Interactions of Roads and Deforestation with Stream Sediment Size and Network Structure in the Western Cascade Range of Oregon

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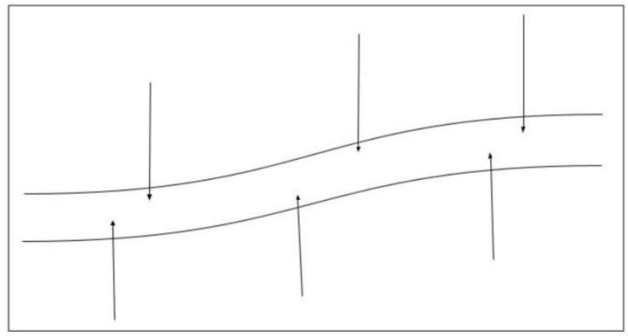
Abstract

This study examines how anthropogenic disturbances affect sediment size in streams. Anthropogenic disturbances such as forest road construction and harvest can interact with the geomorphology and hydrology of forested watersheds to change sediment and water inputs to streams. The study further investigates how river network structure might affect the propagation of these anthropogenic disturbances through streams. It was hypothesized that the network structure of streams within forested watersheds would influence the location and magnitude of the impacts of forest road construction and harvest on sediment size. Longitudinal surveys were conducted every 50 meters for 11 kilometers of third-to-fifth order streams in the H.J. Andrews Experimental Forest in the Western Cascade Range of Oregon. Particle counts were collected to characterize the geomorphic impacts of road crossings and harvest areas as disturbances. Bed sediment sizes were plotted along channel distances to identify deviations from longitudinal trends of sediment size. Survey locations were classified based on proximity to roads and forest harvest areas. A one-way analysis of variance (ANOVA) was used to assess differences in sediment size based on proximity to forest roads and harvest areas. Tukey's honest significant difference (HSD) test was further used to compare differences in sediment sizes for classified areas based on varied proximities to roads and harvest areas. River network structure was quantified by drainage density and number of nodes upstream of survey locations. Cluster analysis was used to assess the significance of survey location, drainage density, number of nodes and number of road crossings upstream of the survey location for predicting sediment size. Results contribute to the understanding of vulnerability to and responses of streams to anthropogenic disturbances.

[1] Introduction

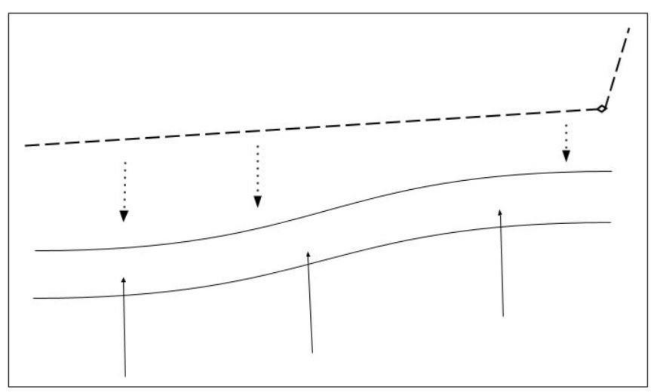
Roads and forest harvest can alter sediment and water fluxes to streams in forested watersheds which may influence channel morphology and habitat for aquatic species. Studies have shown that roads may channelize flows of water and sediment along road surfaces (Jones, Swanson, Wemple, & Snyder, 2000). Roads may further interact with slope mass movement processes to serve as initiation, augmentation or obstruction points for landslides and debris flows (Jones et al., 2000). In turn, harvesting of trees along roads and hillslopes may contribute to the destabilization of hillslopes via reductions in contributions of root strength to soil cohesion (Swanson & Dyrness, 1975). While slope mass movements such as debris flows may degrade aquatic habitat over short temporal scales, these geomorphic disturbances can play a vital role in shaping channel morphology and aquatic habitat over longer temporal scales (Bigelow, Benda, Miller, & Burnett, 2007). Thus, the potential for roads and forest harvest areas to alter the frequency and magnitude of slope mass movements may have ramifications for channel morphology and aquatic habitat downslope of roads and harvest areas (Swanson & Dyrness, 1975, Bigelow et al., 2007). Furthermore, removal of trees from forested watersheds has been shown to impact the spatial distribution and volume of large woody debris in streams (Czarnomski, Dreher, Snyder, Jones, & Swanson, 2008). Conceptual models were developed for the effects of roads and harvest on inputs of windthrow (falling trees) to streams.

Figure 1: Conceptual model of windthrow to a stream without roads or harvest nearby. The stream is represented by two curved lines, while windthrow inputs to the stream are represented by arrows.



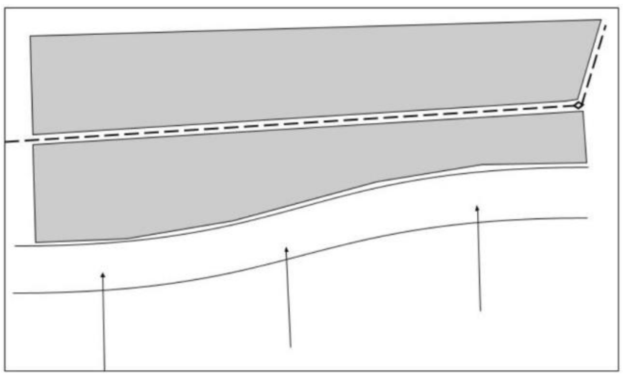
In the above scenario one might expect inputs of large wood to the stream from both sides of the stream, given the existence of forest on both sides of the stream (Fig. 1).

Figure 2: Conceptual model of windthrow to a stream next to a road. The stream is represented by two curved lines, while windthrow inputs to the stream are represented by arrows. Dotted arrow lines represent decreased inputs of windthrow to the stream relative to solid arrow lines. The road is represented by the dashed line.



In the next scenario, one might expect decreased inputs of large wood to the stream from the side containing a road relative to wood inputs from the undisturbed side (Fig. 2).

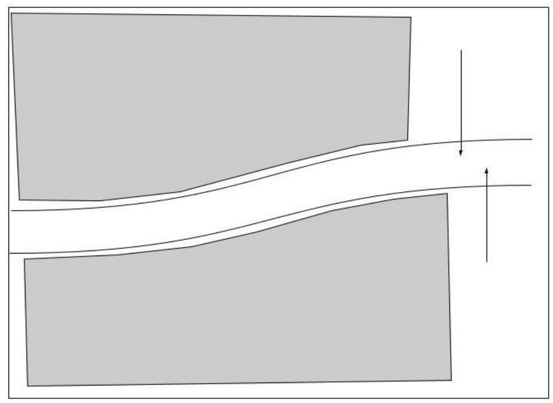
Figure 3: Conceptual model of windthrow to a stream with roads and harvest nearby. The stream is represented by two curved lines, while windthrow inputs to the stream are represented by arrows. Shaded areas represent harvested areas. The road is represented by the dashed line.



In the third scenario one might expect that inputs of large wood to streams from the side with roads and harvested areas would be greatly reduced or nonexistent relative to inputs of large wood to streams from the undisturbed side (Fig. 3). In the fourth scenario one might expect limited or nonexistent inputs of large wood to streams from both sides adjacent to harvested areas relative to inputs of large wood to streams from undisturbed forest (Fig. 4).

Reductions in the volumes of large woody debris in streams in turn modify channel hydraulics and sediment transport (Kuhnle, Shields, Douglas, & Morin, (2001), Faustini & Jones, 2003). The above controls on sediment, water and wood inputs to streams thus necessitate continued study of the mechanisms through which and degrees to which roads and harvest areas influence channel morphology and aquatic habitat.

Figure 4: Conceptual model of windthrow to a stream with harvested areas on both sides of the stream. The stream is represented by two curved lines, while windthrow inputs to the stream are represented by arrows. Shaded areas represent harvested areas.



Additionally, Benda et al. (2004) suggest that forest harvest activities could be analyzed in regard to harvest impacts on aquatic habitat as influenced by river network structure. The interactions of network structure with disturbances to networks have been studied in other fields. For example, Piazzon et al. (2011) found that ecological network structure contributed to resilience against extinctions. In turn, Potterat, Rothenberg and Muth (1999) observed that connectivity of human networks facilitated transmission of disease. Network theory has also been applied to river networks via fractal geometry analyses of rivers (Rodríguez-Iturbe & Rinaldo, 1997), the influence of mathematical network structure on carbon fluxes between streams and riparian areas (Sabo & Hagen,

2012) and the impacts of network structure on the dispersal of biota through a network (Rodríguez-Iturbe, Muneepeerakul, Bertuzzo, Levin, & Rinaldo, 2009). However, little quantitative research exists to document the influence of network structure in mediating anthropogenic disturbances in streams. Thus, an analysis of field observations and network characteristics is applied to the investigation of river network resilience to disturbances.

