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A HISTORY OF THE FULLER CURVE

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ABSTRACT

The gradation (size distribution of aggregate particles) in Portland cement and hot mix asphalt concretes is important to their strength, performance, and economy. Fuller developed mathematical functions based on empirical evidence for determining maximum density gradation blends of aggregates. Over the subsequent century, Fuller's methodology is cited as the seminal research that has lead to the current state of the practice. Fuller's original research reports were consulted in an attempt to better understand the methodology.

Fuller actually proposed two different but similar curves and a physical test procedure in order to produce workable, dense Portland cement concrete using the most widely available aggregates at the turn of the 20th Century in the New York City area. In the 1920s Richard Grün, a German Portland cement researcher, accepted Fuller's curve based on a trade journal summary of Fuller's research. Fuller's caveat of fitting the curve to each aggregate or combination of aggregates seems to have been dropped. In the early 1940s, L.W. Nijboer, a Dutch asphalt researcher, adopted the Fuller curve from Grün's work and tested asphaltic mixtures using triaxial testing. Based on his research he proposed changing the curve and plotting it logarithmically. This gave rise to a different ideal form (a straight line instead of a parabola). In the early 1960s American researchers Goode and Lufsey proposed adopting Nijboer's results. This form of the Fuller curve has remained unchanged for over 45 years. The Fuller curve is now far enough from its origins that it needs to be revalidated for its present use or be replaced.

INTRODUCTION

The distribution of sizes of particles in a granular material is termed its gradation. Usually, for convenience, it is expressed in terms of weight percent although volume percent is more important. Data on the frequency distribution is usually gathered by sieving the material and weighing the amount retained on each sieve. The data are usually analyzed graphically.

Knowing the gradation is useful in civil engineering for such purposes as estimating the engineering properties (Scott 1980), filter design (Craig 1983), asphalt mix design (Roberts et al. 1996), and Portland cement concrete. In applications such as the filter and asphalt mix design, knowledge of the space not occupied by particles can be as important as knowledge of the space occupied by particles.

In asphalt mix design, gradation is one of the most important, if not the most important, property of the aggregate (Roberts et al. 1996). A dense particle packing is desired for reasons of economy (since the aggregate is cheaper than the asphalt) and stability (the asphalt is a viscoelastic material that would flow under the pressures encountered in highway use and the aggregate does not). Dense packing gives more particle-to-particle contact and a more stable pavement, but too dense an aggregate mixture does not leave enough room for asphalt to coat the aggregate particles, resulting in a pavement which will fail in multiple modes, such as raveling and fatigue. The most widely used technique for assessing gradation is known as the Fuller curve after its originator, William

B. Fuller. A widely used asphalt design and practice textbook (Roberts et al. 1996) gives the Fuller curve as:

$$i = 100(d_i / D)^n$$

i is the total % passing through sieve *i*,
D is the maximum aggregate size,
d_i is the opening size of sieve size *i*

Fuller found that maximum density is obtained when n = 0.5. The Federal Highway Administration recommended in 1962 that the value of n be changed to 0.45 (Goode and Lufsey 1962), which is the value and procedure used today in the asphalt design process. In practice, however, the use of the Fuller curve is more complicated than the simple equation suggests it might be. In order to leave room for the asphalt in the mix, the densest packing is not desired. Parts of the gradation curve actually used therefore run parallel to, but within a few percent of, the maximum line. This need to leave room for the asphalt gave rise to the concept of voids in the mineral aggregate (VMA). Satisfying the Fuller curve and the VMA requirements can be the most difficult part of the design process (Anderson and Bahia 1997). If use of the Fuller curve and the resulting VMA requirements are so difficult then why is the Fuller curve still used? To try to answer this question the history of the Fuller curve and its use are traced.

MATERIALS AND METHODS

WILLIAM B. FULLER AND HIS PHILOSOPHY

William B. Fuller was a civil engineer whose career went from 1883 to at least 1913. He seems to have been a graduate of MIT since he is mentioned in class notes in the MIT newspaper and alumni magazine as being in the class of 1883. He is first mentioned in 1884 (Fry 1884) as "assistant traveling engineer on railroad between St. Paul and Helena, and constructing engineer of water works at Bismark, Dakota." Apparently, water supply interested him since he was mentioned as being the resident engineer at the slow sand-filtration plant being built at Albany (ASCE Anonymous, 1900a) and as having returned from similar work in Philadelphia. In 1902 he is listed in the class notes as the resident engineer of the Jersey City Water Company in Paterson, NJ, and as being in charge of a masonry dam project (ASCE Anonymous 1902).

By this time in his career, Fuller was active professionally, being a member of the American Society of Civil Engineers (ASCE Anonymous 1900b) and the Municipal Engineers of New York City (Taber 1908). He listed himself as a consulting engineer with an office at 170 Broadway [Manhattan] (Taber 1908). This address is the same as that for the firm Hering & [George W.] Fuller, with whom he was associated in the Little Falls project. Opinion differs on whether the Fullers were related. Zink (Zink 2002) says "no relation", whereas Hall (Hall 1993) says they were brothers. In the last reference that can positively be identified as the William B. Fuller who devised the Fuller curve, he is chased out of Mexico at gunpoint while he was working on a water supply dam (Anonymous 1913).

At the time when he did the research which led to the original Fuller curve, he was a trained, experienced civil engineer at the height of his career. His working philosophy can best be summarized by this comment he made on a paper which described the use of arched groins to cover a slow sand filter bed (ASCE Anonymous, 1900b):

> *It is to be regretted that in demolishing a theory on which formulas are based, other formulas cannot be set up in their place, but the writer believes that the case of the groined arch is too complicated for the development of theoretical formulas which can be even approximately correct, and suggests that practical experimenting and the development of empirical formulas is the only solution to such questions.*

FULLER'S ORIGINAL CURVE

The first version of Fuller's maximum density curve resulted from the work he did at Little Falls, New Jersey. The project at Little Falls has been extensively documented by George W. Fuller (Anonymous 1903). William B. Fuller comments at the end of the George W. Fuller paper on the concrete work, but the comment mostly had to do with the stresses in the concrete. His only comment on the gradation used comes in his last sentence: "A great deal of care was taken with the grading of the sizes of the sand and the stone, so as to have the voids filled very thoroughly before any cement was placed in the mass."

However, in a treatise on concrete published in 1905 (Taylor and Thompson 1905) Fuller wrote Chapter XI entitled "Proportioning Concrete". It is in this chapter the first version of the Fuller curve, a parabola, appears:

$$d = \frac{P^2 D}{10\,000}$$

where d = any given particle diameter, P = percentage of mixture smaller than any given diameter, and D = the largest diameter of stone.

The equation cited by Roberts (Roberts et al. 1996) is an algebraic manipulation of this Fuller curve. Fuller's purpose was not to find an expression for the maximum density of aggregate. He was attempting to improve Portland cement concrete. Specifically, he was trying to make a strong, watertight, and economical concrete. The overall goal of his work was to improve proportioning of the concrete, i.e. finding the best ratio for the water, cement, sand, and stone in the mixing of the concrete. Based on his experience and upon experiments he made using transverse breaking strength and ease of workability ("works the smoothest in placing"), he determined that an aggregate with a gradation (which he termed "mechanical analysis") that "forms a curve approaching that of a parabola with its beginning at zero coordinates (0) and passing through the intersection of the curve of the coarsest stone with the 100% line, that is, passing through the upper end of the coarsest stone curve" was the best.

It appears that for Fuller, the importance of his maximum density curve is not in its shape but in the use to which he can put a maximum density curve. Fuller discussed how the curve allows him to have a method for selecting the right proportions of materials and how it allows him to evaluate the suitability of these materials in comparison with other materials and with other available sizes. Fuller's original curve and the simplest exposition of his method, which can be done either graphically or using ratios, is shown in Figure 1. The authors of the book of which Fuller's chapter is a part add the caveat in a footnote that the exact form of the curve is less important than Fuller's method and that another curve may eventually be found. They also mention that Fuller's method of a fairly even gradation is at odds with Mr. R. Feret's method of a gap-grading, which probably was close to what would be called "packing" today.

The chapter as a whole is largely a discussion of various methods of proportioning concrete. Brief mention is made of French practice and reference is made to Mr. George W. Rafter's method of proportioning. Arbitrary selection is discussed with the comment that it works better than might be expected, and a table of recent projects was provided to aid in arbitrary selection. Proportioning by means of void determination as practiced at that time gave poor results in Fuller's opinion. The voids were determined by the amount of water it took to apparently fill the void space. Fuller gives good physico-geometrical reasons why this method of void determination gives poor results, producing inferior quality concrete.

The two methods that Fuller treats at some length are what he calls *volumetric synthesis* or *proportioning by trial mixtures* and *proportioning by mechanical analysis*, which is a sieving and graphing method. The volumetric synthesis method is quite simple. It consists of making trial mixtures with an arbitrary starting point in a cylinder and noting which mixture gives the smallest volume in the cylinder. He does mention the necessity of discarding the mixture before it sets up. He also mentions a similar, but not identical, method by Frederick Schutte of Warren Brothers Asphalt Company that apparently did not include mixing asphalt into the trial mix.

Fuller's method of mechanical analysis, although apparently novel at the time, contains much that is familiar today, such as sieve analysis and graphing the results. An application of the methods today might substitute a spreadsheet on a digital computer for the graph paper or the slide rule of Fuller's original description. Another aspect to Fuller's method is that he was intensely cost-conscious. His chapter opens with a discussion of the economic advantages of using his method. The curve itself is cost-neutral, being a mathematical construct, but Fuller takes pains to show that with his method there is a considerable cost-savings per yard of concrete. Fuller's method aims to design an economical concrete as well as a high quality concrete.

FULLER'S REVISED CURVE

After Fuller worked at Little Falls, New Jersey, he worked on building the Jerome Park Reservoir in what is now the Bronx. This reservoir, which was only recently taken out of service, is large (over a third of a square mile) and involved the excavation of a large amount of rock (Anonymous 1901). In a progress report in *Scientific American*, it is reported that approximately seven million cubic yards of rock had been excavated and that ten million cubic yards would probably eventually be excavated. To dispose of some of the material a four-mile-long railway was built across the Bronx. Fuller was given considerable resources for a laboratory investigation on this project. He reported in considerable detail in the Transactions of the American Society of Civil Engineers (ASCE Anonymous 1907). Although Fuller's name is remembered, the paper is actually coauthored with Sanford E. Thompson, who was the coauthor of the earlier book where Fuller's chapter gave the first version (and better remembered one) of Fuller's curve. The relative contributions of the coauthors are unclear.

In this phase of his work Fuller has a slightly different approach. Instead of assuming that the curve of maximum density will approach an ideal mathematical curve, Fuller did extensive work on different sizes and types of materials and fits mathematical curves to the empirically determined analyses. By definition, these curves start with 7% cement content in the fines so that the curves run from 7% on the *x*-axis rather than zero. From this starting point, the curve is an ellipse to the % passing at one tenth maximum aggregate size. A straight line then connects the % passing at one tenth maximum aggregate size point to the maximum aggregate size at 100% passing. This curve (Figure 2) is thus similar to, but not the same as, the previous parabola.

In his earlier work Fuller calls the material he was working with "trap". In this context *trap* means the crushed stone made from a dark, fine-grained, nongranitic, extrusive or shallow intrusive rock (Bates and Jackson 1987). Fuller does not give a source for the rock used at Little Falls but traprock is reasonably common in northeastern New Jersey. An example (although probably not used on the Little Falls project) would be the basalt cliffs, the Palisades, seen while crossing the George Washington Bridge westbound. In contrast, in his work at Jerome Park Reservoir, Fuller is careful to describe his materials. One is the rock at the site itself, which is mica schist. In the paper he mentions the variable nature of the material and how the specific gravity of sample varies. The other material is Cow Bay sand and gravel (which Fuller for some unexplained reason spells "Cowe Bay"). The Cow Bay sand and gravel was uniform and the major source of sand and gravel for making Portland cement concrete in the New York City area for many years. An estimated 140 million cubic yards were shipped, which accounted for 90% of the sand used for concrete in the area (Hogan 2008). In contrast to the Jerome Park Reservoir material, which is a metamorphic rock that needed to be crushed and screened before it was used, the Cow Bay material is unconsolidated glacial outwash that only needed to be washed and screened. Fuller thus did his studies on the site material (which was available in enormous quantities) and on the predominate concrete aggregate in the area, which was easy to mine and which was transported by barge from the nearby mines. Fuller and Thompson note in their paper that the curves obtained from different materials are different.

Fuller's 1907 ASCE paper is usually cited as the source of the Fuller curve (Roberts et al. 1996), although the Fuller curve is given as a parabola. However, in the cited paper is the combination ellipse-straight line. In the 1907 ASCE paper Fuller attempted to use a parabolic curve for the analysis of the material used at the Jerome Park Reservoir but the results were unsuitable. Hence he developed the combination ellipse-straight line curve shown in Figure 2. For some time the combination of ellipse and straight line was used by other engineers.

Even within the 1907 ASCE paper, however, the Fuller curve was changing. In the written discussion of Fuller and Thompson's paper, James L. Davis gives some plots of other aggregates available in downstate New York using Fuller's approach. Davis assumed that the parameters given for Jerome Park Reservoir crushed stone would adequately represent all crushed stone. For an example, see Figure 3. However, as Fuller and Thompson state in their reply to Davis' discussion, it is unclear if he used a 7% cement content starting point. Examination of the best images available of Davis' graphs reveals that Davis did not use the 7% starting point.

