Suitability of Aerial Photography for Riparian Buffer Monitoring

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WASHINGTON STATE DEPARTMENT OF
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Doug Sutherland - Commissioner of Public Lands

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Forest Practices Adaptive Management Program

The Washington Forest Practices Board (FPB) has adopted an adaptive management program in concurrence with the Forests and Fish Report (FFR) and subsequent legislation. The purpose of this program is to:

> Provide science-based recommendations and technical information to assist the board in determining if and when it is necessary or advisable to adjust rules and guidance for aquatic resources to achieve resource goals and objectives. (Forest Practices Rules, WAC 222-12-045)

To provide the science needed to support adaptive management, the FPB made the Cooperative Monitoring, Evaluation and Research Committee (CMER) a participant in the program. The FPB empowered CMER to conduct research, effectiveness monitoring, and validation monitoring in accordance with guidelines recommended in the FFR.

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Project Summary

The purpose of this project was to evaluate the suitability of collecting riparian vegetation monitoring data by different remote methods that have varying degrees of resolution, accuracy, and cost. This will provide guidance in selecting appropriate data collection methodologies for the state Forest Practice Board's Timber, Fish, and Wildlife (TFW) Cooperative Monitoring, Evaluation, and Research Committee's (CMER) future research and monitoring studies. This project evaluated the most suitable instrumentation and imagery to use for evaluating the potential accuracy of a suite of riparian variables that address CMER extensive, prescription effectiveness, and intensive watershed scale monitoring questions. The accuracy, cost, and feasibility of the different resolutions of remotely sensed data are compared.

Suitability of Aerial Photography for Riparian Buffer Monitoring

Final Report

Prepared for:

Cooperative Monitoring, Evaluation, and Research
(CMER)

State of Washington Forest Practices Board
Adaptive Management Program

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TABLE OF CONTENTS

Appendices

Supplemental Report—The Potential of Softcopy or Digital Photogrammetry for Riparian Buffer Data Collection

LIST OF FIGURES

LIST OF TABLES

Table 10. The field count from southeast Alaska of the number and percent of erroneously classified species by super large scale photography and the species mistakenly called (Grotefendt, 2005). The species codes are: A= Sitka alder *Alnus sinuate* ; AKC=Alaska cedar *Chamaecyparis nootkatensis*; LP=lodgepole pine *Pinus contorta*; MH=mountain hemlock *Tsuga mertensiana*; SP=Sitka spruce *Picea sitchensis*; WH=western hemlock *Tsuga heterophylla*; WRC=western redcedar *Thuja plicata*.

Table 11. Down tree land spot classification.

Table 12. Count of down tree bases (i.e. root wads) detected by field and photo scale 1:2,000.

Table 13. Washington summary statistics of tree heights from 1:2,000 scale photography and field measurements at the pilot study site #27 (n=26), (Grotefendt, 2005).

Table 14. Southeast Alaska summary statistics of tree heights from 1:2,000 scale photography and field measurements at Control Lake and Upper Carroll (n=376), (Grotefendt, 2005).

Table 15. Labor costs to interpret and measure riparian variables on three study sites from four different scales of aerial photography.

Table 16. Cost to collect four scales of aerial photography for the four current study sites in the Willapa and Mt. St. Helens areas of southwestern Washington. Note these costs do not include aerotriangulation.

Table 17. Cost to collect two scales of aerial photography for 31 riparian buffer study sites distributed over 360 square miles in the central eastern and western Cascade mountains in Washington state (Grotefendt, 2005), (Curtis , 2005), (Curtis, 2007). Note these costs do not include aerotriangulation. (See Appendix Table 4 for more details).

Table 18. Range of field validation versus photo data collection costs.

Table 19. The effect of forest density and photo scale on grouped detection variables.

Table 20. The effect of forest density and photo scale on grouped measured variables.