This study addresses the following questions as they relate to disturbances and network structure:

1) Does the proximity of roads and forest harvest areas to streams affect sediment size?

2) If the above disturbance impacts are observed, how might the quantitative structure of the river network influence the location and magnitude of the effects on channel substrate?

[2] Methods

The study was conducted in streams within the H.J. Andrews Experimental Forest in the Western Cascade Range of Oregon (Fig. 5). The 64 km2 forest has been the subject of long-term ecological research studies for the past 50 years (Jones et al., 2000). The underlying surficial material of the watershed is volcanic, including sediments and rocks from pyroclastic deposits and lava flows (Fred Swanson, personal communication). There is also evidence of glaciation in the upper Lookout drainage area (Swanson & James, 1975). The forest is dominated by old-growth Douglas-fir (*Pseudotsuga menziesii*), and approximately twenty-five percent of the watershed has been harvested since 1950 (Jones et al., 2000). Forest harvest declined in the 1970's, and much of the harvested area was logged without use of riparian-area buffers (Fred Swanson, personal communication). The road network in the forest is dense relative to the catchment area (roughly 2km/km2), and the roads were primarily constructed between 1950 and 1970 (Jones et al., 2000).

Longitudinal surveys of channel cross sections were conducted every 50 meters for approximately 11 kilometers of streams in the H.J. Andrews Experimental Forest. The data collected included cross section location, grain size distributions, channel width and gradient, and an inventory of large woody debris. Locations of cross section surveys were recorded in a smart phone GPS with use of Avenza Maps software. Photos were taken upstream and downstream of cross-sections and georeferenced to GPS locations. Grain size was recorded into geometric size classes with use of gravelometers and Wolman particle counts (sample size of 100 per cross section). Channel width was measured with a measuring tape and included mid-channel bars if side channels thought to be part of the active channel were present. Channel gradient was measured every 50 meters with use of a clinometer and stadia rod. Large woody debris was counted via estimates of size based on a size classification developed by Czarnomski et al (2008). Single pieces of large wood and pieces that formed accumulations were noted. Large woody debris was categorized as an accumulation if there were at least three pieces of wood within the lowest size class and two points of contact between the pieces. Sizable log jams were noted based on perceived hydraulic effect of large woody debris in the accumulation on the channel. Prominent features such as tributary confluences, debris flow runout tracks, road crossings and transitions from old growth forest to new growth were also noted. Log jams were classified based on longitudinal position within a 50 meter reach. All field data were compiled into online databases.

ArcGIS was used to create a layer of mainstem stream segments from a stream network (Catalina Segura, unpublished data). The hydrology toolset was used to create flow direction, flow length, flow accumulation and watershed layers for the river network. The watershed tool was used to calculate drainage area upstream of the cross sections. A geometric network of stream edges and nodes was created with use of the network analyst toolset (Fig. 6). The road network layer was intersected with the stream network layer to identify road crossings. The network analyst toolset was used to calculate drainage density, number of nodes (confluences) and number of road crossings upstream of the survey locations.

Figure 5: Map of H.J. Andrews Experimental Forest watershed. Data courtesy of H.J. Andrews Experimental Forest, Catalina Segura, & 2017 Eco-Informatics Summer Institute.

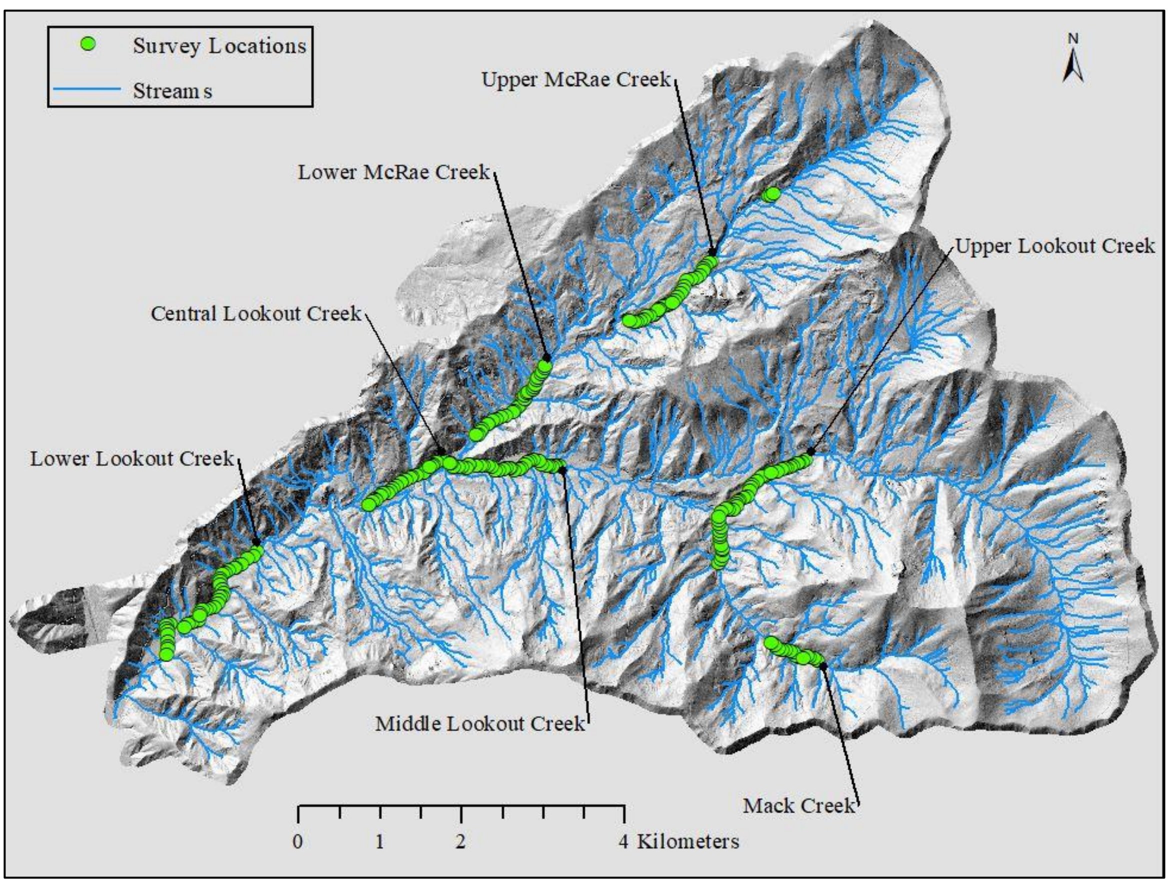
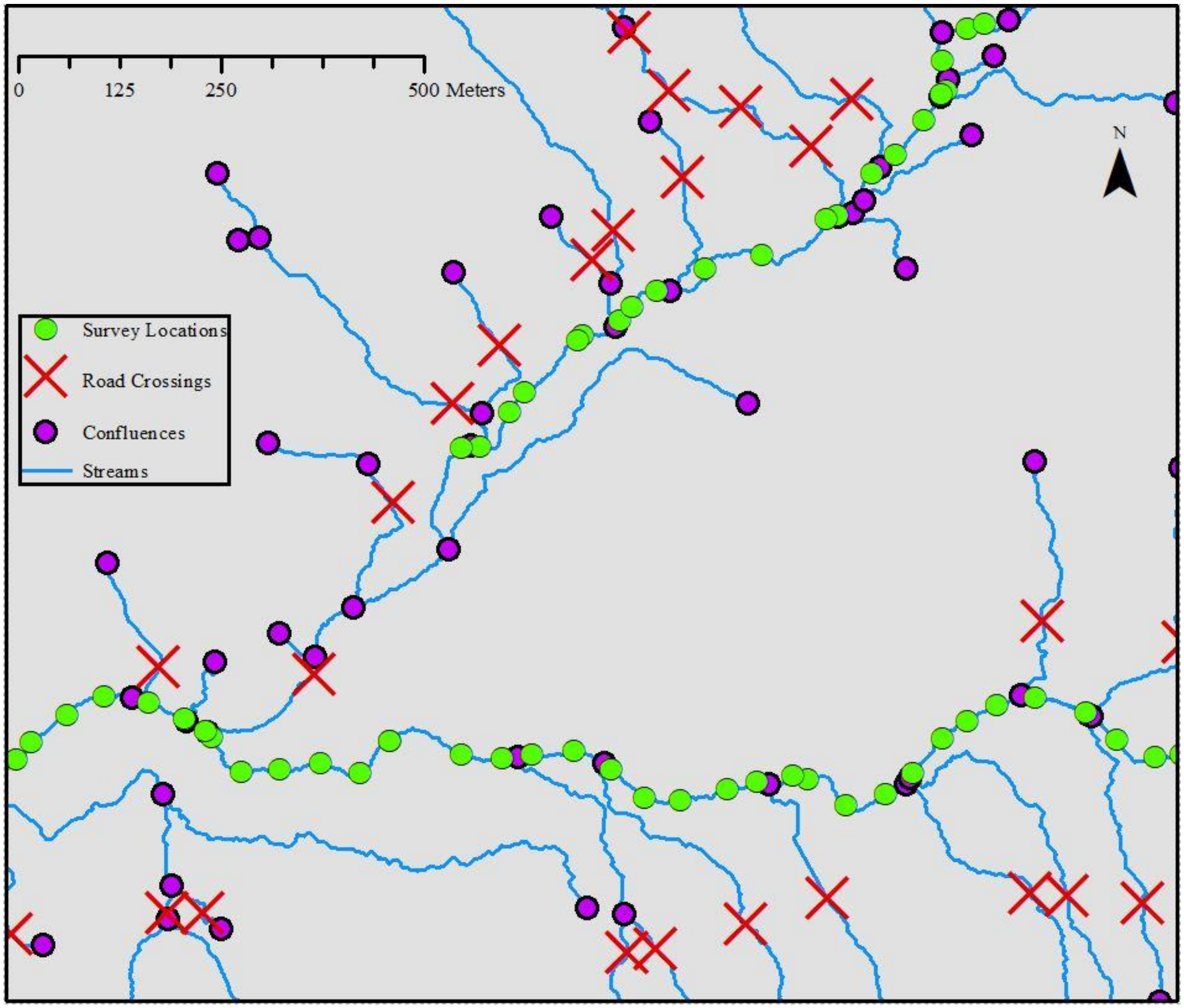