FULLER'S WORK PUBLICIZED

Taylor and Thompson's treatise, which contains Fuller's parabolic equation, must have had a certain success and influence since it appeared in at least four editions. Publications of ASCE are widely distributed, albeit to members and to specialized libraries. However, it seems that what publicized Fuller's work is publication in a trade journal, *Engineering News*. Interestingly, at this time the volumetric synthesis and mechanical analysis methods are separated from each other. The volumetric synthesis method is given in a short paper (Fuller 1907), abstracting what Fuller said to the National Association of Cement Users in Chicago, January 8-11, 1907.

The mechanical synthesis method is given as an anonymous summary (Anonymous 1907) of the ASCE paper. No equations are given as equations, although they are alluded to verbally. There are a number of figures in the paper but the only ones that show the Fuller curve are those of Davis from the discussion. These graphs are the version that Fuller and Thompson had reservations about.

THE FULLER CURVE GOES TO EUROPE: THE WORK OF GRÜN

The main stream of the history of the Fuller curve then moves to Europe. Richard Grün was a leading German Portland cement concrete researcher who was active in the 1920s, 1930s, and perhaps into the 1940s. In 1926 he published a book (Grün 1926) that is mainly concerned with what attacks and degrades concrete. However, in the front of the book Grün gives an account of how concrete was made in Germany at the time and shows his interpretation of the Fuller curve and other, similar curves resulting from European research (see Figure 4). The reference Grün cites for the Fuller curve is the *Engineering News* account of

Fuller's work and Grün's curve looks very much like Davis' version.

THE FULLER CURVE JUMPS TO ASPHALT: THE WORK OF NIJBOER

Working in the early 1940s in the Royal Dutch Shell laboratories in Amsterdam, L.W. Nijboer did a considerable amount of research on asphalt-bound concrete (as opposed to the Portland cement-bound concrete of previous workers who used the Fuller curve). Using methods from soil mechanics he came up with results that are still known, if not widely read, today. Nijboer cites Grün who used the Fuller ellipse-straight line curve; however, Nijboer presents graphical evidence that using a parabolic equation with the exponent n = 0.45 for determining the maximum density blend for aggregates gives improved results. Nijboer also draws on European research on parabolic maximum density curves (Wilhelmi 1935; Andreasen 1930). Andreasen presents theoretical and experimental results from his work on parabolic curves in a dense, aggregate packing. He references Grün and Fuller. His paper shows familiarity with a Fuller curve that starts at 7% and is elliptical; his paper uses some of the constants reported by Fuller and Thompson but the citation does not refer to Fuller and Thompson's 1907 paper.

THE FULLER CURVE RETURNS TO AMERICA: THE WORK OF GOODE AND LUFSEY

Fuller favored the ellipse-straight line approach to determining maximum density blends of aggregates. Knowledge in America of Fuller's curves was never completely lost. In 1941 Hveem (Hveem 1941), who worked with asphalt in California, gives an example of both Fuller curves plotted on the same graph and an example of the Fuller curve plotted semi-logarithmically (see Figures 5 and 6). The currently applied parabolic curve with n = 0.45 is commonly attributed to the work of Goode and Lufsey (Goode and Lufsey 1962), who evaluated and recommended the work of Nijboer. Goode and Lufsey did develop the graphical technique of altering the scale of the abscissa to a "power 45" scale such that the parabolic equation plots as a straight line (see Figure 7). They did this transformation to make the maximum density line a straight line rather than what they term "a deeply sagging curve, the shape of which is hard to define." They felt that the ease of interpretation with their graphical treatment made it preferable to the semi-logarithmic treatment of the previous 30 years, as in Hveem's plot (Figure 6).

RESULTS

THE ROLE OF THE FULLER CURVE IN ASPHALT DESIGN TODAY

Although it was devised a century ago for use with Portland cement concrete, the Fuller curve as modified is still used as a guide in the design process for asphalt mixes. It is the starting point to get an acceptably dense, well-graded aggregate mix.

DISCUSSION

The Fuller parabolic curve is still used to get a good aggregate blend for use in asphaltic concrete although perhaps not in the form and spirit that Fuller devised it. As noted above, it is not without some extra effort that the curve makes its contribution. Is this due to the curve itself or the way it is being applied? Perhaps it is time to go back to the curve where Fuller left it and see if more research can improve it.

ACKNOWLEDGEMENTS

The patient Interlibrary Loan Office of the WVU libraries had been very helpful in getting obscure references not available at WVU.

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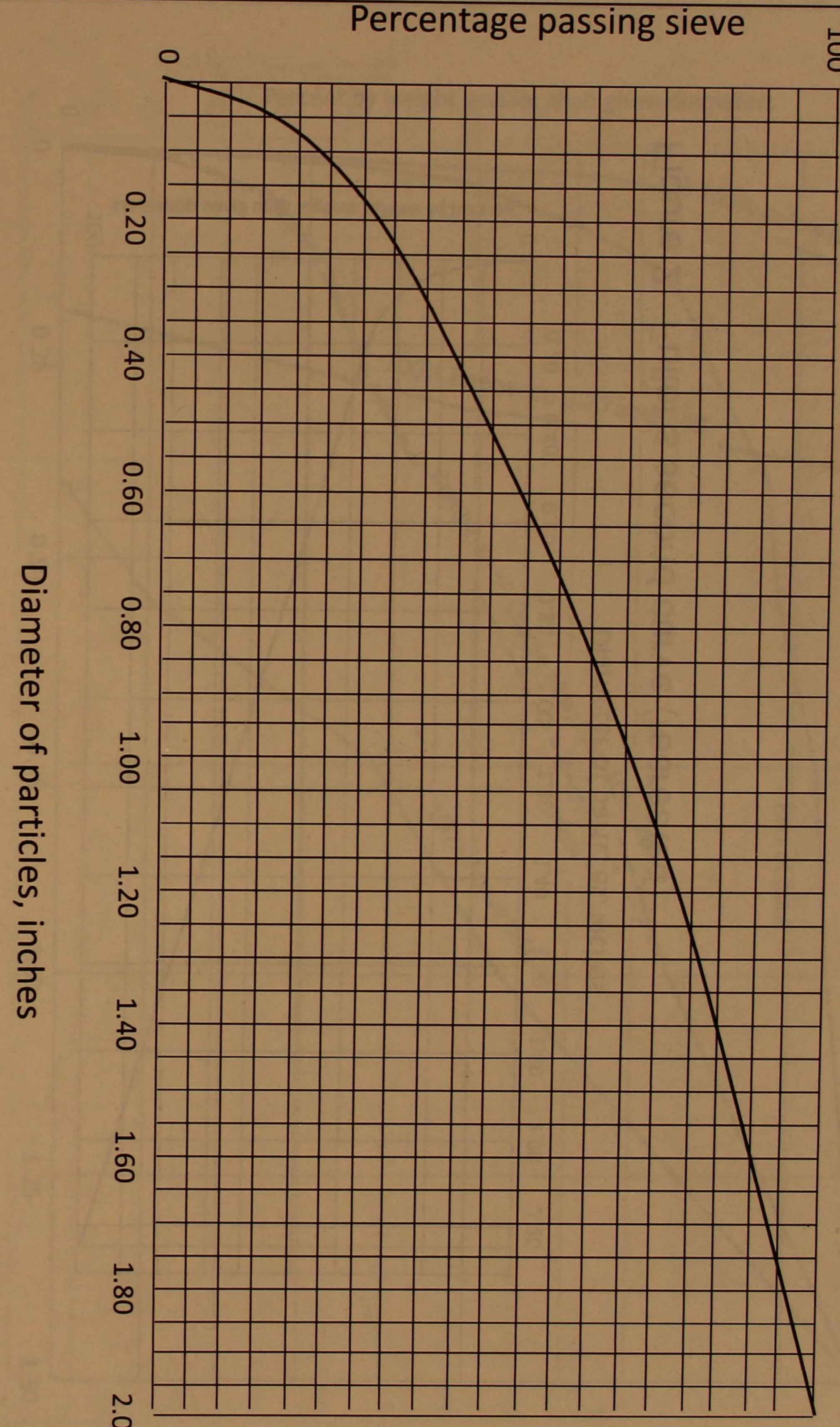

Figure 1. Fuller's original curve (recreated).

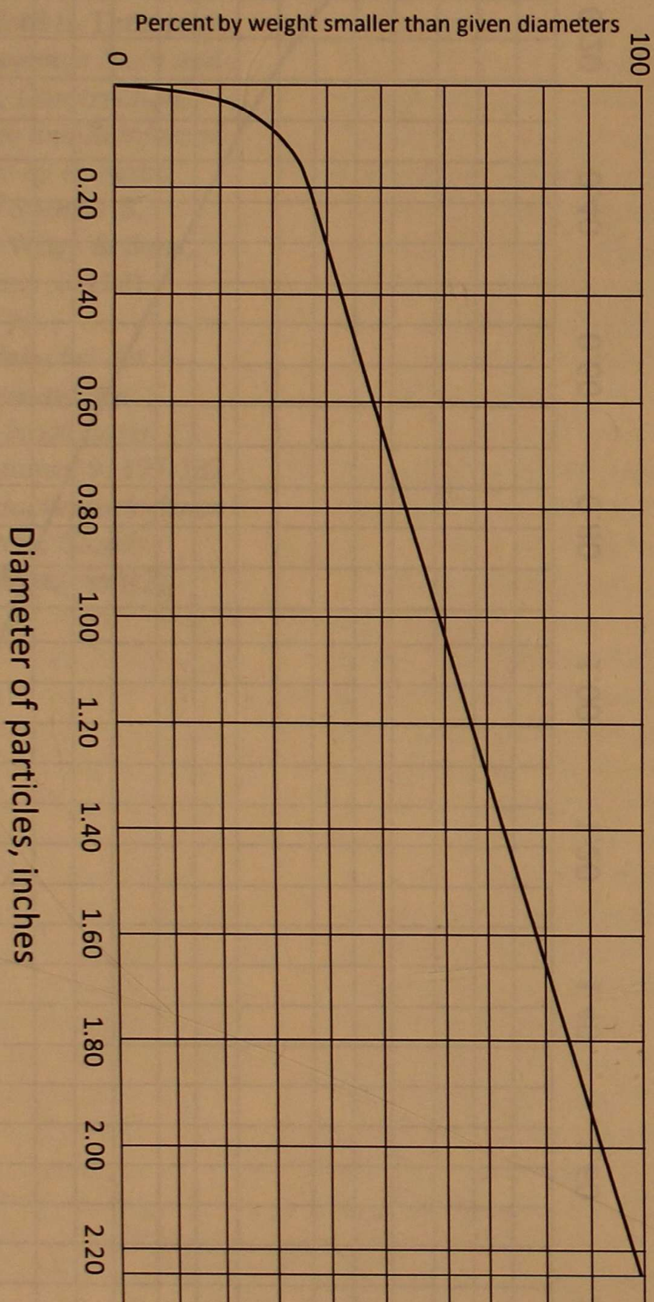

Figure 2. Fuller's second curve (recreated).

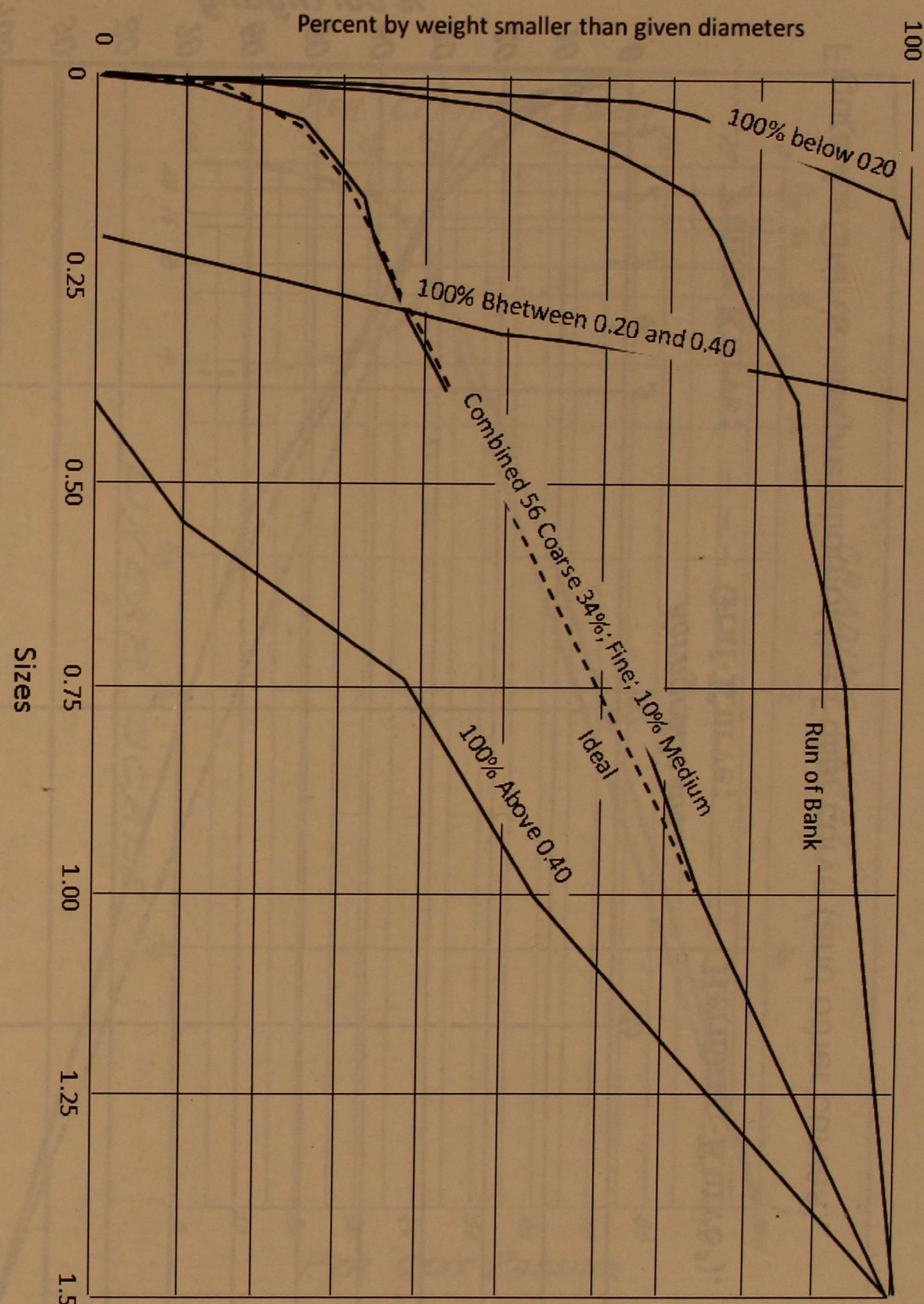

Figure 3. Davis' interpretation of the Fuller curve using other data (recreated).