1.0 INTRODUCTION

Natural resource regulatory requirements such as the Endangered Species Act, the federal Clean Water Act, the Northwest Forest Plan, and state forest practice regulations have increased the importance of monitoring forest resources. Landowners must comply with these regulations by monitoring key plant and animal populations and characterizing their habitat conditions while at the same time still utilizing the forest and its environment in a productive way (Wright, P.A., et. al. 2002).

In May of 2001 (as reported in Schuett-Hames, et. al., 2003), the Washington Forest Practices Board adopted rules designed to maintain and restore salmonid populations and meet the requirements of the federal Clean Water Act (WPFB, 2001). These rules are recommended in the Forests and Fish Report (FFR) and were the product of negotiations between the National Marine Fisheries Service, US Fish and Wildlife Service, US Environmental Protection Agency, timber landowners, state resource agencies, and some tribal and local governments (USFWS et al., 1999).

The riparian prescriptions within the FFR rules are designed to meet water quality standards, provide harvestable levels of fish, and maintain viable populations of stream associated amphibians. The prescriptions are designed to maintain important ecological functions provided by riparian forests, such as large woody debris (LWD) recruitment, shade to control stream temperature, sediment filtering/bank stability, and litter fall (Schuett-Hames, et. al., 2003).

The Washington State Forest Practice Board established a Timber, Fish and Wildlife (TFW) Cooperative Monitoring, Evaluation and Research Committee (CMER) to “conduct research, validation and effectiveness monitoring to facilitate achieving the resource objectives” and to “advance the science needed to support adaptive management” for state forest practices rules (WFPB, 2001). This committee also receives guidance from a Riparian Scientific Advisory Group (RSAG).

CMER has been working to develop methods for accurate and precise data collection that enable prescription monitoring to ensure federal Clean Water Act compliance. The problem is how to collect this data in an efficient manner to address questions that have a wide spatial component: landscape; watershed; and individual forest stands. The objectives of monitoring are to assess: stand characteristics (e.g. density, composition, tree size); stand processes (e.g. tree mortality, regeneration); large woody debris (LWD) recruitment (e.g. quantity, quality, and function); vegetative shade (e.g. coverage of the channel); and site attributes (e.g. buffer and stream characteristics). The monitoring may be by field, remote, or a combination of these methods. For an example of field and remote methods see Roorbach and Schuett-Hames, 2004 and Grotefendt, 2005, respectively.

Remote methods include data collection by aerial photography, light detection and ranging (LIDAR), high spatial resolution satellite imagery and hyper- or multi-spectral sensors. Aerial photography generally provides the highest resolution views of riparian buffer conditions and is comparable to field sampling. This project was designed to evaluate the capability of collecting riparian vegetation monitoring data from four different scales (1:2,000, 1:6,000, 1:12,000 and 1:32,000) of aerial photography that have varying degrees of resolution, accuracy, and cost because of the wide spatial scale of the prescriptions. Aerial photography was available from a special study and routine collection. The purpose is to determine what can be photo interpreted and measured from streams and riparian habitat and how accurately and costly it is. The accuracy will be based on one pilot study site, the 1:2,000 scale photography, and previous studies. This evaluation will provide guidance for the selection of appropriate data collection methodologies for future research and monitoring studies by CMER. Other non-aerial photographic remote methods will be reviewed by CMER via a one-day workshop with experts (http://www.ruraltech.org/video/2006/wadnr_remote_sensing/index.asp).

In addition to this report there is an additional report included in the appendices entitled "The potential of softcopy or digital photogrammetry for riparian buffer data collection". The purpose of the additional report is to evaluate the use of a different photo interpretation and measurement system than was used in this report.

2.0 METHODS

2.1 STUDY AREA

Areas with non-fish bearing (Type N) streams from all of western Washington were chosen from Washington Forest Practices harvest permit applications for an earlier field and aerial photo riparian buffer data collection study comparison (Schuett-Hames, 2003), (Schuett-Hames, et. al., 2003). These sites were candidates for the application of the FFR prescriptions. Field and aerial photo samples were taken from 15 of these areas, each containing a treatment and control site. Figure 1 shows all the possible Type N sites from which these 15 samples were collected. The field plots were sampled by CMER in 2003 and large scale (1:2,000 and 1:6,000 fixed-base) aerial photography was collected for CMER in March and April of 2004. This sample provided a total of 30 sites, 15 treatment and 15 control, although one photo control site was missing due to low clouds.

