach for assessing cover depends upon how much of an effect the position of the camera had on vegetative cover, we describe these results first. There were no differences in percent cover between the two photographic locations for all subsections combined ($P = 0.859$) or by cover class (well vegetated $P = 0.705$; moderately well

Table 2 Cutbank sections included in each aspect category; refer to Fig. 2 for the locations of the cutbank sections

Aspect category	Cutbank sections
Northeast (25–45°)	118, 119, 120
East (80–125°)	115, 116, 117, 122, 123
South (160–210°)	125, 126, 127, 128
Northwest (300–320°)	110, 111, 112, 113
North northwest (325–345°)	104, 105, 106, 107, 108, 109

Sections 114 and 129 were not included in analyses in this paper

Fig. 5 Vegetation coverage in each cutbank section by time period



vegetated $P=0.290$; poorly vegetated $P=0.940$), suggesting that our technique provided reasonable estimates of percent cover. The lack of statistical differences by cover class indicates that the photograph orientation (portrait or landscape) also did not affect the results.

Cutbank vegetative cover

Even though vegetation was very sparse in 2003 prior to monitoring, by 2004, 16 of the 22 sections had at least 40% vegetative cover (Fig. 5), and the mean cover was 64%. The remaining six sections averaged 32% vegetation. Average percent cover for all sections in 2004 was 55% (Table 3).

The largest single-year gain in vegetation occurred between 2004 and 2005pre (Table 3). Over that year, vegetative cover increased by nine percentage points. Later increases were very small or negative, even when the cutbank sections in the harvest area were removed from consideration (Table 3). After 2 years of growth, overall vegetative development appeared to have reached a plateau of about 60% to 64% cover.

Azimuth was important at explaining cover ($P = 0.0111$); there were differences in vegetative growth on sections with different aspects. Northeast-, east-, and north northwest-facing cutbank sections comprised more than half of the subsections (Table 2) and followed the general pattern of quickly reaching a plateau between 60% and 70% cover (Table 4). By contrast, the northwest-facing cutbank sections continued to increase slightly through time (excluding the harvest-year effect) reaching an average cover of 83%. These northwest-facing cutbank sections may have had an advantage over other cutbank sections in that they had the combined benefits of the afternoon sun and later day warming associated with west-facing slopes, along with lower direct solar radiation and evapotranspirational losses associated with north-facing slopes.

Table 3 Mean percent vegetative cover by time period

Time period	Dates photographs were taken	Vegetative cover		
		All sections	Sections not in harvest area	Sections in harvest area
		%		
2004	July 20, 21, 23, 29	55.4a	47.5ab	64.9a
2005pre	June 16, 29	64.4bc	54.3ab	76.4b
2005post	Sept. 7–8	–	–	40.8c
2006	July 6	64.1b	54.9a	75.1b
2007	July 3	60.7ac	50.5b	73.0b

Time periods with different letters within a column were significantly different at $\alpha = 0.05$

Table 4 Means and standard deviations of percent vegetative cover in the different aspect categories measured on the road cutbank

Time period	Aspect category				
	Northeast (25–45°)	East (80–125°)	South (160–210°)	Northwest (300–320°)	North northwest (325–345°)
	%				
2004	45.8 ± 9.4a	56.6 ± 32.5a	37.3 ± 5.1a	70.1 ± 6.3a	61.5 ± 12.5a
2005pre	68.1 ± 8.2a	67.8 ± 27.3a	27.1 ± 10.0b	78.7 ± 7.2a	75.0 ± 9.5a
2005post	–	–	–	51.1 ± 4.9a	33.9 ± 9.6b
2006	64.0 ± 6.3ab	64.3 ± 20.4a	36.2 ± 5.4b	82.4 ± 5.1a	70.2 ± 10.4a
2007	61.2 ± 8.8a	62.4 ± 20.9a	27.5 ± 8.1b	83.0 ± 4.3a	66.4 ± 11.1a
All time periods[a]	59.8 ± 11.3a	62.8 ± 24.0a	32.0 ± 8.2b	73.0 ± 13.2c	61.4 ± 17.7ac

Aspect categories with different letters were significantly different within a time period at $\alpha = 0.05$

[a] Excluding 2005post for the northwest and north northwest aspect categories

North-facing soils also tend to have less soil drying in the winter and less frost heaving because they go through fewer freeze–thaw periods (Hursh 1949; Miller and Buell 1956).