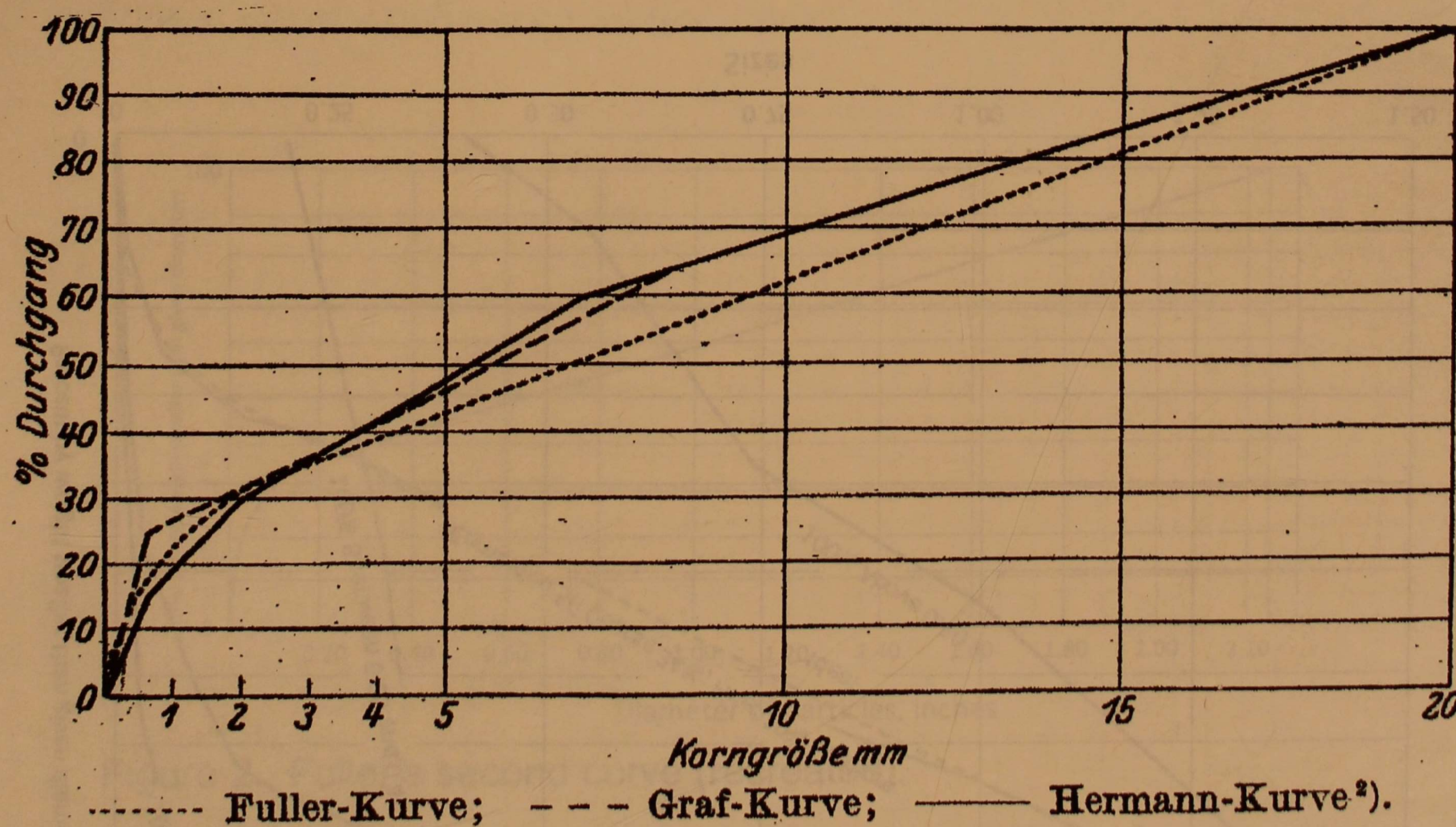

Figure 4. Grün's interpretation of the Fuller curve (and other curves).

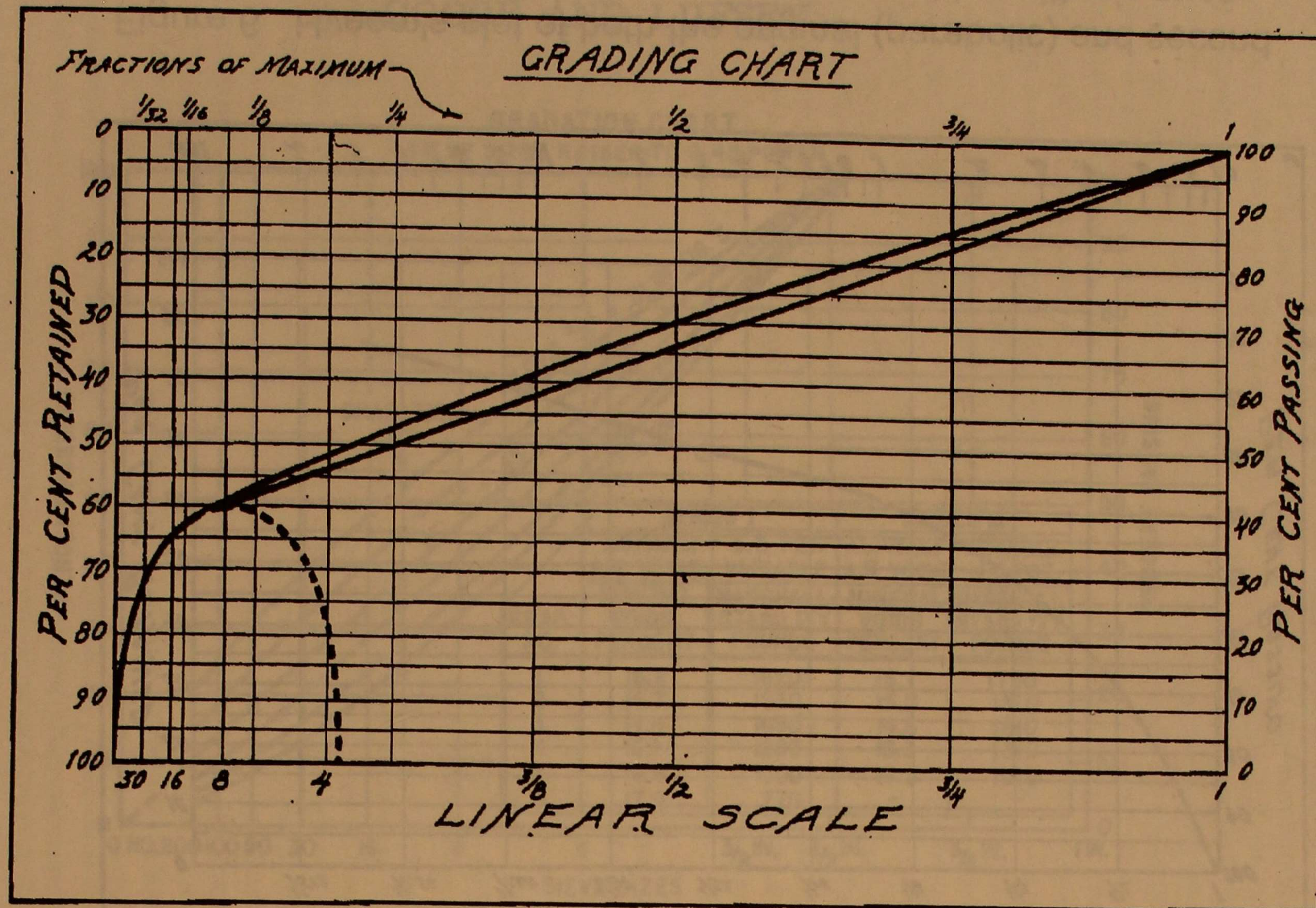

Figure 5. Hveem's plot of both the original (parabolic) and second (elliptical-straight line) Fuller curves using arithmetic axes.

Figure #2

Semi-logarithmic scale with Fuller's curve superimposed.

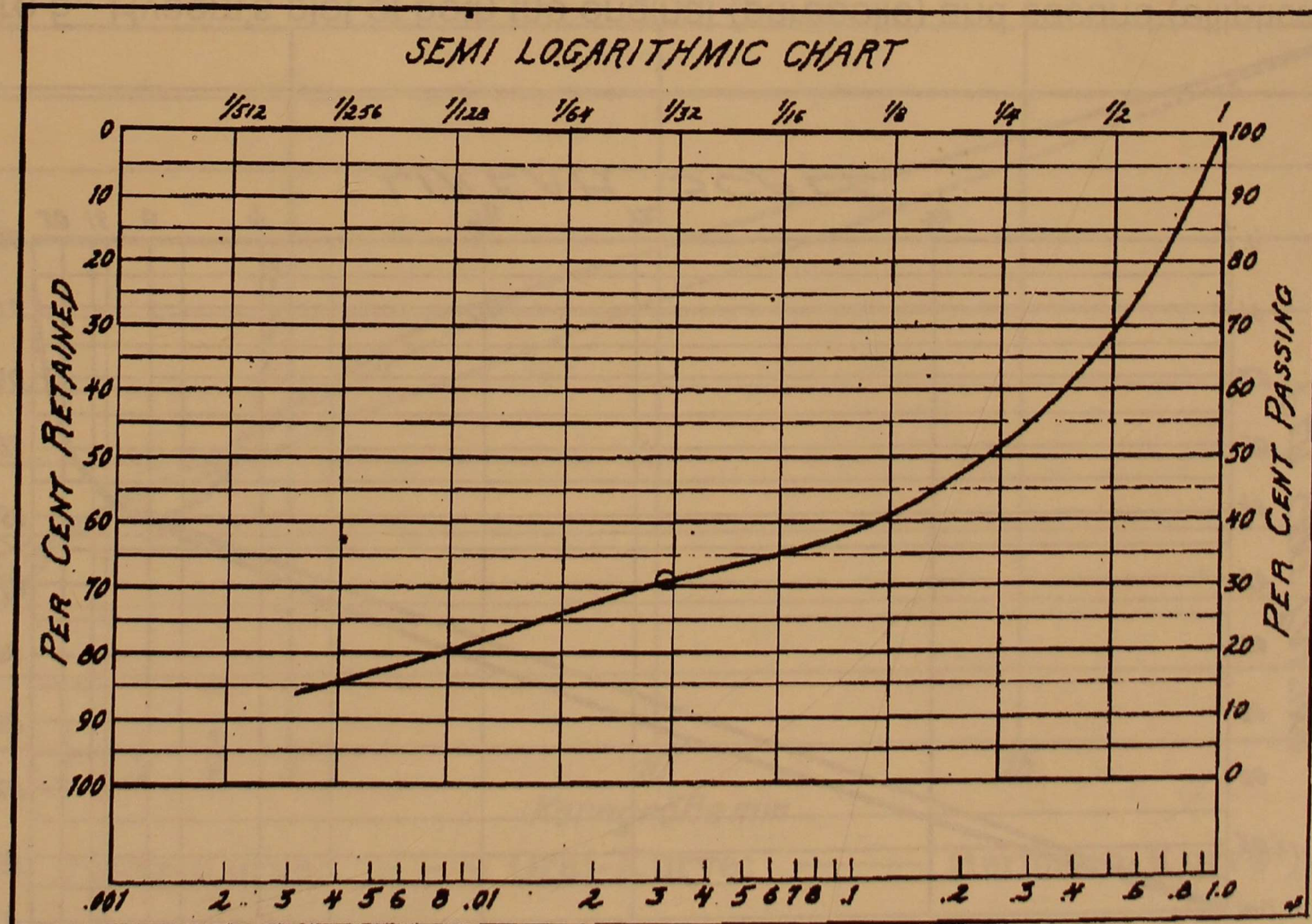

Figure 6. Hveem's plot of both the original (parabolic) and second (elliptical-straight line) Fuller curves using semi-logarithmic axes.