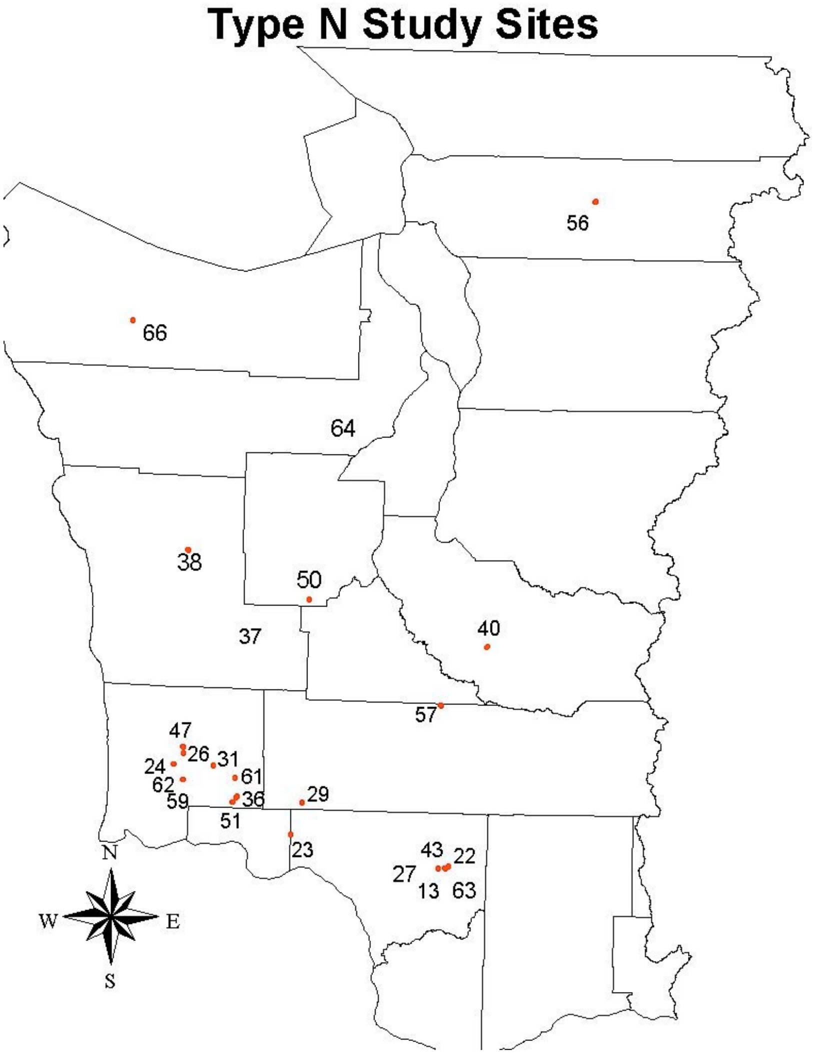

Figure 1. Non-fish bearing stream (Type N) study site locations in western Washington from which a subsample was selected for large scale (1:2,000 and 1:6,000) aerial photography collection.

2.2 PHOTO POPULATION

The photo population for this study was selected from the 2004 CMER photography and from existing Washington State Department of Transportation (DOT) public photography (scales of 1:12,000 and 1:32,000) that is collected for the Washington State Department of Natural Resources (DNR). The 2004 aerial photography (scales of 1:2,000 and 1:6,000) were collected with a fixed-base dual camera system from a slow moving helicopter (< 3 knots) and the DNR photography was collected by a fast moving airplane (> 100 knots) with a single camera system. The DOT photography is an effective source for data because the photos were already scanned and oriented by the DNR. Also these photos are routinely collected (i.e. every few years) statewide and are a potential source for collecting riparian data remotely in the future. The DOT photography examined for this study were from 1999, 2001, 2003, and 2005 for 1:12,000 scale and 1998, 2003, 2004, and 2005 for 1:32,000 scale. The DOT 2005 1:12,000 and 1:32,000 photo scale was chosen for this study because it overlapped the study sites and occurred after the logging.