Figure 6: Snapshot of geometric stream network created in ArcGIS. Data courtesy of H.J**.** Andrews Experimental Forest, Catalina Segura, & 2017 Eco-Informatics Summer Institute.



Buffers of 50 meters from the mainstem stream segments were created and intersected with layers of forest harvest and road networks. 50 meter buffers from individual survey locations were also created and intersected with the stream buffers to give areas of forest harvest and lengths of roads within 50 meters of the survey location points on either side. A buffer radius of 50 meters was chosen based on the size of trees within the H.J. Andrews Experimental Forest and the potential range of windthrow to streams from hillslopes and riparian areas (Julia Jones, personal communication). The resulting layers detailing proximity of roads and harvest areas to survey locations were amalgamated based on survey location identifiers, and the attribute tables of the categorized layers were joined to a layer of survey location points. The attribute table of the survey location point layer was then exported as an Excel spreadsheet and categorical classifications were assigned to survey location points based on the proximity of roads and harvest areas to the survey locations (Fig. 7). The classifications were derived from Czarnomski et al. (2008) as follows:

- ❑ No roads within 50 meters of the cross section on either side (NR)
- ❑ Roads within 50 meters of the cross section on one side (RO)
- ❑ Roads within 50 meters of the cross section on both sides (RB)

- ❑ No harvest within 50 meters of the cross section on either side (NH)
- ❑ Harvest within 50 meters of the cross section on one side (HO)
- ❑ Harvest within 50 meters of the cross section on both sides (HB)

The road and harvest classifications were then concatenated to produce distinct classifications. An example of one classification is that of roads within 50 meters of the survey location on one side and harvest within 50 meters of the survey location on both sides (ROHB). An interpolation function was used to calculate D16, D50 and D84 sediment sizes with use of a logarithmic transformation to account for the field classification of particles into ranges via gravelometer measurements (Ohio Department of Natural Resources, see Appendix A).

The D50 values for each survey location were plotted against the distance of the survey locations from the outlet of the stream network. This chart was used for preliminary assessments of deviations in sediment size from the expected longitudinal profile of increased fining of sediment with downstream distance through a river network (e.g. Gomez, Rosser, Peacock, Hicks, & Palmer, 2001).

One-way analysis of variance (ANOVA) was conducted in R to test for significant differences between means of the D16, D50 and D84 values for the different classifications specified above. Tukey's honest significant difference (HSD) test was then performed in R to compare pairs within the ANOVA. Both the ANOVA and Tukey HSD tests were performed with use of a 95% confidence level ($\alpha = 0.05$).

[3] Results

There did not appear to be any trend in fining of sediment with distance downstream through the river network (Fig. 8). On the contrary, a coarsening of sediment was observed in plots of sediment size against longitudinal distance through the river network from the headwaters to the outlet (Fig. 8).

The ANOVA performed to compare the mean D16 values for each classification was significant ($F(8, 207) = 4.112$, $p = 0.000143$). The ANOVA used to compare the mean D50 values for each classification was also significant ($F(8, 207) = 4.772$, $p = 2.14e-05$), as was the ANOVA used to compare the mean D84 values for each classification ($F(8, 207) = 4.482$, $p = 4.93e-05$).

These results led to the rejection of the null hypotheses that there were no significant differences between mean D16, D50 and D84 sediment sizes for the various classifications. Tukey HSD tests were performed in R to compare mean D16, D50 and D84 values between each classification.

The results of the Tukey HSD test are shown in the following tables for each sediment size (Table 1, 2, & 3).

The mean D16 value for locations with roads on one side and harvest on one side was significantly larger than the mean D16 values for locations with no roads on either side (Table 1). The mean D16 value for locations with roads on one side and no harvest on either side was significantly larger than the mean D16 value for locations with no roads on either side and harvest on both sides (Fig. 9).

The mean D50 value for locations with roads on one side and harvest on one side was larger than the mean D50 values for locations with no roads on either side (Table 2). The mean D50 value for locations with roads on one side and harvest on one side was also larger than the mean D50 value for locations with roads on one side and no harvest on either side (Fig. 10).

The mean D84 value of locations with roads on one side and harvest on one side was larger than the mean D84 values of locations with no roads on either side (Fig. 11). The mean D84 value of locations with roads on one side and harvest on one side was also larger than the mean D84 value of locations with roads on one side and no harvest on either side (Table 3).

Figure 7: Snapshot of streams and survey locations overlaid in ArcGIS with roads and harvested areas in the H.J. Andrews Experimental Forest. Data courtesy of H.J. Andrews Experimental Forest, Catalina Segura, & 2017 Eco-Informatics Summer Institute

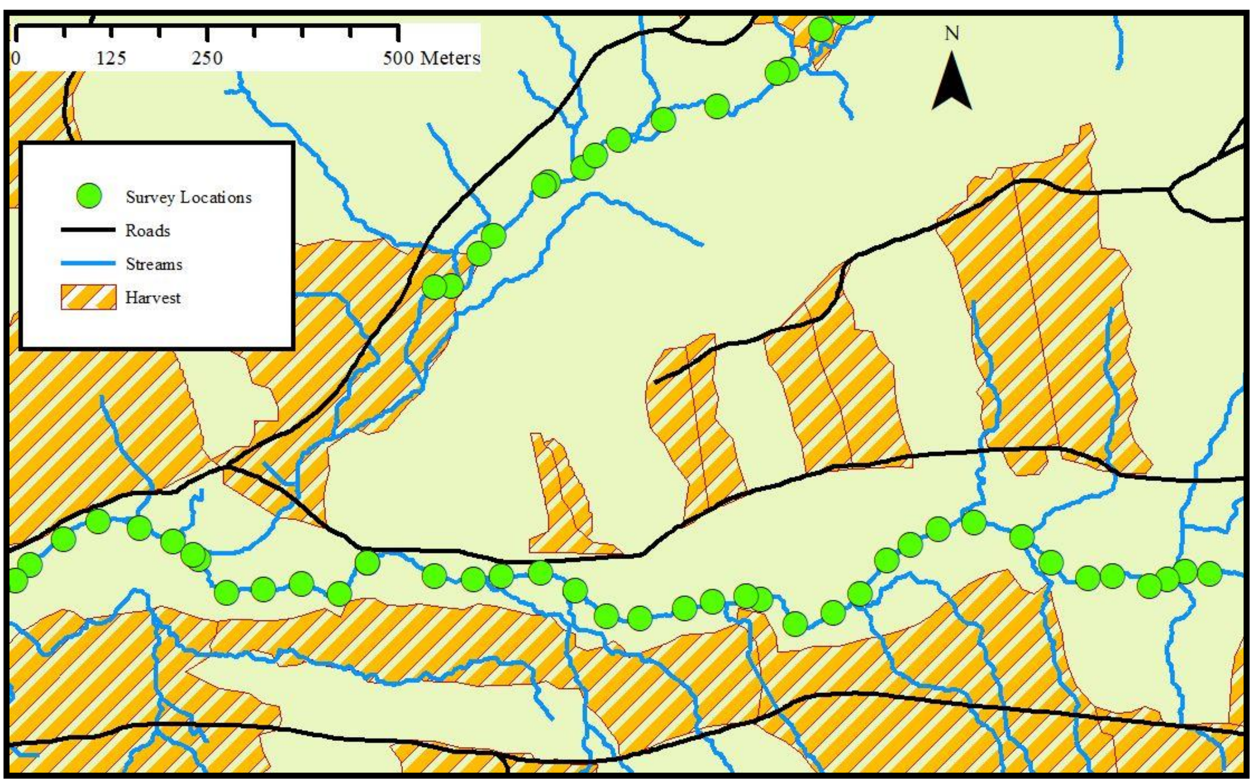


Figure 8: Longitudinal trends in D50. Confluences at which tributaries enter the sampled mainstems are represented as blue vertical lines. Confluences at which two sampled mainstrems merge are represented as green vertical lines.