South-facing cutbanks (sections 125–128) clearly had the most difficulty becoming vegetated and retaining vegetation (Fig. 5). For all time periods combined and all individual time periods, cover on the south-facing slopes was less and usually significantly less than all other aspects (Table 4). Even in 2004 when there was not a significant difference among aspect categories, cutbanks on south-facing aspects still had considerably less percent cover than the other aspects. Percent cover on the south-facing cutbanks ranged from about 27% to 37% through all time periods, and unlike other aspects, cover was greatest in 2004 (Table 4), the first year after seeding. Cover may have been densest that year due to residual effects from the lime and fertilizer that were applied in 2003 at the time of seeding. Such amendments have been shown to significantly improve growth and vigor of grass species immediately after application, but the effects decrease quickly without reapplication (Swank et al. 1988). Residual effects of these amendments presumably also were present on the other aspects since vegetation was relatively dense on these sections (Table 4), but less stressful growing conditions (e.g., greater soil moisture) apparently contributed to continued expansion of ground cover through 2005.

These poor growth responses on south-facing sections are consistent with other studies. Bochet and García-Fayos (2004) found cutbanks on south-facing aspects had lower rates of vegetation establishment than other aspects in Valencia, Spain. They attributed the lower growth rates to significantly lower soil moisture. In the southern Appalachian mountains, Swift (1984) reported that south-facing cutbank soils tend to dry out and lose cohesiveness more than soils on other aspects, so south-facing slopes are susceptible to dry ravel. South-facing slopes also tend to have a higher incidence of freeze–thaw occurrences, creating conditions less conducive for vegetation establishment and survival (Hursh 1949; Miller and Buell 1956).

Cutbank slope was not a significant explanatory variable for the percent vegetation in this watershed ($P = 0.1515$). The average cutbank slope for the entire length of cutbank was 96.4% with a standard deviation of ±8.3%. The relative similarity in the average slopes across all sections and the steepness of all cutbank sections probably explains why cutbank slope was not a significant variable. However, the fact that mean slope was not statistically significant does not mean that slope had no effect on vegetation. Bochet and García-Fayos (2004) reported that steep slopes can be difficult to vegetate because seed can be washed off the soil surface by precipitation. The cutbanks on this road were steep; in some cases, the mean slope exceeded 100% (Fig. 4).

Harvesting effects

Harvesting in summer 2005 was confined upslope of cutbank sections 104 to 113 (Fig. 2). These were the northwest- and north northwest-facing cutbank sections. Felling trees onto and dragging them up over the cutbank resulted in substantial damage to cutbank vegetation: For those sections only, percent vegetative cover from 2005pre to 2005post declined significantly from about 76% to 41% (Table 3). Cover on the harvesting sections that had northwest aspects declined from 79% in 2005pre to 51% in 2005post, and on the north northwest-facing sections cover declined from 75% to 34% over that same time (Table 4).

However, recovery of the affected cutbanks was quite rapid. By summer 2006, less than 12 months after harvesting, vegetative cover returned to 2005pre levels (Table 3). Established plants in adjacent undamaged areas would have provided readily available sources of seeds and root sprouts that could have exploited the growing space in the damaged areas. The soil scouring that resulted from dragging the logs up the cutbank also may have created a favorable growing condition for seed germination since scouring applied purposely as a site preparation tool has been shown to increase seed germination on exposed soil (Lhotka et al. 2004; Yoshida et al. 2005).

The cutbank sections in the harvest area coincided with aspects supporting the most-rapidly growing vegetation (Table 4). It is likely that other aspects would have remained less vegetated for a longer time period. For instance, damage to south-facing sections of cutbank probably would have been very long-term, given the general lack of vegetation expansion after the first year of measurement (Table 4).

Proper use of directional felling could have eliminated the cutbank damage caused by the harvesting. Alternatively, most, if not all, damage to the cutbank could have been avoided by changing the road construction contract. The road contract required removal of only the trees that were within the road right of way, which extended from slightly above the top of the cutbank to slightly below the base of the fillslope. The separate harvesting contract included all other timber removal in the harvest areas. Extending the right-of-way width in the road construction contract to include those trees that were within one tree length of the top of the cutbank (and hence could have fallen onto the cutbank during harvesting) would have effectively eliminated damage to the cutbank during subsequent timber harvesting.

Utility of the photographic and analysis techniques

Many quantitative techniques exist for assessing percent vegetative cover from the ground. The most common approaches are the point intercept method (Wilson 1960; Floyd and Anderson 1987), the line intercept method (Gregoire and Valentine 2008), the subplot frequency method (Bråkenhielm and Qinghong 1995), and visual estimation methods (Daubenmire 1959; Sykes et al. 1983). Except for the line intercept method, these other methods involve some type of fixed-area sampling, usually accomplished by a frame of a specified area set on the ground, from which ground cover is estimated. Of these approaches, visual methods are most often employed because of the speed that these estimates can be made relative to other options (Sykes et al. 1983); however, even accurate visual estimations can be labor intensive and time consuming.