2.3 SAMPLE FORMATION

Sample size was limited by the funding available, therefore two control and two treatment pairs (i.e., four sites; CMER control sites 24 and 27 and CMER treatment sites 27 and 29, Figure 2) were examined for this study (Iles, 2003), (Schreuder, 1993). Each sample consisted of four scales of aerial photography taken over the same study site, Figure 3. One of these study sites was identified as a 'pilot' study site (i.e. Treatment at Site 27) and detailed field data was budgeted for collection. The treatments had riparian buffers along the stream banks logging according to the FFR prescriptions. The controls were unlogged sites with continuous forest surrounding the stream banks. The four sample sites were selected in a biased fashion as follows. The 1:2,000 scale photography was examined to find which sites had streams that were visible. The non-fish bearing (Type N) streams were very small (e.g. less than 3m wide) and difficult to see, even in the field sometimes. Sites where the stream was visible on the largest scale photography and where the four scales of imagery occurred within as similar a time frame as possible were preferentially chosen. Those forest stands that had medium to high density were chosen. Higher densities were chosen because photo interpretation is more difficult as stand density increases obscuring tree details and these conditions are likely to occur more frequently under stands logged under the FFR prescriptions. All photography had to occur after logging for treatment sites. This project was planned to give an indication of the different photo scale's utility, not to provide sufficient data to make inferences from its results across all Washington TYPE N streams nor to determine the accuracy of photo measurement and interpretation compared to field measurements of the same sites. For a review of these two issues, the reader is directed to Martin and Grotefendt (in press) and Grotefendt (2005).

Additional riparian habitat photo samples were used from previous studies from old growth in southeastern Alaska (Grotefendt, 2005) and second growth in the western and eastern portion of the central Cascades Mountains in Washington State (Grotefendt and Light, 2004). The southeast Alaska sites centered around two locations, Control Lake and Upper Carroll Inlet, west of Ketchikan on Prince of Wales Island. The Washington sites included the Green river drainage in the west to the upper Yakima River drainage in the east. Washington sites on the southern Olympic peninsula west of Shelton also provided measurement data.