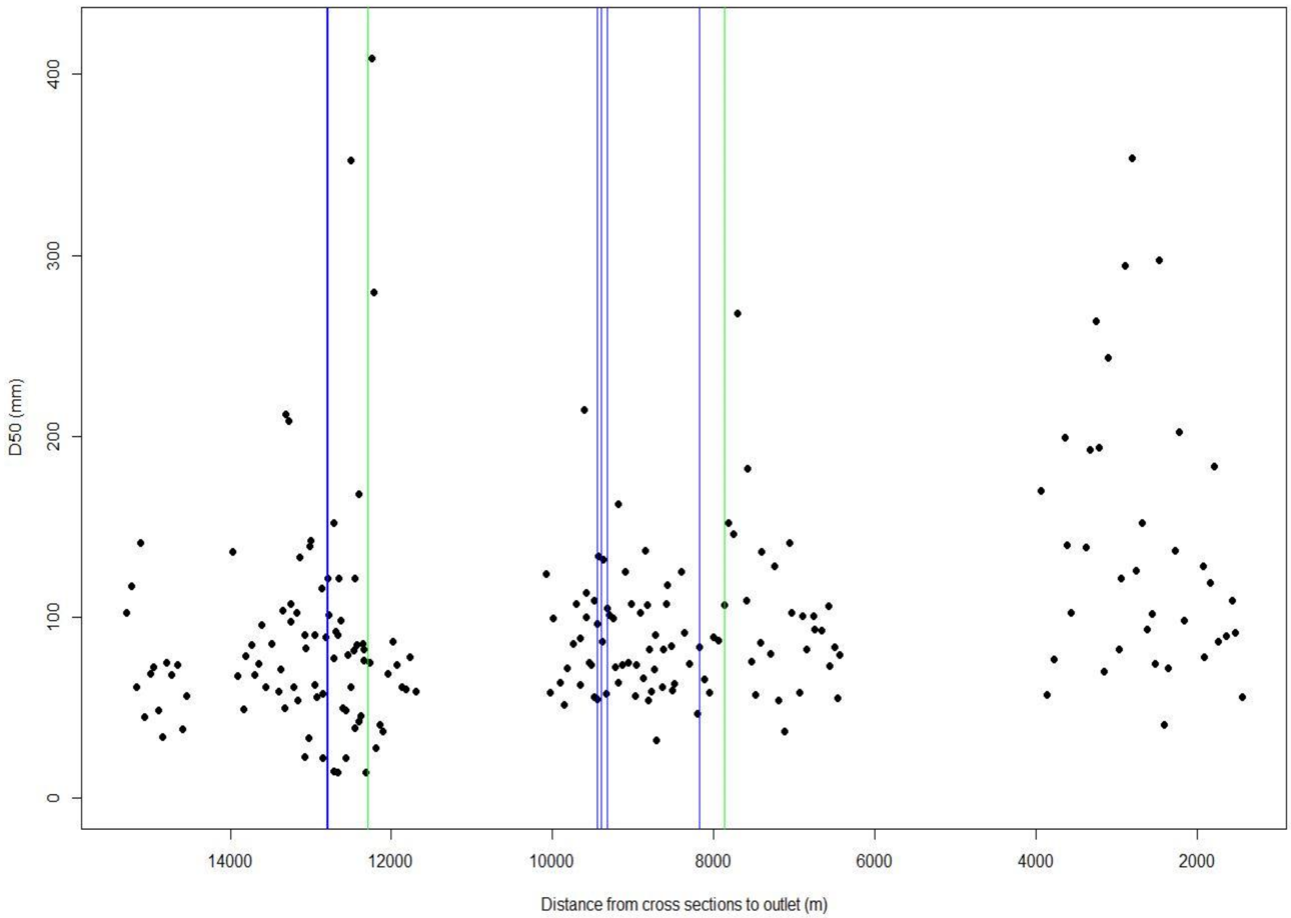


Table 1: Results of the Tukey HSD test for D16 values. Mean values that share any following letters with other mean values were not significantly different at a 95% confidence level (α= 0.05).

Classification	Classification Code	Mean D16 Value (mm)	N
No roads on either side and…			
Harvest on both sides	NRHB	24.5b	51
Harvest on one side	NRHO	29.4bc	32
No harvest on either side	NRNH	26.5bc	96
Roads on both sides and…			
Harvest on both sides	RBHB	12.9	2
Harvest on one side	RBHO	23.7	2
No harvest on either side	RBNH	11.3	1
Roads on one side and…			
Harvest on both sides	ROHB	30.3	3
Harvest on one side	ROHO	47.6a	10
No harvest on either side	RONH	37.3ac	19

Figure 9: D16 values for each classification. Mean D16 values are represented by black points. Classifications sharing a grey background color or box outline color were not significantly different at a 95% confidence level (α= 0.05).

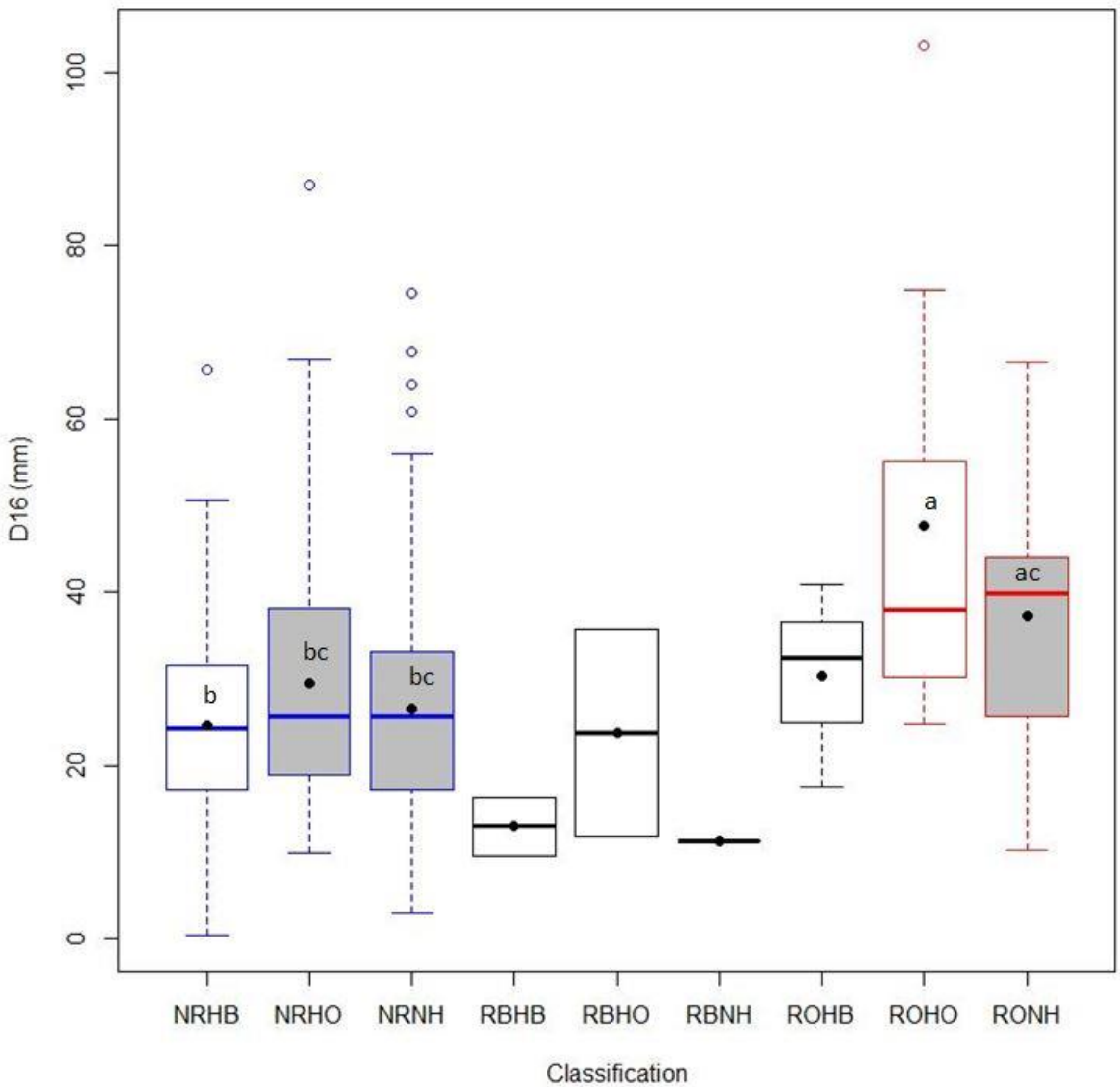


Table 2: Results of the Tukey HSD test for D50 values. Mean values followed by the same letter were not significantly different at a 95% confidence level (α= 0.05).