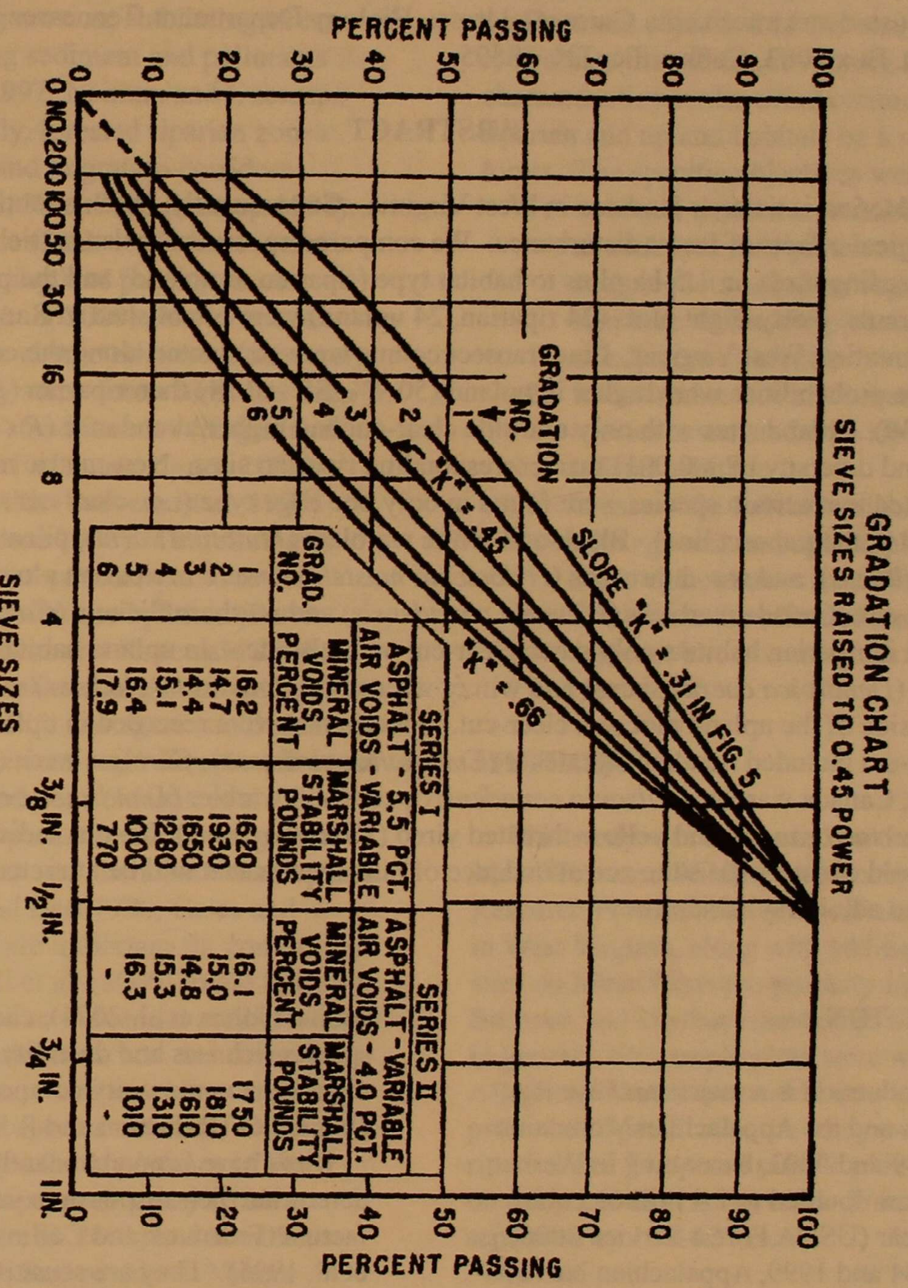

Figure 7. Goode and Lufsey's power 45 curve.

CLEARCUTS AND HABITAT TYPE AFFECT NEIGHBORING AVIAN COMMUNITIES

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ABSTRACT

Timber production is a major land use in West Virginia. Consequently, much attention has been given to ecological effects of forest disturbance. We compared species abundance, richness, and diversity of breeding birds on 1.5-ha plots to habitat type (riparian or upland) and the presence of bordering clearcuts. Forty-eight plots (24 riparian, 24 upland) were established in Randolph, Upshur, and Barbour counties, West Virginia. Line transect counts were conducted along the center line of each plot. Detection probabilities were higher in upland (50.9%, SE = 0.04) than riparian (33.8%, SE = 0.03) plots ($P = 0.030$). Upland sites with only one side clear-cut had higher abundance ($P < 0.001$), richness ($P < 0.001$), and diversity ($P < 0.001$) than corresponding riparian sites. Non-metric multidimensional scaling indicated that certain species were found in only one edge type (i.e., clear-cut sides of zero, one, or two parallel to the transect line). Black-and-white warblers (*Mniotilta varia*), pileated woodpeckers (*Dryocopus pileatus*), and wood thrushes (*Hylocichla mustelina*) were in riparian plots only when one side was clear-cut. Canada warblers (*Wilsonia canadensis*) and northern flickers (*Colaptes auratus*) were recorded in riparian habitats only when clear-cut on both sides. In upland habitats, black-throated blue warblers (*Dendroica caerulescens*) and winter wrens (*Troglodytes troglodytes*) were found only when neither side of the upland plot was clear-cut. Species that were recorded in upland sites with only one side clear-cut included Acadian flycatcher (*Empidonax virescens*), Carolina wren (*Thryothorus ludovicianus*), Canada warbler (*Wilsonia canadensis*), cerulean warbler (*Dendroica cerulea*), indigo bunting (*Passerina cyanea*), and yellow-throated vireo (*Vireo flavifrons*). Results indicate that forest managers should consider the suite and abundance of bird species that will be attracted to harvested woodlands and adjoining habitats.

INTRODUCTION

Timber production is a major land use in West Virginia and the Appalachian Mountains. Between 1989 and 2003, harvesting in West Virginia almost doubled to 2.4 million cubic meters per year (USDA Forest Service 2006). Between 1984 and 1999, Appalachian harvests as a whole increased by nearly 9.6 million cubic meters per year. Selective cutting has been used in some areas as a means to reduce the impacts on aesthetics and wildlife. Regardless, passerines dependent on mature forests have experienced a gradient of responses to forestry activities. Effects can be caused by altered habitat (Jobes et al. 2004), changes in vegetation species richness and diversity, and shifts in vegetation community composition and relative abundance (Robinson and Robinson 1999).

Birds have been abundantly studied to determine their response to various disturbance factors (Freemark and Collins 1992; Donovan et al. 1995). They are sensitive to, and respond rapidly to, environmental changes and occupy a wide variety of landscape classes (Glennon and Porter 2005). One portion of the landscape that has received particular attention is riparian zones. Due to the high edge-to-area ratio, these areas are vulnerable to changes in the surrounding landscape (Martin et al. 2006).

These ecosystems are important not only for birds, but for a relatively large number of plant and animal species. Essential environmental functions also are performed in these zones, including reducing erosion, stabilizing stream banks, and trapping sediment and pollutants (Kauffman et al. 1997; Naiman and Decamps 1997). Additionally, forested riparian zones provide dispersal and migration corridors (Schumacher 1993; Knopf and Samson 1994).

Avian abundance (Saab 1999; Knutson et al. 2000) and breeding bird pairing success (Rodewald and Yahner 2000) also have been linked to landscape characteristics. Conversely, habitat selection by some forest birds has been explained by local stand features (Hagan and Meehan 2002; MacFaden and Capen 2002), including forest width (Darveau et al. 1995; Hodges and Krementz 1996). Therefore it is important to consider various spatial scales when explaining habitat use by birds (Porter et al. 2005; Bakermans and Rodewald 2006). With significant emphasis on conservation of riparian zones, wildlife managers could make more informed decisions regarding the effects of the surrounding landscape (Martin et al. 2006).

Because some riparian forests have greater bird species richness and abundance than upland forests (Stauffer and Best 1980; Gates and Giffen 1991), they are important for conserving bird habitat. Riffell et al. (2006) found that size of forested area was an influential predictor of riparian species richness, and that diversity of vegetation structure was most important in determining upland species richness. Other studies have revealed the importance of the surrounding landscape on diversity (Cam et al. 2000; Boulinier et al. 2001) and abundance (Howell et al. 2000; Rodewald and Yahner 2001; Bakermans and Rodewald 2006) of breeding birds within forests. Bird distribution also has been related to vegetative structure. James and Wamer (1982) found the highest density of birds in forests occurred at high values of tree species richness and canopy height and at intermediate values of tree density. They likewise found the lowest density and species richness of birds in areas of low tree species richness, low canopy height, and high density of small trees.

The main objective of this study was to evaluate the effects of varying habitat characteristics on the avian community in riparian and upland habitats on a managed forest. The specific objectives were as follows:

1. to obtain detection probabilities and abundances for riparian and upland sample plots based on vegetative structure within the plot and the presence of adjacent clearcuts;
2. to determine tree and breeding bird species associated with riparian and upland habitats;
3. to assess the habitat variables associated with riparian and upland plots and the avian communities in each; and
4. to evaluate the effect of clearcuts on adjacent bird communities by habitat type.

METHODS

This study was conducted on the MeadWestvaco Wildlife and Ecosystem Research Forest (MWERF) in Randolph County in West Virginia, along with additional, similar sites on MeadWestvaco property in Randolph, Barbour, and Upshur counties in West Virginia. In general, the sample plots were within the Allegheny Mountains and Plateau physiographic province. Specifically, the study occurred on 24 riparian and 24 upland sample plots measuring 60 m by 250 m (1.5 ha) each. Plots were separated by 100–127 m.

BIRD SAMPLING

Breeding bird counts were conducted twice per plot between late May and late June of 2006 with a single observer. Transects were walked parallel to the long sides of each plot between 0500 and 1100 h on days without heavy rain or high winds. Line transects were chosen over point counts for this research due to the size and shape of the plots, and the low density and high mobility of some species in the sample plots. Use of line transects has been supported by other studies that found this method to be more effective than point counts for songbirds (Wilson et al. 2000). While walking transects, all birds seen or heard were recorded by species. The distance from the observer to a bird was determined using a range finder, along with the compass angle from the line. Date, time, and weather conditions for each count were noted.

VEGETATION SAMPLING

Vegetation sampling was conducted following the method described by James and Shugart (1970). Four 0.04-ha circular subplots were established 50 m apart within each 1.5-ha sample plot. Vegetation sampling subplots were placed along the same line as transects. Each subplot had a radius of 11.3 m, and all trees >8 cm diameter at breast height (dbh) within the circle were measured and recorded by species. The number of snags >8 cm in the subplot were recorded as a separate variable. Within 5.0 m of the subplot center, the number of woody stems ≤8 cm dbh and >0.5 m high were recorded. At all subplots per sample plot, an ocular tube was used to categorize ground and canopy cover. Two 22.6-m transects were established in each plot, one perpendicular and one parallel to the slope. At every 2.26 m along each transect, the type of ground vegetation and level of canopy cover viewed through the ocular tube were recorded.

Vegetation data were categorized into ground cover classes, tree diameter classes, and canopy height classes. Ground cover was divided into four groups (woody debris, leaf litter, bare rock, and green vegetation). Tree diameter data were separated into four dbh classes of 8–23 cm, 24–38 cm, 39–53 cm, and >53 cm (Wood et al. 2005). Canopy height was divided into six classes of 0.5–3 m, 3.1–6 m, 6.1–12 m, 12.1–18 m, 18.1–24 m, and >24 m (James and Shugart 1970).

Local vegetation analysis was performed with ARCMAP™ 9.1 (Environmental Systems Research Institute, Redlands, CA). West Virginia landcover data from the National Land Cover Database (2001; 1:24,000) and digital orthophoto quarter quadrangles (DOQQ; 1:4,800) from the West Virginia Statewide Addressing and Mapping Board (2003) were used as references. Each plot was downloaded as a layer from global positioning system (GPS) tracks, and was considered an experimental unit. The number of plot sides bordered by a clearcut was initially determined by viewing the geographical information system (GIS) data, and later verified visually at each plot.

DATA ANALYSIS

To achieve the first objective, bird sampling data were analyzed between habitat types (riparian vs. upland) using program DISTANCE (Thomas et al. 2005) to calculate detection probability, density, and abundance of total birds. Line transect information was imported into DISTANCE and analyzed with a hazard rate function and hermite polynomial series expansion. Input data included plot name, bird species, bird count, habitat type, and number of long sides bordered by a clearcut. Data were filtered to obtain output regarding riparian and upland habitats, along with plots bordered by a clearcut on zero, one, or two long sides. Differences were considered significant at $P \leq 0.05$.

To achieve the second and fourth objectives, Mann–Whitney tests were conducted to compare avian abundance, diversity, and richness to habitat type and number of sides clearcut, respectively, using R© statistical software, version 2.4.1 (R Development Core Team 2004). Formulas for the above variables were as follows:

Abundance = Number of individuals detected per plot,

Richness = Number of species detected per plot, and Shannon diversity = - $\sum p_i * \ln(p_i)$, where p_i is the proportion of species *i* present.

Comparisons also were made for these variables in plots bordered by a clearcut on zero, one, or two sides. The dissimilarity matrix was derived, and ANOSIM performed on the matrix using R©. The matrix was input into program RNDTST6 (U.S. Environmental Protection Agency) to calculate within-group and between-group similarities. Non-metric multidimensional scaling (NMDS) was conducted on the vegetation data (e.g., number of trees and snags, diameter and height of trees, and ground cover). Bird abundance ($n \geq 5$ observations), diversity, and richness values were fit to NMDS plots to determine relations of bird communities to vegetation variables.