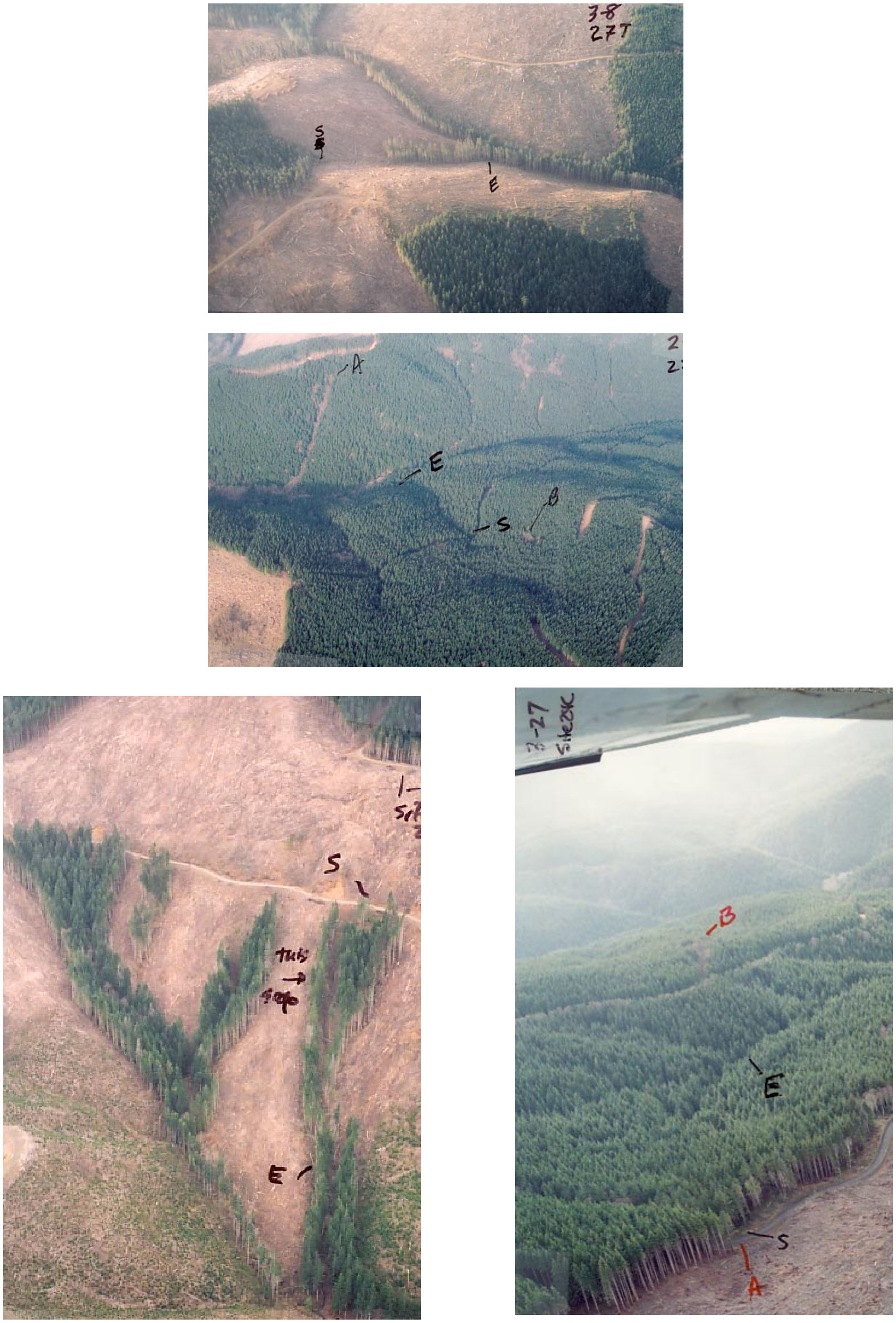

Figure 2. Reconnaissance photographs (© Richard A. Grotefendt) of the four Washington study sites. The top photo is site 27 treatment, the middle photo is site 27 control, the bottom left is site 29 treatment, and the bottom right is the site 24 control.