Classification	Classification Code	Mean D50 Value (mm)	N
No roads on either side and…			
Harvest on both sides	NRHB	92.8b	51
Harvest on one side	NRHO	106.2b	32
No harvest on either side	NRNH	92.6b	96
Roads on both sides and…			
Harvest on both sides	RBHB	60.7	2
Harvest on one side	RBHO	65.1	2
No harvest on either side	RBNH	58.1	1
Roads on one side and…			
Harvest on both sides	ROHB	95.3	3
Harvest on one side	ROHO	1002.7a	10
No harvest on either side	RONH	333.3b	19

Figure 10: D50 values for each classification. Mean D50 values are represented by black points. Classifications sharing the same box outline color were not significantly different at a 95% confidence level (α= 0.05). Note: The y axis has been scaled to account for outliers in the distribution. See Appendix B for plot of full distribution.

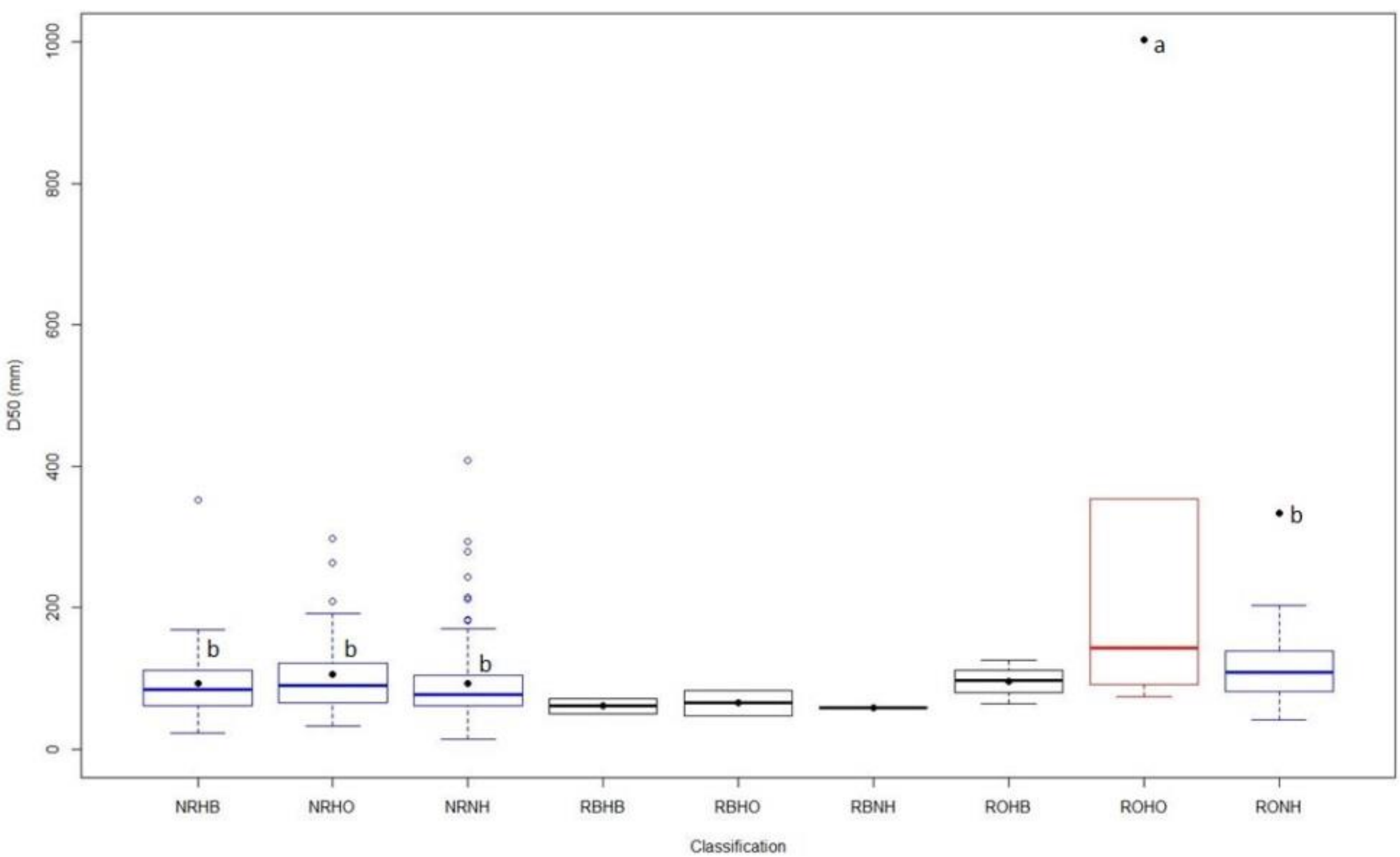
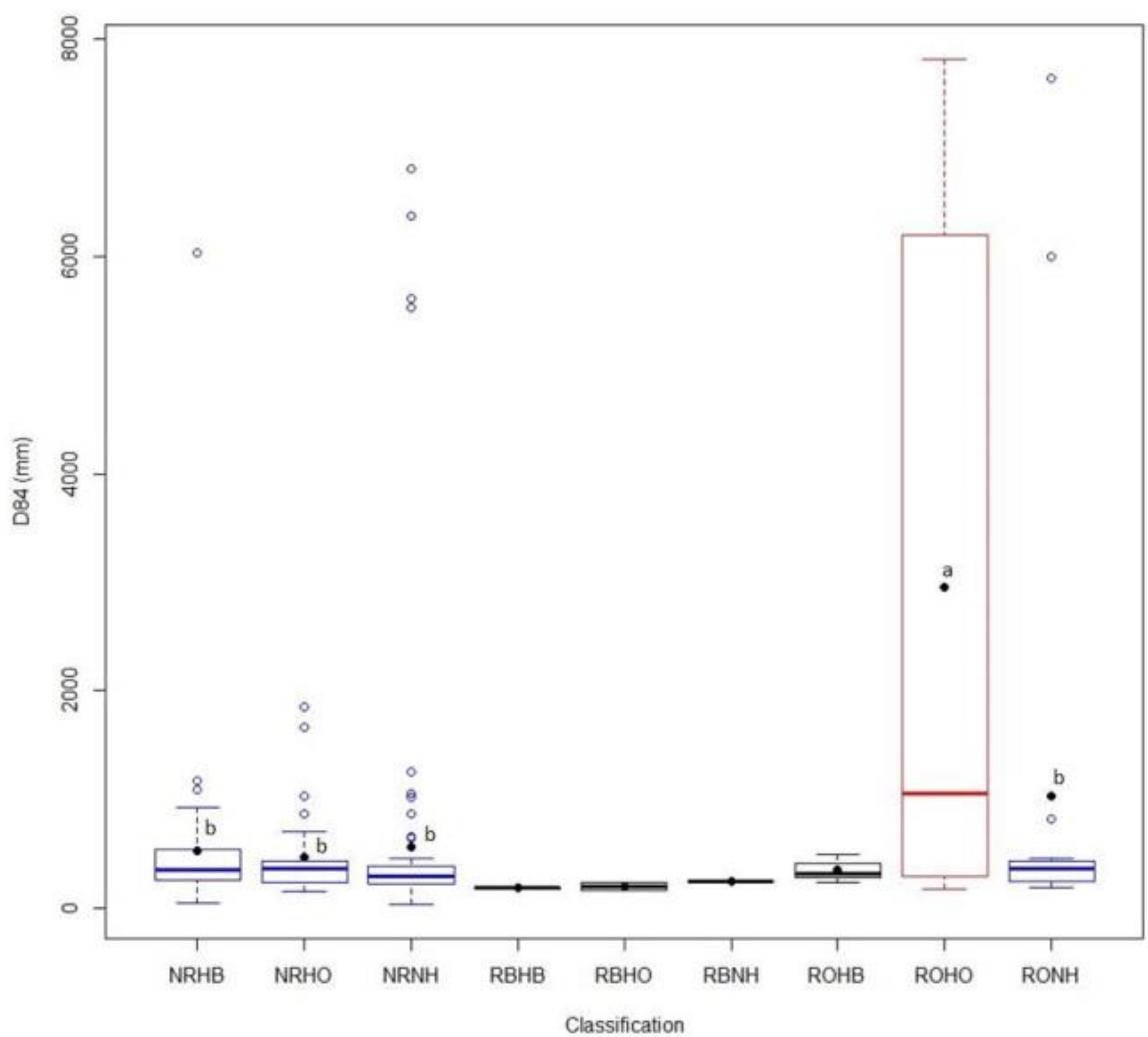


Table 3: Results of the Tukey HSD test for D84 values. Mean values followed by the same letter were not significantly different at a 95% confidence level (α= 0.05).