To achieve the third objective, bird sampling data were analyzed among vegetation variables using Mann–Whitney or Kruskal–Wallis tests. Avian richness, Shannon diversity, and abundance were compared among the total number of trees per plot, total number of snags per plot, diameter distribution of trees, height of trees, and type of ground cover.

RESULTS

We counted a total of 248 birds in riparian plots and 312 in upland plots. Detection probabilities were 17% higher in upland than riparian plots ($F = 2.19$; df = 1, 23; $P = 0.030$; Figure 1). Estimated density (number of birds/ha) from program DISTANCE of riparian (mean = 12.5, SE = 1.37) and upland (mean = 14.9, SE = 1.40) sample sites was not significant ($F = 0.62$; df = 1, 23; $P = 0.467$). Plots with zero, one, or two sides clear-cut had no difference in detection probabilities ($F = 0.30$; df = 2, 21; $P = 0.736$). The interaction between habitat type and number of sides clear-cut had no effect on detection probability ($H = 0.90$; df = 1, 44; $P = 0.328$).

The Mann–Whitney test between all riparian and all upland habitats regardless of number of sides clear-cut revealed no differences in avian abundance ($U = 242.0$; df = 1, 23; $P = 0.348$; Table 1). However, richness was greater in riparian than upland habitats ($U = 1.5$; df = 1, 23; $P = 0.004$), while diversity was higher in upland than in riparian habitats ($U = 166.5$; df = 1, 23; $P = 0.011$). The Kruskal–Wallis test among riparian and upland habitats with zero, one, or two sides clear-cut indicated lower abundance in riparian plots bordered by one clearcut than in riparian habitats bordered by zero or two clearcuts or any upland habitat ($H = 141.66$; df = 1, 23; $P < 0.001$). Richness was lower in upland habitats bordered by two clearcuts than in upland plots bordered by one clearcut or riparian habitats with zero or two sides clear-cut ($H = 142.66$; df = 1, 23; $P < 0.001$). Diversity was lower in riparian habitats with one side clear-cut than in riparian habitats with zero sides clear-cut or any upland habitat ($H = 152.20$; df = 1, 23; $P < 0.001$).

Kruskal–Wallis analyses of avian abundance, diversity, and richness among vegetation variables indicated that canopy height, number of trees, and dbh of trees within the plots impacted bird communities. Riparian avian abundance increased with increasing number of trees ($H = 17.11$, df = 3, $P < 0.001$), avian diversity was highest at average tree dbh 8-23 cm ($H = 31.17$, df = 3, $P < 0.001$; Figure 2), and highest avian richness was found at canopy height 6-18 m ($H = 11.27$, df = 3, $P < 0.004$; Figure 3).

Non-metric multidimensional scaling on riparian versus upland tree species and bird species indicated a separation of tree (Table 2) and bird (Table 3) communities by habitat type (riparian versus upland). NMDS on ground-cover variables indicated that leaf litter was related to higher abundance and diversity, while bare rock was related to higher species richness. Total, riparian, and upland bird communities were then analyzed based on the number of plot sides bordered by a clearcut using NMDS. There were no apparent separations of total, riparian, or upland bird species based on zero, one, or two plot sides clear-cut (ANOSIM statistic R < 0.011, $P = 0.385$). The MEANSIM (RNDTST6) output indicated that differences between groups (bird communities in plots with zero, one, or two plot sides clear-cut) were greater than within groups. The difference, however, was not significant (R = 0.005, $P = 0.289$), and was in agreement with the ANOSIM results.

Certain bird species present in riparian habitats were found only in plots bordered by a clearcut on a specific number of sides. Black-and-white warblers ($n = 4$), pileated woodpeckers ($n = 2$), and wood thrushes ($n = 4$) were in riparian plots only when one side was clear-cut. Canada warblers ($n = 4$) and northern flickers ($n = 2$) were recorded in riparian habitats only when clear-cut on both sides.

In upland habitats, black-throated blue warblers ($n = 5$) and winter wrens ($n = 2$) were found only when neither side of the plot was clear-cut. Species that were recorded in upland sites with only one side clear-cut included Acadian flycatcher ($n = 8$), Carolina wren ($n = 2$), Canada warbler ($n = 2$), cerulean warbler ($n = 2$), indigo bunting ($n = 2$), and yellow-throated vireo ($n = 2$). No species were found in upland habitats exclusively in plots bordered on two sides by a clearcut.

DISCUSSION

Detection probabilities of individual species in varying habitats indicate the percentage of birds recorded versus birds present. The 17% lower detection probability in riparian compared to upland habitats was likely due to stream noise in riparian plots. Also, the amount and interference of environmental noise and the effects on detection of birds would likely change as the growing season progressed and vegetation changed (Bart et al. 2004; Somershoe et al. 2006).

Edge effect created by clearcuts and associated predation (Manolis et al. 2002) could motivate birds to seek undisturbed habitat. A variety of predators have been associated with narrow, linear, riparian zones (Vander Haegen and DeGraaf 1996). Consequently, certain riparian species may move toward the side of the riparian zone that is not clear-cut. Birds may simply not be present in these habitats with one edge. At least one recent study has found that availability, as well as the detection probability, of the monitored species should be considered when calculating abundance (Diefenbach et al. 2007).

In upland plots with one clear-cut side, the diversity in vegetative structure may counteract increased predation (Rodewald and Brittingham 2002). Increased feeding opportunities for some upland species in this type of habitat could create greater activity. Vitz and Rodewald (2006) found that mature-forest songbirds in non-riparian sites readily used clearcut interiors and preferred small (4–9 ha) rather than large (13–18 ha) clearcuts. This was in agreement with an earlier study that found several area-sensitive forest birds fed or nested in clearcuts <5 ha in size (Thompson and Fritzell 1990).

The number of riparian plot sides bordered by a clearcut also had an apparent influence on some bird species. In riparian habitats, Canada warblers and northern flickers were found exclusively when both sides were clear-cut. This can be explained by the preference of Canada warblers for forest undergrowth and shady thickets. Northern flickers prefer open forests and semi-open country to meet its nesting and ground-feeding needs (Elchuk and Wiebe 2002). The availability of this type of habitat in a streamside zone clear-cut on each side would be ideal for Canada warblers and northern flickers. Black-and-white warblers, pileated woodpeckers, and wood thrushes were found in riparian habitats only in plots bordered by one clearcut. Perhaps this group is less sensitive than other woodland birds (e.g., downy woodpeckers (*Picoides pubescens*), Eastern wood pewee (*Contopus virens*), and hermit thrushes (*Catharus guttatus*)) to disturbance and fragmentation (Golet et al. 2001; Hartung and Brawn 2005).

The same explanation could apply to black-throated blue warblers and winter wrens in upland habitats with no clear-cut sides (Jobes et al. 2004). Both of these species are associated with forest understory or brush, which may imply that they would be observed in plots bordered by clearcuts. It is possible that these two bird species are sensitive to the proximity of openings, and merely prefer forests with small, tree-fall gaps that would naturally increase the understory. In upland plots, several species were found only in sites with one clear-cut side. These include species that prefer understory and brushy thickets (Carolina wren, Canada warbler, indigo bunting), and interior woodland (cerulean warbler, yellow-throated vireo). The presence of the understory group is logical due to the increased sunlight and understory growth next to a clearcut. However, their absence in plots with both sides clear-cut may suggest that predation from both sides is too great, and these species move to other sites. More possible proof of increased predation pressure is that no species were found exclusively in upland plots with two sides clear-cut (i.e., it is possible that no species prefers habitat with two edges and proximity to two large openings).

As indicated by NMDS, abundance, diversity, and richness classes were all positively correlated with the presence of tree canopy < 24 m, but not strongly correlated with total number of trees within the plot. This result is in agreement with James and Wamer (1982), who found that bird species richness and density were positively correlated with canopy height, but negatively correlated with tree density. NMDS also indicated that avian abundance and diversity were positively correlated with leaf litter as ground cover, but richness was correlated with bare rock. Perhaps this is due to greater food availability in leaf litter, and therefore, a greater number of birds that could be supported by the habitat. Richness may increase with the presence of bare rock because of greater substrate variability. Timber management techniques will determine whether habitat alteration in forests can increase total avian abundance or relative abundance of various bird species.

MANAGEMENT IMPLICATIONS

Researchers usually are concerned with focal species' responses within treatment boundaries. One research study has indicated that the presence of most bird species could be explained by stand-level, as opposed to landscape-level, variables (Hagan and Meehan 2002). However, some birds were more affected by the surrounding landscape, which would indicate that managers should consider effects outside treatment plots. There is no global model for explaining bird species abundance, richness, or diversity. Likewise, timber management practices should not be globally applied without regard for region or habitat.

The dynamics of the ecosystem also must be considered (Holmes and Sherry 2001). The short-term response of any cutting practice will not likely persist for the long term (Milner et al. 2007). Timber and wildlife managers should consider the desired species not only in the cutting plot but also in surrounding areas (Manley et al. 2005) along with the time frame in which results are desired.

Collecting noise-level data within sample plots, although not gathered for this project, could provide additional information regarding detectability of the entire bird community as well as of certain species. Decibel data could be input into program DISTANCE as a covariate to further explain detection probabilities for specific sample plots. However, noise levels would need to be considered on specific call-counting dates, especially in riparian areas, due to changes in stream flow rates. Nonetheless, it is clear that detection probabilities need to be obtained for bird surveys conducted in riparian zones. Resulting abundance estimates would provide a more accurate representation of the avian community.

Interactions between habitat type and neighboring clearcuts could influence avian response to further habitat alteration. The difference in avian diversity and richness in upland plots with zero sides clear-cut compared to similar riparian cuts indicates the need for further research regarding the effect of stand and landscape characteristics. If increased avian abundance, diversity, and richness are the goals of a management area, habitat with one side (upland) or two sides (riparian) clear-cut and the majority of trees in the 8-23 cm dbh class with canopy 6–18 m in height should be targeted. Habitat managers should consider these interactions, along with detection probabilities, when determining goals for avian communities. Forest managers should be cognizant of clearcut effects on neighboring habitats and employ strategies such as selective cutting.

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Table 1. Bird population indices by habitat type and number of sides clearcut in the MeadWestvaco Wildlife and Ecosystem Research Forest in May and June, 2006.

Number of Sides Clearcut	Habitat Type: Upland Mean (Standard Error) Abundance	Upland Richness	Upland Diversity	Riparian Mean (Standard Error) Abundance	Riparian Richness	Riparian Diversity
0	13.00 (0.82)a[a]	6.00 (0.47)ab	2.04 (0.08)a	11.25 (0.88)ab	7.00 (0.69)a	1.83 (0.09)a
1	12.30 (0.92)a	6.58 (0.42)a	1.88 (0.07)a	9.64 (0.87)b	5.93 (0.58)b	1.63 (0.06)b
2	12.30 (0.88)a	5.00 (1.00)b	1.77 (0.14)ab	11.33 (0.33)ab	6.17 (0.67)ab	1.72 (0.20)ab
Overall	12.60 (0.55)c	5.93 (0.41)c	1.93 (0.05)c	10.90 (0.57)c	6.26 (0.30)d	1.69 (0.05)d

[a] Means followed by same letter are not different ($P > 0.05$) by Kruskal-Wallis test.

Table 2. Tree species associated with riparian and upland habitats (n = number of observations) in the MeadWestvaco Wildlife and Ecosystem Research Forest in May and June, 2006, as determined by NMDS plot.

Riparian ($n \geq 46$)	Upland ($n \geq 17$)
Yellow Birch (*Betula alleghaniensis*)	Red Maple (*Acer rubrum*)
Sweet Birch (*Betula lenta*)	Bitternut Hickory (*Carya cordiformis*)
Yellow Poplar (*Liriodendron tulipifera*)	Chestnut Oak (*Quercus prinus*)
Eastern Hemlock (*Tsuga canadensis*)	Sourwood (*Oxydendrum arboretum*)
	Cucumber Magnolia (*Magnolia acuminata*)
	Black Gum (*Nyssa sylvatica*)

Table 3. Bird species associated with riparian and upland habitats (n = number of observations) in the MeadWestvaco Wildlife and Ecosystem Research Forest in May and June, 2006, as determined by NMDS plot.