The advent of digital photography has made more quantitative measurements of ground cover practical and affordable, because many problems associated with film have been eliminated with digital technology (US Army Corps of Engineers 2005; Booth et al. 2006). In addition, sophisticated software now can allow individual species to be identified electronically (Booth et al. 2006; Luscier et al. 2006), thereby bringing some of the advantages of visual sampling to image analysis. However, digital photography has continued to involve analysis of fixed-area sample plots (Lukina et al. 1999; US Army Corps of Engineers 2005; Booth et al. 2005, 2006; Luscier et al. 2006).

The commonality of all of these approaches is that they involve sampling, which by definition means that measurements or estimates are made on small areas and the results must be extrapolated to the entire area. Thus, accuracy of the results requires the samples to be representative of the entire area, which can be a difficult task to ensure, particularly in continuous populations (e.g., cutbanks) which do not “lend themselves to simplistic description” (Gregoire and Valentine 2008), and because the term “representative sample" has many different interpretations (Kruskal and Mosteller 1979a, b, c).

The novelty and utility of the digital photographic approach used here is the ability to apply image analysis to variable-sized areas so vegetative cover of the entire cutbank, rather than samples, could be estimated. Differences in cutbank heights and camera distances from the bank in different subsections could be accommodated because of the scale adjustments applied to the vertical PVC pipe boundaries. Thus, each year, the entire 0.9 km of cutbank could be photographed in less than 8 h, eliminating problems associated with selecting plot locations and data extrapolation and damage to the cutbank from other on-the-ground measurement techniques. Another 2 weeks of office time was required to develop the signature file, prepare the images, and perform the Geographic Information System analyses used to quantify vegetative cover for the entire length.

We fully acknowledge that visual estimation without the use of plots likely will always be the primary method used to estimate road cutbank cover and cover on many other types of areas (e.g., skid roads) for most land management activities. However, there may be situations where low sedimentation is paramount (e.g., high quality fisheries or potable water supplies) and erosion control measures must be verified; in some cases, subsequent management activities may not be allowed to proceed without that verification. The technique we have described in this paper is well suited for those types of situations, because it can provide both measurements and long-term photographic records of the conditions present. This technique also can provide a method for calibrating and testing inspectors' eyes to improve the accuracy of their visual estimates of ground cover since there otherwise can be substantial discrepancy among different observers (Sykes et al. 1983).

This approach has application to other situations, particularly those involving longitudinal measurements with variable upper and lower boundaries, such as monitoring for invasive species in riparian areas. Because the upslope boundary of the riparian area may not be easily identifiable from photographs, the edge could be defined in the field with rope, landscape paint, etc., so that it is discernable at the time of image analysis. The camera can be mounted on an adjustable pole so the proper camera alignment and height could be attained. The visual output can be routed to a small portable battery-operated display to see the view from the ground and the photograph taken using the remote control that is available for most digital cameras. This setup is described in detail by Davies (2004). Application of photographic techniques (e.g., emitted wavelengths) or software also could be used to focus only on those species of interest (Lukina et al. 1999; Luscier et al. 2006).

Conclusion

The entire length of a 0.9-km cutbank of a forest haul road was photographed from the road to determine the percent vegetation present over several years using image analysis. Unlike previous studies describing photographic analyses, we did not employ fixed-area plots, but instead used variable-sized sections that allowed the quantification of the cutbank vegetative cover from the base to the top of the cutbank. We also compared the percent cover from photographs taken directly above small fixed-area plots to those taken from the haul road and found no significant difference in percent cover, suggesting this approach is a reasonable tool for land managers when there is a need to quantitatively document if vegetative cover requirements are met.

Cutbank slope was not a significant variable for explaining differences in vegetation coverage among cutbank sections. Aspect did significantly affect mean vegetation establishment. Percent vegetation cover was significantly lower on south-facing aspects compared to northeast-, east-, northwest-, and north northwest-facing aspects after the first year following seeding.

Increases in perennial vegetative cover over time were expected; however, significant increases in overall percent vegetation only occurred between the first and second years of monitoring (1 year after seeding) for most sections. They typically reached a plateau of between 60% and 70% vegetative cover. The northwest-facing cutbank sections reached the greatest percent vegetative cover, at about 83% in the last year of the study

(5 years after seeding). This high percent cover occurred despite the fact that a harvest damaged and reduced the vegetation on cutbanks with that aspect by 36% about midway through the study.

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