Classification	**Classification Code**	**Mean D84 Value (mm)**	**N**
No roads on either side and…			
Harvest on both sides	NRHB	521.8b	51
Harvest on one side	NRHO	467.8b	32
No harvest on either side	NRNH	558.7b	96
Roads on both sides and…			
Harvest on both sides	RBHB	182.5	2
Harvest on one side	RBHO	197.3	2
No harvest on either side	RBNH	246.6	1
Roads on one side and…			
Harvest on both sides	ROHB	348.8	3
Harvest on one side	ROHO	2949.0a	10
No harvest on either side	RONH	1029.8b	19

Figure 11: D84 values for each classification. Mean D84 values are represented by black points. Classifications sharing the same box outline color were not significantly different at a 95% confidence level (α= 0.05).



The standard deviations of D16, D50 and D84 values were consistently largest for locations with roads on one side and no harvest on either side, as seen in the following plots of the mean and standard deviation of D16, D50 and D84 values for the various classifications (Fig. 12, 13, & 14).

Non-metric multidimensional scaling (NMDS) performed in PC- ORD with use of river network characteristics and D50 values was not significant. No useful ordination was found for locations in relation to river network characteristics and number of road crossings upstream of survey locations.

Figure 12: Mean D16 values for each classification represented by black points. Error bars represent one standard deviation above and below the mean D16 value. Classifications sharing an error bar color or green point color were not significantly different at a 95% confidence level (α= 0.05).

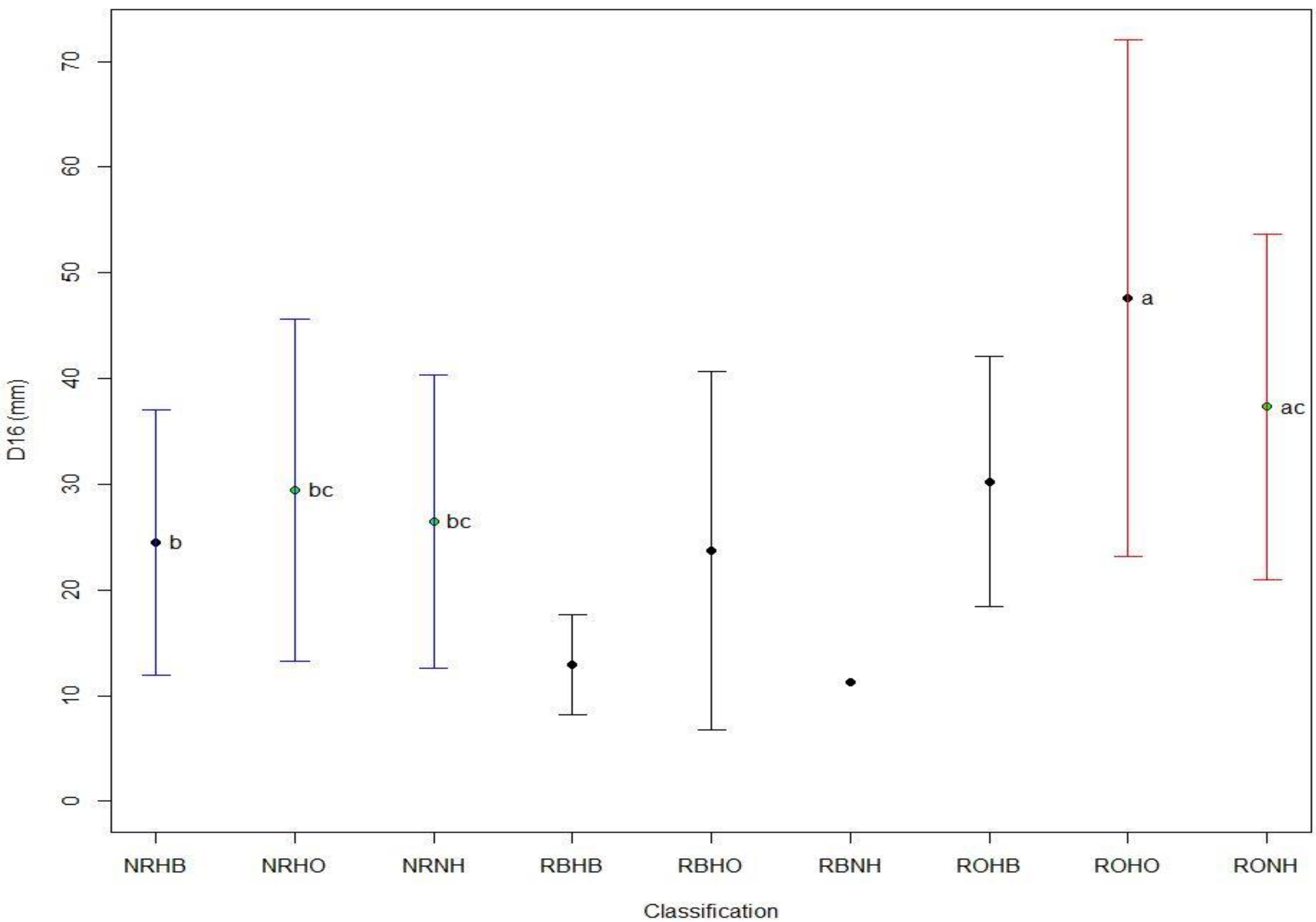


Figure 13: Mean D50 values for each classification represented by black points. Error bars represent one standard deviation above and below the mean D50 value. Classifications sharing an error bar color were not significantly different at a 95% confidence level (α= 0.05).