Riparian ($n \geq 7$)	Upland ($n \geq 5$)
Acadian Flycatcher (*Empidonax virescens*)	American Robin (*Turdus migratorius*)
Black-capped Chickadee (*Poecile atricapillus*)	Black-and-white Warbler (*Mniotilta varia*)
Black-throated Blue Warbler (*Dendroica caerulescens*)	Worm-eating Warbler (*Helmitheros vermivorus*)
Scarlet Tanager (*Piranga olivacea*)	Hooded Warbler (*Wilsonia citrina*)
Louisiana Waterthrush (*Seiurus motacilla*)	Ovenbird (*Seiurus aurocapillus*)
	Eastern Wood Pewee (*Contopus virens*)
	Eastern Towhee (*Pipilo erythrophthalmus*)
	Wood Thrush (*Hylocichla mustelina*)
	Blue Jay (*Cyanocitta cristata*)
	Tufted Titmouse (*Baeolophus bicolor*)

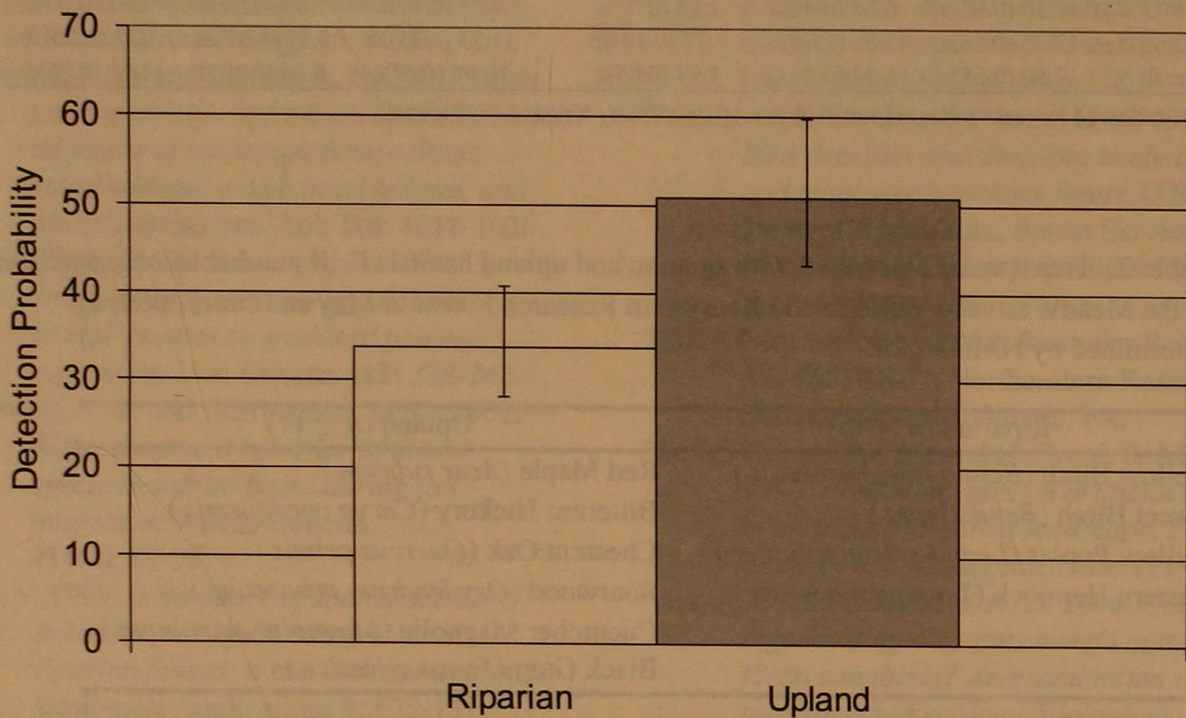

Figure 1. Detection probability with 95% confidence intervals for all bird species combined by habitat type on the MeadWestvaco Wildlife and Ecosystem Research Forest in May and June, 2006.

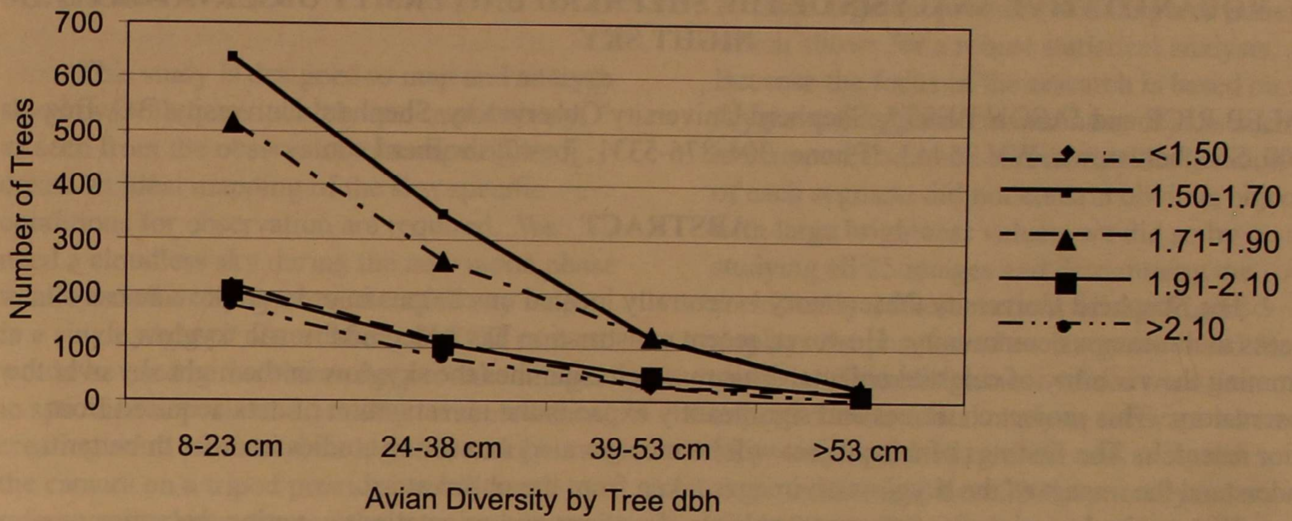

Figure 2. Avian diversity by number of trees per dbh category on the MeadWestvaco Wildlife and Ecosystem Research Forest in May and June, 2006.

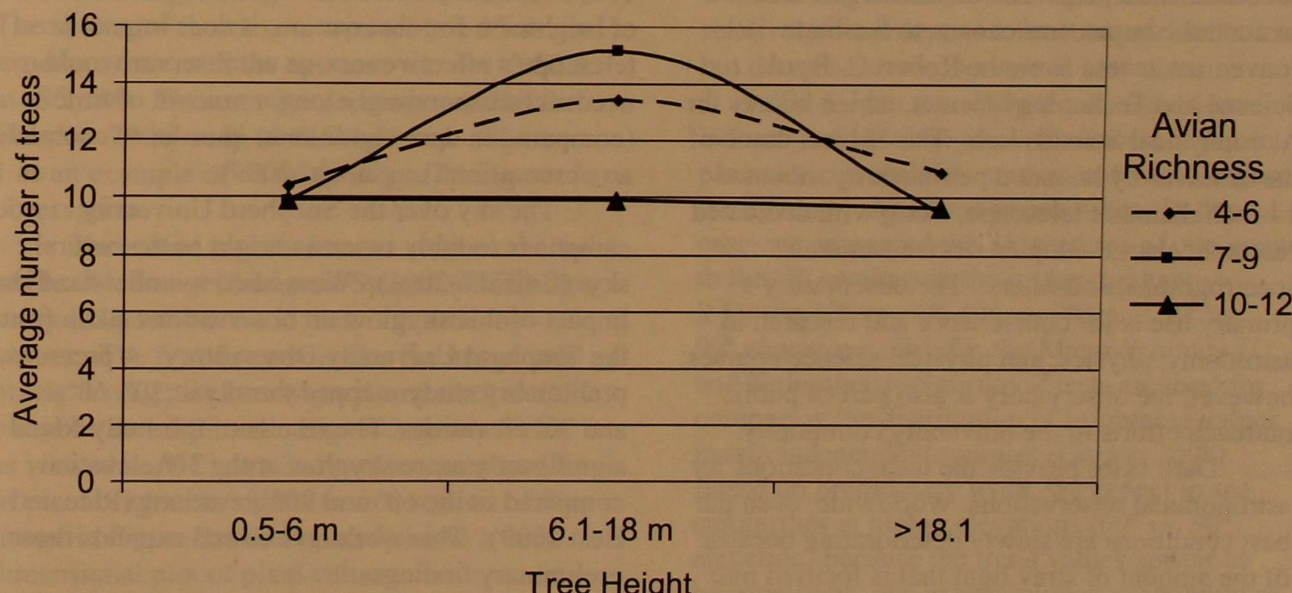

Figure 3. Avian richness by average number of trees per height category on the MeadWestvaco Wildlife and Ecosystem Research Forest in May and June, 2006.

A QUANTITATIVE ANALYSIS OF THE SHEPHERD UNIVERSITY OBSERVATORY'S NIGHT SKY

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ABSTRACT

The Shepherd University Observatory is centrally located on campus in order to provide easy access to the campus community. However, recent construction has added additional skyglow, dimming the visibility of celestial objects. This research examines the skyglow in the night sky over the observatory. This project continues and significantly expands the investigation of data acquired from prior research. The findings of this project will be incorporated into future studies in order to better understand the impact of the skyglow on images taken from the observatory.

We acquired overlapping images at multiple elevations and orientations covering the entire observable sky as seen from the observatory. We took sections from these images and conducted various qualitative and quantitative comparisons. Qualitatively, we find little difference in the brightness once elevation has exceeded 60 degrees. Surprisingly, however, nonparametric tests reveal statistical differences even at the higher, qualitatively similar, elevations.

INTRODUCTION

The Shepherd University Observatory, located on the roof of Robert C. Byrd Center for Legislative Studies, was built in the 2005-2006 academic year. The observatory's location on central campus was chosen to facilitate convenient access from the Robert C. Byrd Science and Technology Center, which houses the Astrophysical Science Lab. The 15-foot dome of the observatory houses a permanently mounted 14-inch diameter telescope, along with dedicated research, charge-coupled device cameras, spectrographs, and filters. The observatory's primary use is for course work and research in astronomy, physics, and physical science courses; however, the observatory is also part of public outreach efforts to the university community.

Dark skies provide the ideal conditions for astronomical observations. Worldwide, even the best conditions are slowly deteriorating because of the amount of stray light that is focused into the sky (Luginbuhl 2009). Excess light from numerous sources is scattered by molecules in the atmosphere, giving the sky a brighter glow than would otherwise be present. If this skyglow is excessive, faint celestial objects become unobservable (Luginbuhl 2009). While skyglow does not usually cause an insurmountable amount of brightness for observation, it does impact a telescope's effectiveness, as an observer would need a correspondingly longer amount of time (compared to dark conditions) in order to complete an observation (Luginbuhl 2009).

The sky over the Shepherd University campus is roughly twice as bright as the natural sky (Cinzano 2001). We wished to understand the impact of this skyglow on observations taken from the Shepherd University Observatory. A previous, preliminary study mapped the sky at 30°, 60°, and 90° elevations. The results of the study found significantly more skyglow at the 30° elevation compared to the 60° and 90° elevations (Rice and Best 2009). This work revises and expands those preliminary findings.

METHODS

This study is designed to map and analyze skyglow, both quantitatively and qualitatively, as seen from the observatory location. To create an ideal mapping of the sky, specific conditions for observation are required. We need a cloudless sky during the new moon phase to allow us the ability to create a full sky map in a single night of observation. A CCD camera would be used at the observatory to take images in specific intervals of orientation and elevation, creating a full picture of the sky. Mounting the camera on a tripod provides stability and reference markings for angular measurements.

Images were obtained in February 2009 during an evening which met all required sky conditions. The 0° degree orientation of the camera was set to North for convenience. We established three elevations from the horizontal: 30°, 60°, and 90°. For the 30° and 60° elevations, we established 12 orientations measured in 30 degree intervals, rotating clockwise as seen from above, from our 0° orientation mark. To complete the compilation of the sky, we obtained a single image of the 90° elevation. The shutter of the camera was set to a 15-second exposure time, and the aperture was set to f/2.8 at ISO 200. These camera settings parallel the Flanders 2006 study of the night sky. Figure 1 as an example of an image taken during our observation.

The stored camera images were converted to Flexible Image Transport System (FITS) files using IRIS software and then imported to *fv* viewer. The *fv* software divides the image into pixels. Every pixel is assigned a numerical value based on its brightness. Figure 2 shows Sirius as viewed in *fv*, Figure 3 shows a representation of pixel brightness values from a section of the image in Figure 2, and Figure 4 shows a three-dimensional plot of pixel values.

For these analyses, we took four 200-pixel x 200-pixel segments of each image. Each segment was taken from a uniform position in each image, as illustrated in Figure 5. Each segment provides 40,000 pixel values, which allows for a robust statistical analysis. Because the focus of the research is based on the skyglow, as opposed to luminous objects such as stars, we had to be careful that the location of each segment did not contain obvious objects with large brightness values: we did so by studying all 25 images and determining the consistently darkest sections of sky. Figure 5 displays the position of each segment used for analysis. These brightness values were then imported to statistical analysis software where they were formatted, plotted, and analyzed.

In Rice and Best 2009, we analyzed a single 200- x 200-pixel segment of each image and plotted surface plots of the brightness values for each segment in order to see if the trend conformed to our prior expectations. We assumed that at lower elevations we would see large qualitative differences in brightness. We also assumed that as we increased the angle of elevation, we would see a more similar qualitative trend in brightness between each interval of elevation. Figure 6 represents the trend found in each image of the current data: within a single image, the brightness values are relatively consistent as a function of orientation, but decrease as we increase in elevation.

To deepen our analyses, we used Mann-Whitney and Kolmogorov-Smirnov non-parametric probability tests in order to compare the different elevations to one other. In this case, we compared the 'A' sections of one image to the 'B' sections in the image right above it for the 30° vs. 60°, 60° vs. 90°, and 30° vs. 90° elevations. Briefly, the Mann-Whitney *U* and Kolmogorov-Smirnov *Z* tests are used for comparing the distribution of brightness values in two independent samples (Garson 2008). Based on preliminary work, we expect to see similarities at higher elevations (60° vs. 90° elevation) because the trend values appear to be consistent. We expect a lower probability of similarity between lower and higher elevations. Significant differences from both tests would demonstrate a low probability for the samples being drawn from the same distribution.

RESULTS

In both the previous research (which used a single 40,000-pixel section of each image for analysis) and the current research (which used four 40,000-pixel sections from each image), we calculated the mean value and standard deviation of brightness. The graph of these values for the previous research is presented in Figure 7, and the graph of theses values for the current research is presented in Figure 8.