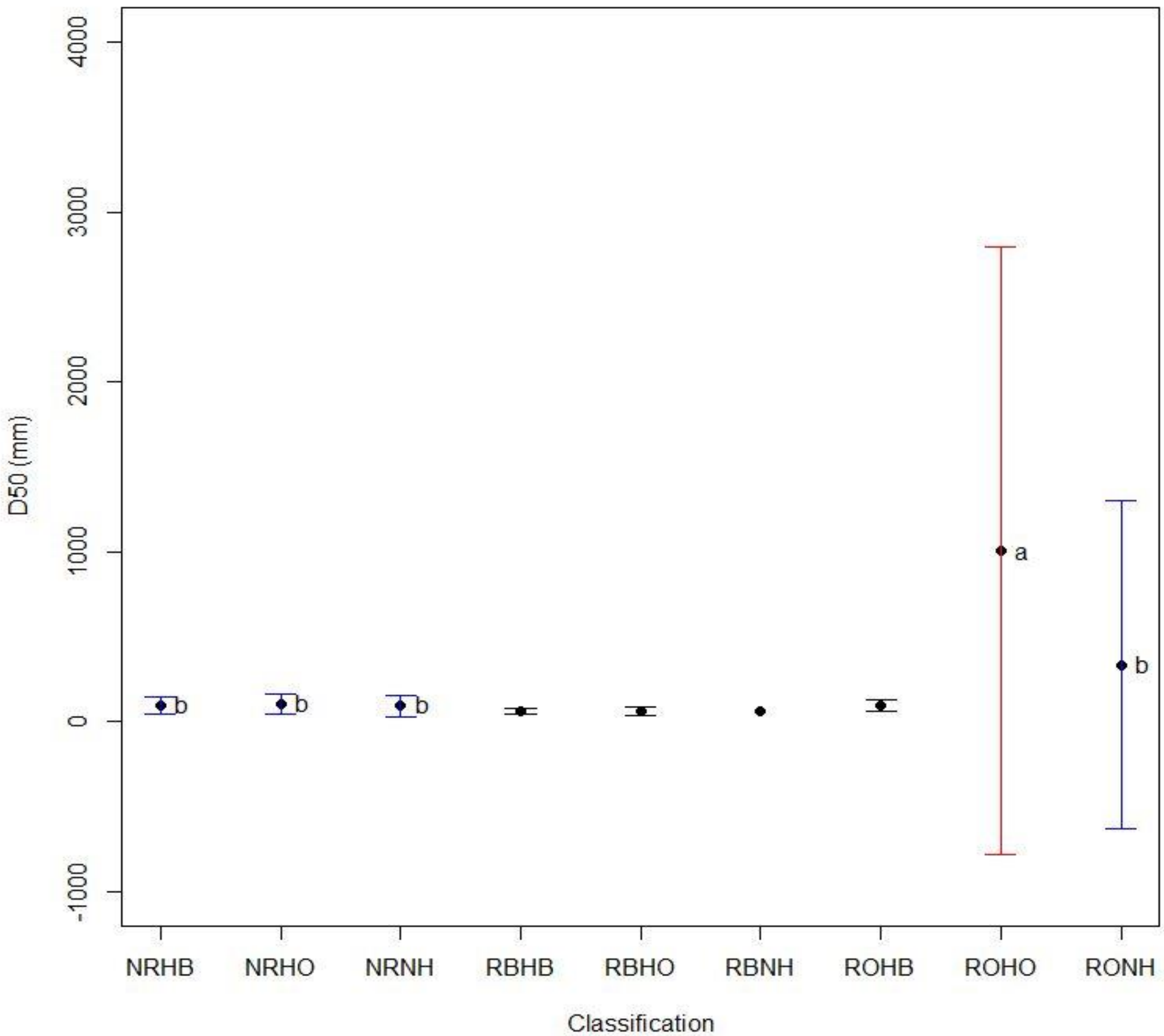
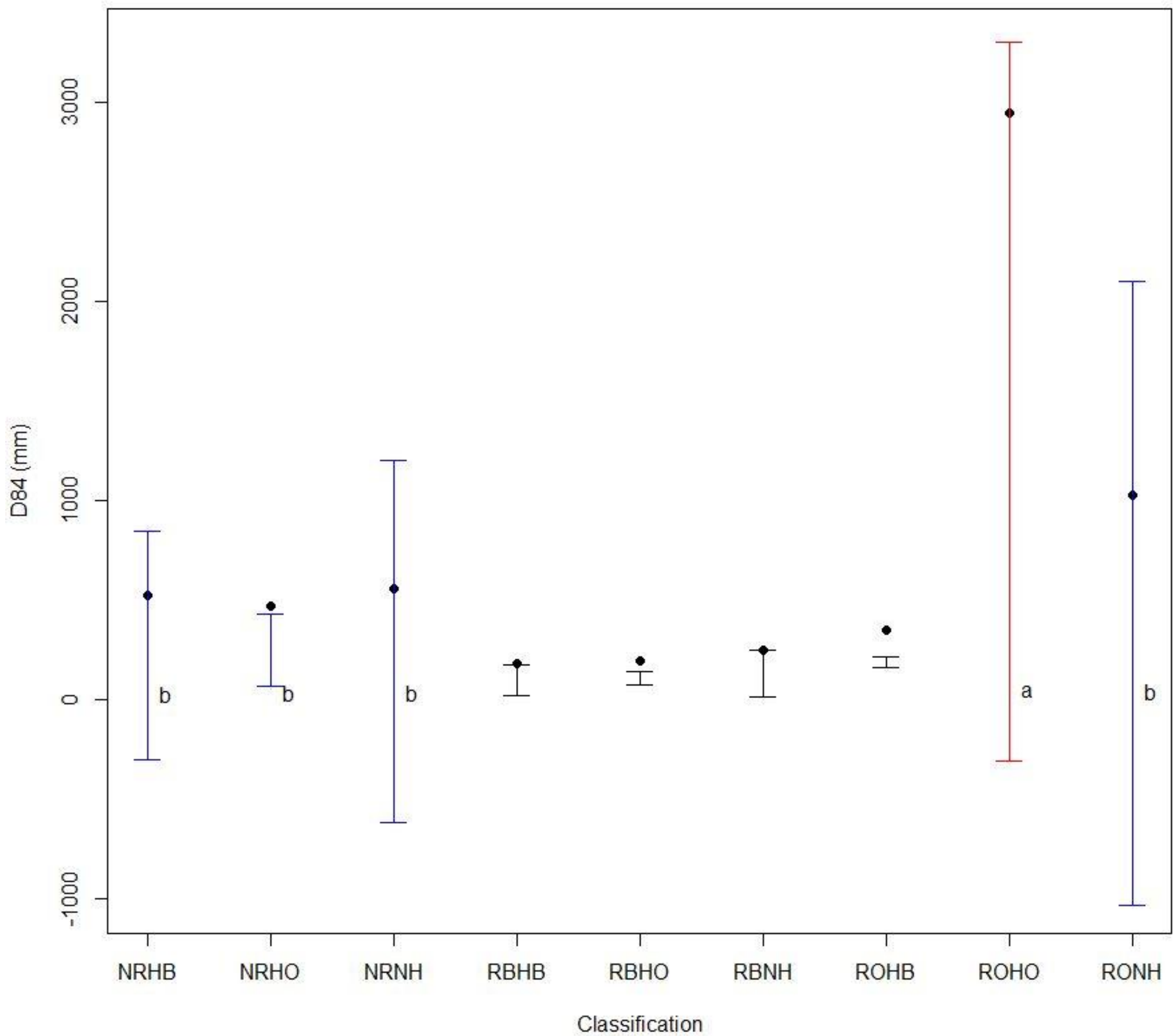


Figure 14: Mean D84 values for each classification represented by black points. Error bars represent one standard deviation above and below the mean D84 value. Classifications sharing an error bar color were not significantly different at a 95% confidence level (α= 0.05).



[4] Discussion

The coarsening of sediment with distance through the river network may be due to colluvial influences and geomorphic history of landslides and debris flows (Grant & Swanson, 1995). It is possible that colluvial processes are providing inputs of coarse material to the streams so as to result in a coarsening of grain size distributions for stream reaches close to the outlet of the river network.

Sediment sizes for locations with roads on one side and harvest on one side were larger than sediment sizes for locations without roads. This result implies that roads may have a greater impact on sediment size than that of harvest on sediment size. This implication is supported by the variety of findings suggesting that roads have a greater potential than deforestation for facilitating erosion (as cited in Swanson & Dyrness, 1975). Swanson and Dyrness (1975) attributed this difference to the potential for roads to alter surface and subsurface flow of water as well as to the potential for cut-and-fill road construction to redistribute material on a slope surface. Wemple, Swanson, and Jones (2000) additionally found that roads could serve as conduits for sediment and water so as to facilitate transport of sediment from harvested areas to streams.

One might expect that the presence of roads and harvest areas close to streams would result in decreased sources of windthrow to the streams. In turn, this decrease in windthrow could result in a reduction in the volume of large woody debris in streams close to roads and harvest areas (Czarnomski et al., 2008). Large woody debris can act to increase frictional resistance to flow in streams and thus facilitate deposition of sediment (Morin, Cooper, & Shields, 2004, Faustini & Jones, 2003). However, removal of large woody debris in streams can also reduce hydraulic diversity and reduce the maximum velocity of flow (Gippel, 1995). It is possible that this potential effect of decreased hydraulic diversity on sediment deposition outweighed the potential effect of reduced frictional resistance to flow on sediment erosion.

Alternatively, it is possible that the larger sediment sizes of locations with roads on one side and harvest on one side relative to sediment sizes for locations without roads could be due to the interactions of roads and harvest areas with colluvial processes. Specifically, Swanson and Dyrness (1975) found that slope mass movements in harvested areas of forest transported greater volumes of material than did slope mass movements in undisturbed areas of forest. In turn, the observation that survey locations near to roads and harvest areas had larger sediment sizes as compared to areas without roads nearby could be due to the potential for roads to act as initiation or magnification points for landslides, debris slides and debris flows (Jones et al, 2000). This interaction between roads and slope mass movements could result in increased supply of coarse material to streams downslope of hillslopes with roads.

One might expect that the existence of roads on both sides of a given location would result in greater disturbance impacts on sediment size as compared to disturbance impacts on sediment size for locations with roads on one or no sides. However, no differences in sediment sizes were observed between areas with roads on both sides as compared to areas without roads nearby. This result may be due to the fact that few sampled locations were bordered by roads on both sides. The sample sizes for classifications with roads on both sides of the cross sections may be low enough such that any impact of roads on sediment size for these locations was obscured due to insufficient data.

The mean D16 value for locations with roads on one side and no harvest on either side was significantly larger than the mean D16 value for locations with no roads on either side and harvest areas on both sides. This reinforces the idea that roads have a greater coarsening effect on grain size distributions relative to the impact of harvest on grain size distributions. However, this difference was not observed for the D50 and D84 analyses. Specifically, the mean D50 and D84 values for locations with roads on one side and harvest areas on one side were larger than the mean D50 and D84 values for locations with roads on one side and no harvest on either side. This result suggests that harvest also influences sediment size.

From this result one might also expect that areas with harvest on one side and no roads nearby would have larger mean D50 and D84 values than those for areas with no harvest and no roads nearby. However, no difference of this kind was observed in the data. This might imply that the effects of harvest on sediment size are coupled with the presence of roads near to the harvest areas. It is possible that roads within harvest areas or occurring on the perimeter of harvest areas may interact with harvest areas to magnify the potential influences of harvest areas on erosion. Specifically, the magnitude of slope mass movements initiated at roads within harvest areas might be augmented by reduced cohesion and frictional resistance to erosion due to a deficit of trees and root systems below the roads. Additionally, the presence of roads below slope mass movements initiated on harvested slopes might result in the magnification of the slope mass movements initiated above the roads.

Many of the roads intersected or bordered the harvested areas, but some of the survey locations classified as having roads on one side and harvest on one side represent locations with a road on one side and harvest on the other side of the stream. The coupling effect of roads and harvest on sediment size would not explain why these locations with roads on one side and harvest on the other side would have greater sediment sizes than areas with roads on one side. In turn, all roads and harvest areas were considered as part of a uniform group. However, different types of harvest might have different influences on large woody debris in streams (Baillie, Cummins, & Kimberley, 1999). Also, the time passed since harvest may relate to the potential for fluvial redistribution or erasure of the disturbance effects. Grant and Wolff (1991) suggest that the timing of land use disturbances in reference to storm events affects the extent to which the land use disturbances influence sediment production. Furthermore, the road position on the hillslope may influence road impact on erosion (Wemple et al., 2001). Future research could utilize a classification scheme incorporating the timing of road and harvest disturbances in relation to sizable storm events, the age and type of harvest and the road position on the hillslope to account for potential heterogeneity within the disturbances.

The 50 meter buffer was chosen because it was thought to provide a conservative estimate for the height of trees in the H.J. Andrews Forest and thus represent the area of influence of windthrow to streams from nearby hillslopes (Julia Jones, personal communication). However, trees in the H.J. Andrews Forest can grow to heights greater than 50 meters. A buffer of 100 meters was also used to classify locations based on occurrence of roads and/or harvest within 100 meters of survey locations. The ANOVA for the data classified with this 100 meter buffer was not significant. This result might be explained by the rationale that 100 meters is far enough from streams such that the signal of the impact of roads and harvest on sources of large woody debris in streams is too faint when considered at the 100 meter scale. However, the results pointed to the idea that the impact of roads and harvest on sediment size is due to factors other than removal of sources of windthrow from streams. Thus, the lack of significant comparisons when using the 100 meter buffer could be due to the spatial extent of slope mass movements. It is possible that slope mass movements initiated in harvest areas or roads 100 meters from streams might not reach the streams as frequently as slope mass movements initiated in harvest areas or roads 50 meters from streams.

The NMDS was performed with network characteristic variables calculated for areas upstream of the cross sections. However, these variables were measures of cumulative network characteristics (ie drainage density, number of confluences) upstream of the cross sections in the geometric stream network. It is possible that network characteristics scaled to smaller drainage areas (ie density of confluences per localized area draining into the streams) could better represent the heterogeneity of the controls on each location. In turn, density of road crossings scaled to localized areas draining into each cross section could potentially give more meaningful results. It is possible that the effects of road crossings on tributaries draining into the sampled mainstem stream reaches are localized such that the effects of roads on sediment sizes upstream of the sampled locations is not apparent. Swanson and Dyrness (1975) posited that the maximum influence of roads on erosion likely occurs in the first several substantial storms following road construction. In turn, the road network was largely constructed in the 1950’s and 1960’s, with declines in logging in the 1970’s (Jones et al., 2000). It is possible that impacts of roads and harvest areas in tributaries draining into sampled mainstem streams have been erased by fluvial processes due to the substantial temporal gap between this study and the initial road construction and harvest (Fred Swanson, personal communication).

Further research could also incorporate slope stability into the analysis. Wemple et al. (2001) suggested that variations in the stability of soils upon which roads have been constructed could obscure analyses of the geomorphic impacts of roads in the H.J. Andrews Experimental Forest. Spatial inventories of slope mass movements and susceptibilities of streams to slope mass movements were considered in the analysis. However, the spatial resolution of the mass movement inventories was not sufficient to relate the presence of slope mass movements with sediment size. Nonetheless, it is possible that analyses of the survey locations in reference to maps of past debris flows could inform the inference that disturbance impacts of roads and harvest on sediment size are related to interactions between roads, harvest and slope mass movements.

Lastly, the Wolman particle counts provided further uncertainty in the analysis. As detailed in Olsen, Roper, Kershner, & Archer (2005), Wolman particle counts may result in undersampling of various components of the grain size distribution. In turn, the sample size of 100 particles could be increased to account for greater heterogeneity within the grain size distributions. Survey locations consisting primarily of bedrock were removed from the analysis due to the difficulties of comparing these channels with non-bedrock channels (Desirée Tullos & Catalina Segura, personal communication). Accounting for these channels in the analysis could alter the percent finer values. Future research could attempt to develop conceptual and quantitative models to incorporate bedrock channels into the grain size distribution analyses. Furthermore, active channels separated by a mid-channel bar were considered as forming part of a single cross section. Further analyses might compare channel characteristics for two active channels separated by a mid-channel bar as well as compare the individual channel characteristics for each bar against amalgamated channel characteristics for both channels to assess the lateral variation in channel characteristics on either side of a mid-channel bar.

[5] Conclusion

Sediment sizes for surveyed streams with roads within 50 meters of the streams on one side and forest harvest areas within 50 meters of the streams on one side were larger than sediment sizes for streams without roads within 50 meters of the stream on either side. This difference might be due to the potential for roads and deforestation to accelerate erosion on hillslopes and thus supply coarse material to streams downslope of the roads and harvest areas. However, no linkage between sediment size and network characteristics such as drainage density, number of confluences and number of road crossings upstream of surveyed locations was found. As seen in the deviation of longitudinal trends in grain size throughout the river network, streams in the H.J. Andrews Experimental Forest represent a multifaceted history of fluvial and non-fluvial processes alike. Classical geomorphological models for sediment transport and longitudinal trends in channel characteristics (especially those developed for sand-bed rivers in low-relief terrain) may not be able to explain the morphological effects of geomorphic constraints on streams in the H.J. Andrews Experimental Forest.

Further research is necessary to separate the impacts of the legacy of volcanism, glaciation and colluvial transport of sediment and boulders to streams (e.g. Grant & Swanson, 1995) from the potential impacts of roads and deforestation on stream channel characteristics in the H.J. Andrews Experimental Forest.

Results of this study may provide further evidence for the use of riparian buffers in conjunction with harvest activities due to the potential for roads and harvest disturbances to influence sediment size in adjacent streams. Further studies can refine the results via analyses of comparable forested watersheds in the Pacific Northwest with recent occurrences of road and harvest disturbances. One of the substantial challenges posed by making inferences from analyses of disturbance impacts of roads and deforestation on channel characteristics lies in developing a baseline level of background variation for channel characteristics from which to compare areas possibly subject to road and harvest disturbances. Annual replications or refinements of this study in the H.J. Andrews Experimental Forest could help to further construct a quantitative knowledge base for the range of variation in channel characteristics in streams both adjacent and removed from road and harvest disturbances. In turn, the complexity of the history of streams in the H.J. Andrews Experimental Forest might imply that management decisions such as road construction or harvest in comparable watersheds may have similarly complex ramifications for streams and aquatic biota. Further research must be completed to continue to analyze the effects of road and harvest disturbances on channel characteristics so as to inform a comprehensive understanding of the effects of anthropogenic disturbances on streams and aquatic life in forested watersheds.

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Appendicies

Appendix A: Logarithmic interpolation function used to calculate percent finer than values. All material below was directly taken from the Ohio Department of Natural Resources document titled “Calculating D50”:

“S = Size
S^+ = Size at the top of the range
S^- = Size at the bottom of the range
P = Percent smaller than such as 50% for D50
P^+ = Percent of particles smaller than S+
P^- = Percent of particles smaller than S-

$$\frac{\left[\log_2(S) - \log_2\left(S^-\right)\right]}{\left[P - P^-\right]} = \frac{\left[\log_2\left(S^+\right) - \log_2\left(S^-\right)\right]}{\left[P^+ - P^-\right]}$$

$$\log_2(S) = \log_2\left(S^-\right) + \left[P - P^-\right] * \frac{\left[\log_2\left(S^+\right) - \log_2\left(S^-\right)\right]}{\left[P^+ - P^-\right]}$$

$$S = 2^{\log_2\left(S^-\right) + \left[P - P^-\right] * \frac{\left[\log_2\left(S^+\right) - \log_2\left(S^-\right)\right]}{\left[P^+ - P^-\right]}}$$ ”

Appendix B: Plot of full distribution for mean D50 values based on classification.