In our previous research, we noticed two distinct values of brightness for our data. All of the orientations observed at the 30° elevation are grouped around the higher value. There is a dip in brightness value as the direction of the camera moves in orientation. The values obtained at the 60° elevation fall along a lower mean value of brightness. The skyglow is much more consistent at this elevation. Surprisingly, at the 90° elevation we measure a value of mean brightness that is comparable to that found at the 60° elevation. From the preliminary research, it appears that once past the 30° elevation, the skyglow is relatively consistent no matter the orientation. This is good for extended viewing times of the sky, but only for the high elevations. Celestial objects move with time, so having consistent skyglow values give you consistent data measurements. Observations become problematic at the lower, 30° elevation, where the skyglow fluctuates more. From the Mann-Whitney and Kolmogorov-Smirnov tests, we found a 99% probability that for any of the elevations, these brightness values are not drawn from the same distribution. Despite similarity in trends between the 60° and 90° elevations, the statistical tests show that this apparent similarity may not be as strong as we thought.

As shown by the current research graph in Figure 8, the data cluster around three distinct brightness values. The 30° elevation B1 and B2 data fall along the highest brightness value. The 30° elevation A1 and A2 data create a "mid-range" brightness group. All of the 60° and 90° elevation data fall along the lowest grouping of mean brightness. The conclusion here is that once the elevation exceeds a value of approximately 45°, the skyglow becomes much more uniform. No matter the orientation, once the observer is pointed above a 45° elevation, we would expect to see the same background of brightness.

More specifically, we see the largest brightness values in the B1 and B2 sections of the 30° elevation. One can see the orientation-dependent variation in this group, following the pattern in the previous research (Figure 7). As before, any observation conducted in this region would have a noticeable variation of skyglow within this elevation level. The A1 and A2 samples of the 30° elevation lie at roughly one-half the brightness value of the B1 and B2 samples and are much more consistent in brightness values.

The 60° and 90° elevations possess the lowest brightness values. At some angles of orientation there is little distinction between the A1 and A2 samples compared to the B1 and B2 samples. As a comparison of means shows, there is also little distinction between the 60° and 90° elevations overall. Therefore, we conclude that these elevations provide the best conditions for observation at our specific location.

As a final note with regard to Figure 8, the standard deviation of the sample at 60° elevation, 150° orientation, A2 segment is significantly greater than those around it. It is not uncommon to come across a few bright objects within a segment, no matter how one tries to eliminate such objects. In this case, we believe that a star in the constellation Gemini is causing the large standard deviation. Notice that the mean value of the brightness is relatively consistent with surrounding data. Sampling such a large amount of data points in each segment reduces the biases that bright objects may cause.

From the Mann-Whitney and Kolmogorov-Smirnov tests, we found a 99% probability that for any of the elevations, these brightness values are not drawn from the same distribution. This result is consistent with our prior research findings. Therefore, despite similarity in trends between the 60° and 90° elevations, the Kolmogorov-Smirnov and Mann-Whitney test comparisons show that this apparent similarity may not be as strong as we thought.

FUTURE DIRECTIONS

We plan to acquire images from lower and intermediate elevations, such as 45° and 75°. Furthermore, more numerous segments from each image will be taken to fill in gaps between the current elevation data. This will hopefully minimize the variation along the lower elevations and give us a more comprehensive picture of the sky.

CONCLUSION

It is essential to understand the conditions under which you observe any phenomenon. Valid analyses cannot be conducted if contributing external forces are not identified. For astronomers at the Shepherd University Observatory, one of the unaccounted external forces is skyglow. We must understand the contribution of skyglow to our observations. Through this research, we have assembled a record of the entire sky brightness over the Shepherd University Observatory, allowing observers to discern effects on observations.

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Garson, D. 2008. *Tests for Two Independent Samples* [online]. Accessed at http://faculty.chass.ncsu.edu/garson/PA765/mann.htm.

Luginbuhl, C.B. 2009, *Lighting and Astronomy*. Physics Today **62**: 32-37.

Rice, C. and Best, J. 2009. *A First Look Study of the Skyglow Around the Shepherd University Observatory.* Presented at the Central Pennsylvania Consortium Astronomers' Meeting, Carlisle, PA.

ACKNOWLEDGMENTS

This research was made possible by a NASA WV Space Grant Fellowship awarded by Shepherd University to Mr. Rice and by funds from the Richard Stephan Memorial Observatory Endowment and Scholarship Fund.

Figure 1. This is an image taken from our CCD camera. The bright star above and to the left of center is Sirius.

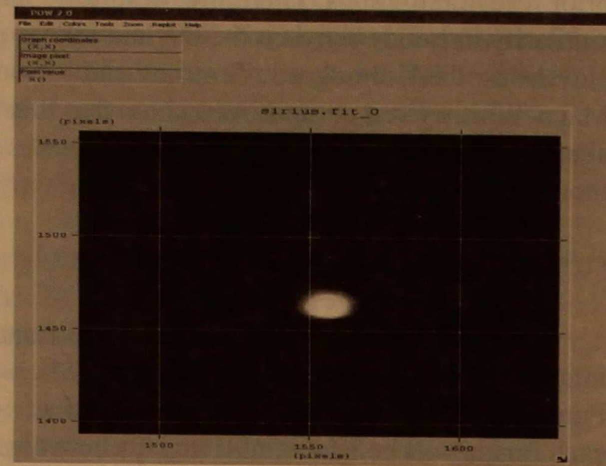

Figure 2. Sirius as seen in the *fv* viewer. This software subdivides the image into smaller pixels and assigns each pixel a value of brightness.

10	10	10	10	11	12	12	11	11	11
11	11	11	11	11	11	11	11	11	10
12	11	11	11	10	11	11	11	11	11
11	11	12	12	12	12	11	11	10	10
10	10	10	10	12	12	12	13	12	12
12	11	11	11	11	12	13	13	12	12
13	12	11	10	11	12	13	13	12	11
13	12	12	11	11	12	13	13	13	12
13	12	12	10	11	13	14	14	13	12
9	9	10	10	11	12	14	14	13	12

Figure 3. A representative section of Figure 2. The position of each number corresponds to the position of a pixel in the image. The number represents the brightness of that pixel.

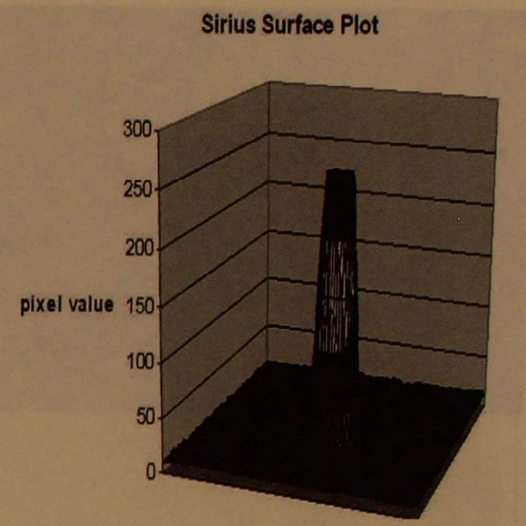

Figure 4. A 3D visualization of pixel brightness. The vertical axis along the left side is the brightness value of each pixel. The bottom axes represent the position of each pixel. The brightness of the object in the middle, Sirius, soars above the brightness of the surounding night sky.

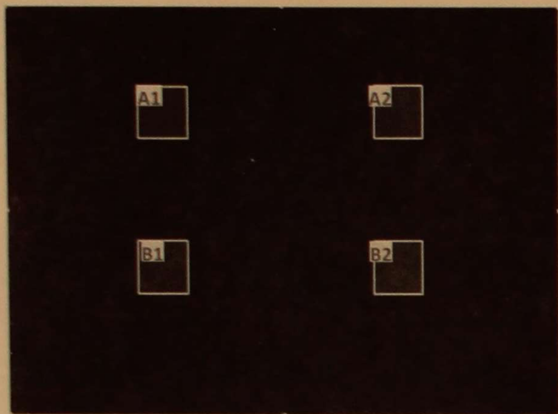

Figure 5. The positions of the four, 200 x 200 pixel segments taken from each image. Starting in the upper left and continuing clockwise, the segments were labeled A1, A2, B2, and B1.

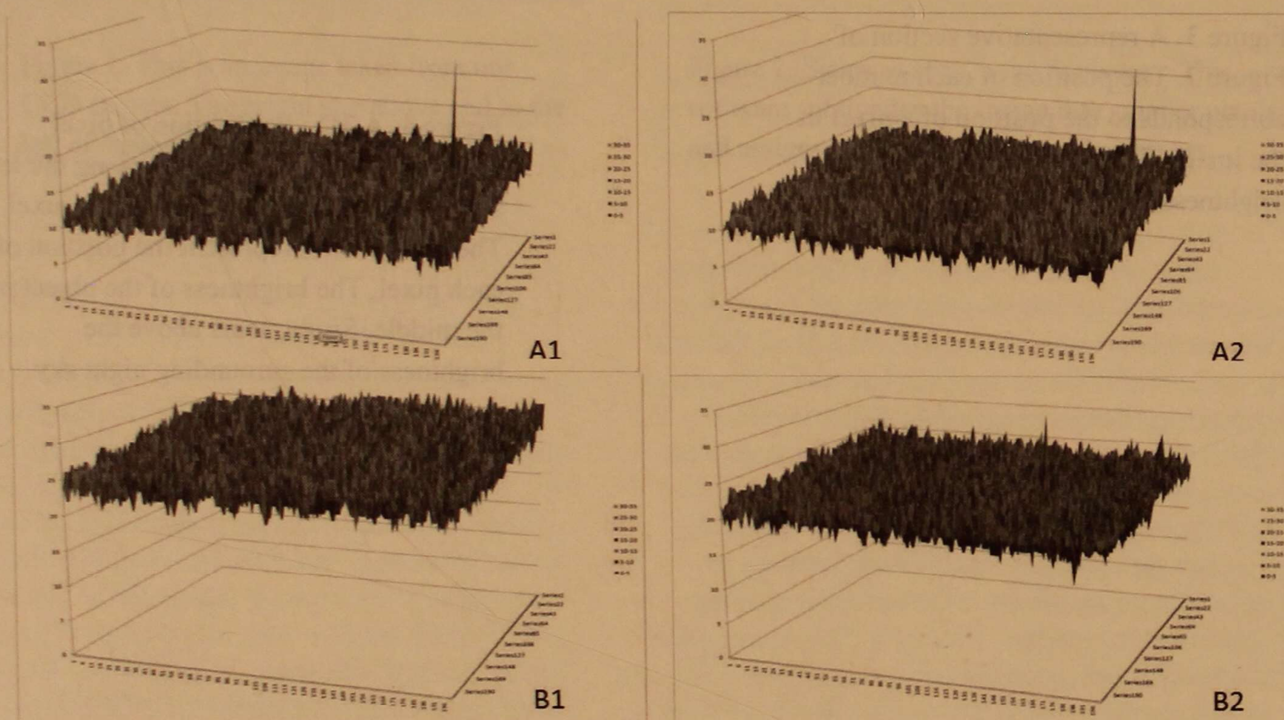

Figure 6. Surface plot representations of the four samples taken from Figure 5: A1, A2, B1, and B2. The vertical axis represents brightness; the horizontal axes represent the position of each pixel. One should note that these four sections, while similar in appearance, are not identical.

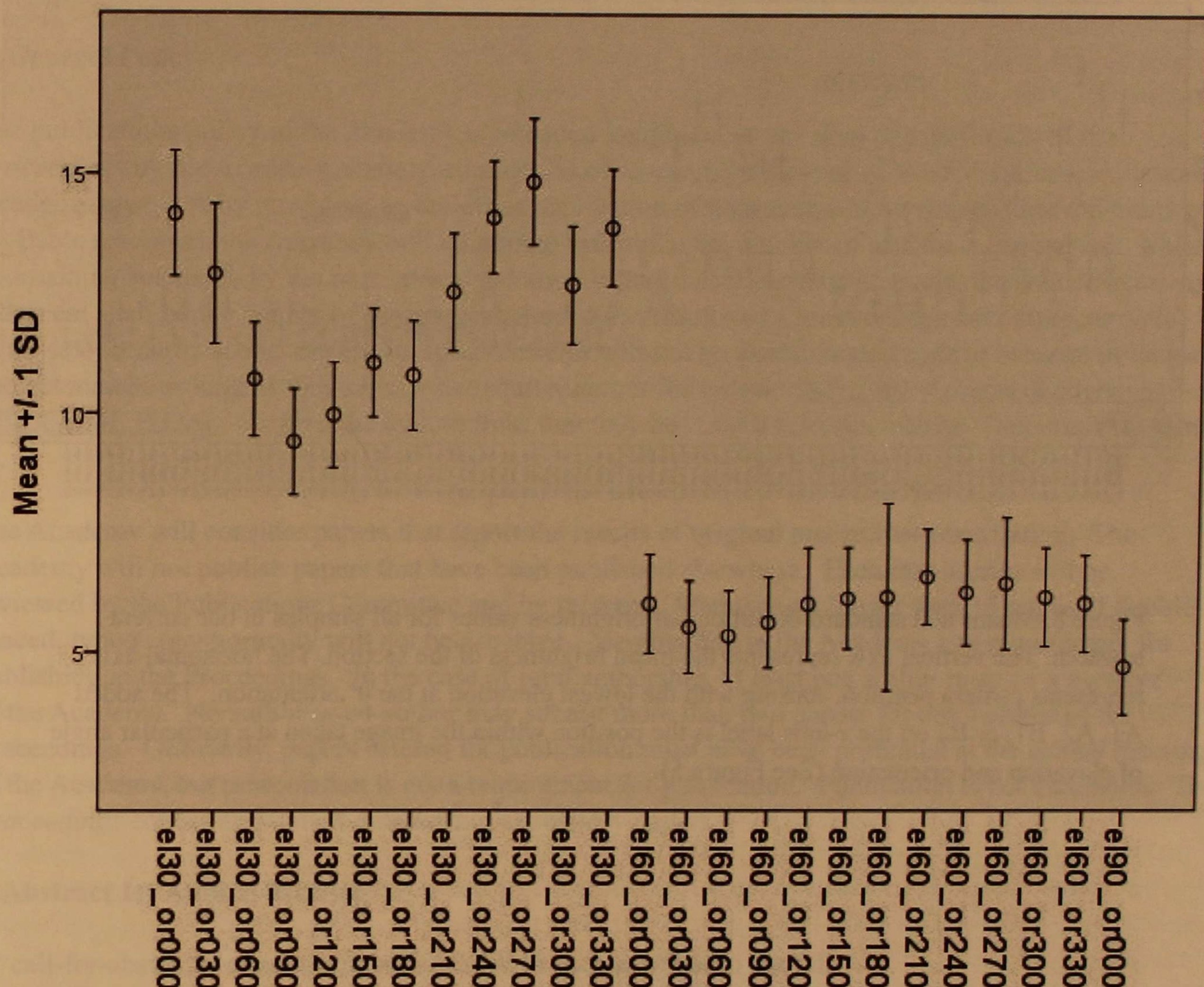

Figure 7. Means and standard deviations of brightness values for all samples in our prior research (Rice and Best 2009). The vertical axis represents the mean brightness of the segment. The horizontal axis represents camera position, starting with the lowest elevation at the 0° orientation. For the labels on the horizontal axis, the number associated with '*el*' is angle of elevation. The number associated with '*or*' is angle of orientation.

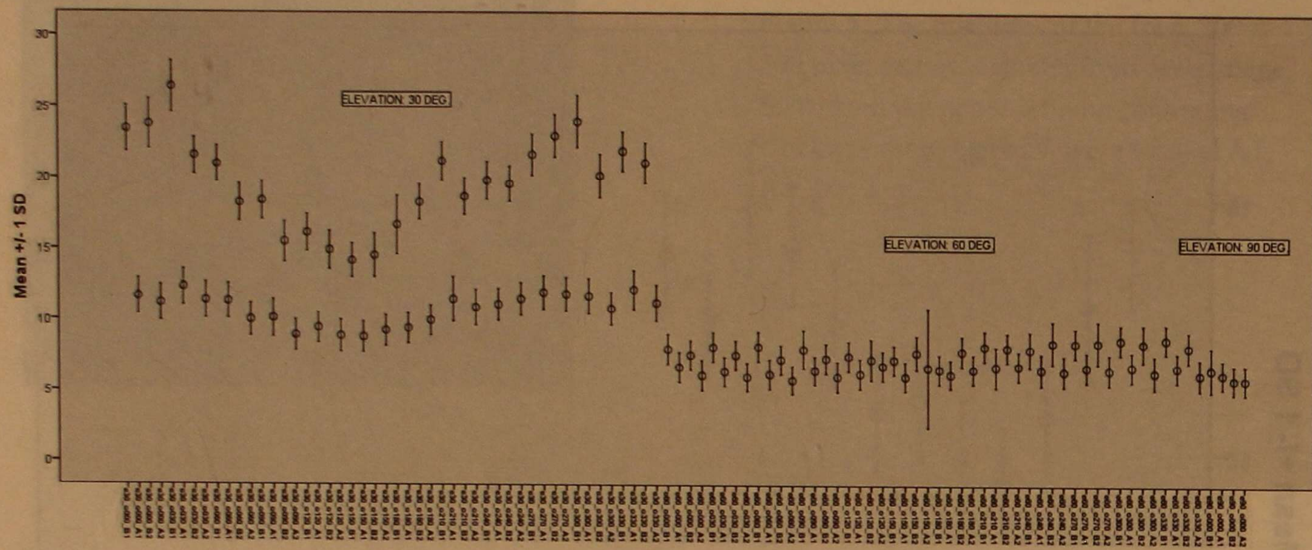

Figure 8. Means and standard deviations of brightness values for all samples in our current research. The vertical axis represents the mean brightness of the section. The horizontal axis represents camera position, starting with the lowest elevation at the 0° orientation. The added A1, A2, B1, or B2 on the *x*-axis label is the position within the image taken at a particular angle of elevation and orientation (See Figure 5).

INSTRUCTIONS TO AUTHORS [from http://www.marshall.edu/wvas/AUTHORS.HTML]

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Text of the abstract will begin here without indentation. Skip one line and begin the first paragraph of text. Single-space the text. Start each new paragraph by indenting 3 spaces. Do not skip a line between paragraphs. Standard abbreviations may be used. The abstract should contain a brief statement of (a) the objectives of the study, (b) the method of study used, (c) the essential results including data and statistics, (d) the conclusions, and (e) the source of support (if applicable). Figures and tables cannot be accommodated. Please check the abstract for misspellings, poor hyphenation, and poor grammar. The text of the abstract should not exceed 250 words.

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Manuscripts for publication should be sent to the editor, Dr. G. Paul Richter, 112 Fayette Street, Buckhannon, WV 26201. Manuscripts must be sent electronically (email or compact disk) in Microsoft WORD to richter_p@wvwc.edu. One hardcopy should also be sent to the address above. Proofs, edited manuscripts, and all correspondence regarding papers for publication should be directed to the editor. For additional information, call (304) 472-3317.

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b. Organization of Manuscripts

Each manuscript shall start with an abstract (no more than 250 words) that should summarize the primary results. In general, the introductory abstract will replace a summary. This abstract should be suitable for sending to international abstracting services for immediate publication in the event that the paper is accepted for publication in the *Proceedings*.

The following sequence is suggested for organizing a paper: Introduction, Materials and Methods, Results, Discussion, Acknowledgments, and Literature Cited.

The text should be double-spaced (New Times Roman 12 pt. font size), and pages should be numbered consecutively in the top right-hand corner of each page preceded by the author's last name.

Major section headings **(INTRODUCTION, METHODS,** etc.) are to be bold and all caps and subsection headings should presented in 10-pt font size, in all caps but not bolded.

Indent each paragraph 3 spaces.

c. Grammatical Considerations

Place two spaces between the period at the end of one sentence and the first letter of the next sentence.

Hyphenate compound modifiers and compound words. A modifier made up of an adverb (other than adverbs ending in -ly) + adjective, adjective + noun, or two nouns is a compound or unit modifier. E.g., *plum-pox-resistant, transgenic plum,* where *plum-pox-resistant* is the compound modifier. Note: chemical names used as modifiers are not hyphenated except when misinterpretation is likely. Examples: 1. Iron sulfide containing bacteria is commonly found ... ; 2. Iron sulfide-containing bacteria are … (In example 1., a sample of iron sulfide that contains bacteria within it is the subject; in example 2., the bacteria contain iron sulfide and *bacteria* is the subject.

Include a comma after each member in a series of words that form a list in a sentence, form a series of modifiers modifying the same item, or for a series of phrases, as this sentence itself exemplifies. E.g., ... *dogs, horses, antelope, and trout...* A different example exemplifies an important exception: When an adjective or noun acting as an adjective is conceptually very closely related to the immediately following noun, as *big* in *big apple*, it is not considered part of the series of modifiers modifying the noun. Thus in *...moldy, green, foul-tasting big apple ...* commas follow all of the modifiers prior to *foul-tasting,* but because *big* is closely associated with *apple*, it is not in the series; hence *foul-tasting* is the last modifier in the series (it could have been preceded by *and*).

Latin epithets used in scientific names for animals and plants follow a different set of rules than English names, even "official" English names. The guideline for English names is based on the rule "only proper nouns are capitalized in sentences". E.g., *coastal plain oak, raspberry horntail sawfly* would not be capitalized in a sentence. Capitalize the first letter of the first word in a sentence and capitalize the first letter for each major term in titles, figure captions, and table headings. Note: the symbol *pH* <u>always</u> has a lowercase *p* and uppercase *H*; it should not be the first "word" in a sentence, caption, or title if things can be conveniently rearranged.

Spell out numbers "one" through "nine"; use numerals for numbers higher than nine. As with *pH*, avoid beginning sentences, captions, and titles with a numeral.

There exist hyphens, en-dashes, and em-dashes, and each has a use. One should distinguish especially between the hyphen (the shortest of these marks) and the en-dash (the intermediate in length of the three). The en-dash should be used in two-word concepts (e.g., *nickel–metal hydride battery*) and spans of time (e.g., *for the period January–June*), among other situations. In "Word" for PCs, the en- and em-dashes are available in the "Special Characters" tab of the "Symbol" sub-menu, which is under the "Insert" menu. In Macintosh computers, the en-dash is also available directly when the "alt/option" key is held down while striking the hyphen key.

For other grammatical considerations, please consult a good scientific writing reference, such as the *Scientific Style and Format: The CSE Manual for Authors, Editors, and Publishers* by Council of Science Educators Style Manual Committee.

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Each table or figure should be supplied with a legend sufficiently complete to make the table or figure intelligible without reference to the text. Footnotes may be used in connection with tables and figures where necessary. Footnotes should be avoided whenever possible in the text itself. Complicated formulas should be prepared with care in a form suitable for camera-copy reproduction. Avoid such formulas in the text. Acceptable fonts include Times, New Times Roman, Arial, Courier, Helvetica, and Symbol. Table and figure format should follow those in issue **79***(2)* or later.

Example Table:

Table 1. Synthesis of PIT tag retention rates from American eel studies.

Study	Location of Study	Duration	Eel Length (mm)	Tag Location	Tag Retention
Thomas (2006)	Laboratory	6 months	> 500	Dorsal musculature	100%
Morrison and Secor (2003)	Hudson River, NY	2 months	Mean = 457	Visceral cavity	89%
Verdon and Desrochers (2003)	St. Lawrence River, NY	1998-1999	Mean = 471.7 (1998) Mean = 468.7 (1999)	Behind the head	98%
Verdon et al. (2003)	Richelieu River, Quebec	1997-1999	Mean = 379.7	Dorsal Musculature	93.9%

Prepare figures and illustrations to be close to the expected size within the publications, with a width of no less than 3 inches (column width) or 6.5 inches for full-page width.

All illustrations and photographs will be published in black and white or grayscale. Use shaded fills for shapes and graphs. For figures with bars, shading, diagonal, and horizontal lines are allowable. Each bar fill-type should be clearly distinct. All drawn lines must be greater than 0.25 pts (0.1 mm) thick. All figures should have a white chart area. See WVAS *Proceedings* **79***(2)* or later for example formatting.

The recommended file format and resolution for various types of line drawing and photos are:

- Black and white line art, use 1000 dpi minimum resolution
- Half tone and grayscale – use minimum resolution of 600 dpi
- Images and photos need to be in grayscale with a minimum resolution of 600 dpi

All illustrations should be submitted electronically as a separate file for each figure. Acceptable file format are TIF, PDF, Microsoft PPT, DOC, or XLS. No other formats are accepted at this time.

Please note: Illustrations, graphs, and photos that do not comply with the recommended format will be returned to the author for correction. The manuscript will not be considered for review until it is resubmitted with the required corrections. Figures and tables covering more than one page should have the figure or table number repeated at the top of each of the other pages followed by the word "continued" within parentheses. Data, legends, and other identifiers that appear within a figure or table need to be large enough in the published version to be easily read.

5. Literature Cited

References shall be collected at the end of the manuscript as "Literature Cited" and must be cited in the text.

• Citations within text:

References should be cited by author and date within the text. Separate multiple citations with a semicolon.

• Example citations within text:

Single author: (Dare 2003)
Two authors: (Buzby and Deegan 1999)
Multiple authors: (Feldheim et al. 2002)
Multiple citations: (Buzby and Deegan 1999; Feldheim et al. 2002)

• Citations at the end of paper:

The title of the papers cited and the inclusive page numbers must be given.
The article title should be italicized and the journal name should be in normal font.
Bold the volume number, italicize the issue, and present page numbers in normal font.
End each citation with a period.
Citations should be formatted with hanging indentation of 0.5".
Do not skip a line between citations.

• Example journal citations:

Buzby, K. and L. Deegan. 1999. *Retention of anchor and passive integrated transponder tags by arctic grayling.* N. Am. J. Fish. Manage. **19***(4)*: 1147-1150.

Dare, M.R. 2003. *Mortality and long-term retention of passive integrated transponder tags by spring Chinook salmon.* N. Am. J. Fish. Manage. **23**: 1015-1019.

Feldheim, K.A., S.H. Gruber, J.R.C. de Marignac, and M.V. Ashley. 2002. *Genetic tagging to determine passive integrated transponder tag loss in lemon sharks.* J. Fish Biol. **61**: 1309-1313.

Example book citation:

Stacey, M. and S. A. Barker. 1960. *Polysaccharides of microorganisms.* Oxford Univ. Press. London. 228 pp.

Freemark, K. and B. Collins. 1992. *Landscape ecology of birds in temperate forest fragments* in J. M. Hagan, III and D. W. Johnston (eds.), Ecology and Conservation of Neotropical Migrant Landbirds, pp. 443-454. Smithsonian Institution. Washington, D.C.

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