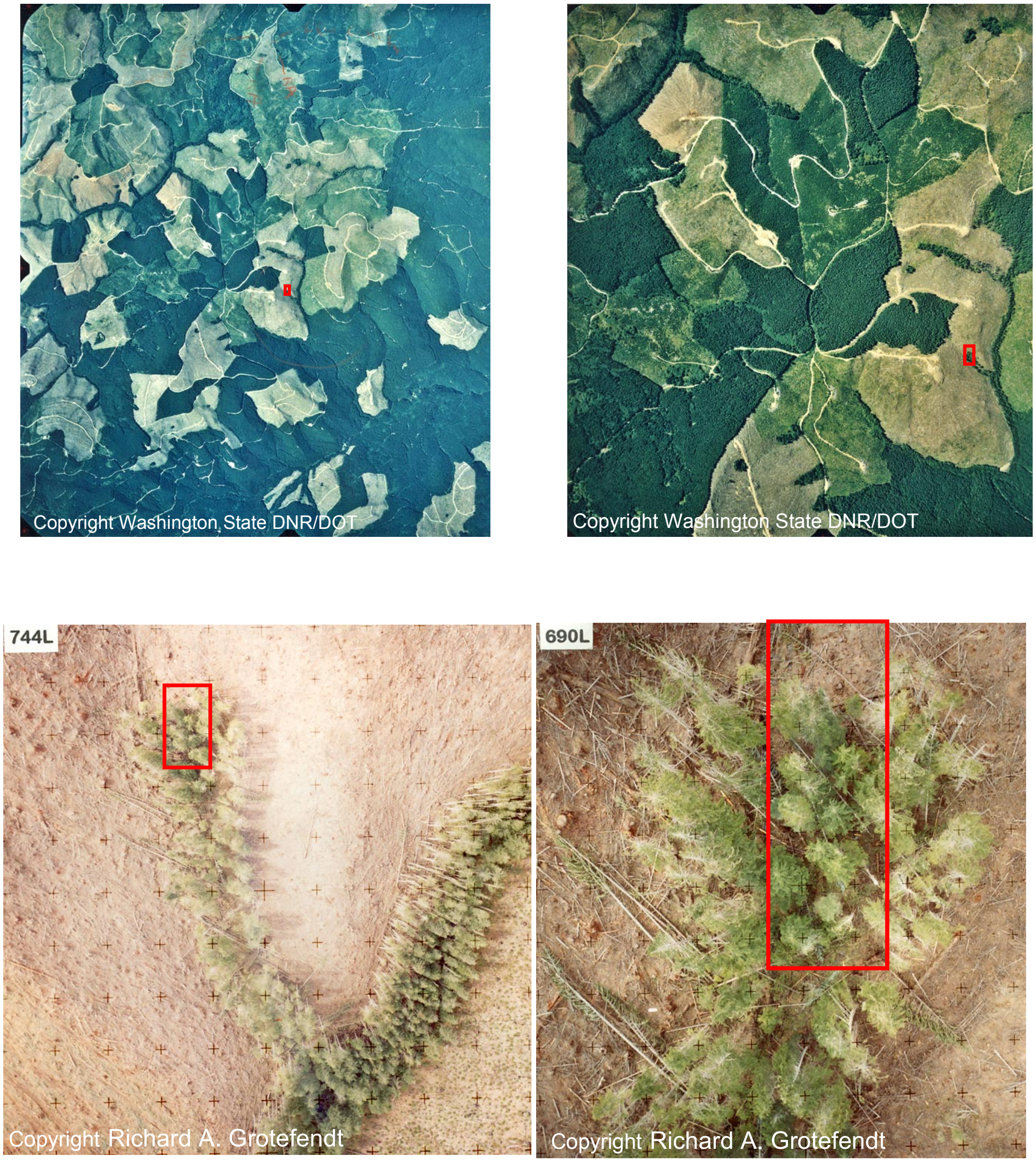

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Figure 3. Photos used to interpret and measure pilot study site #27 on the western slope of Mt. St. Helens. The top left photo is 1:32,000 scale, the top right photo is 1:12,000 scale, the bottom left photo is 1:6,000 scale and the bottom right photo is 1:2,000 scale. The red box approximately outlines the 50 by 200 ft plot area on the left bank of the non-fish bearing (Type N) stream. Note that the bank side is determined from a position standing in the stream and looking down stream. The study site stream is flowing down towards the bottom of each photograph in this figure.

2.4 MONITORING VARIABLES

Tables 1 and 2 provide lists of riparian zone monitoring variables that may be detected and measured from aerial photography, respectively, and that are of potential interest to CMER. The tables denote variables that were included in this study and those that were excluded or briefly examined due to funding limits.

Table 1. Monitoring variables that are detected and were collected from aerial photography for the comparison of different photo scales (Status: I=included; B=briefly examined; E=excluded).

Variable name Detect	Status	Variable definitions or codes
Tree condition	I	(live, snag, down, cut)
Tree type	I	(conifer or hardwood)
Tree decay class (when down)	I	(foliage [needles or leaves] recent [i.e. green or brown], twig [i.e. secondary or tertiary branches], or unknown)
Down tree landing spot	I	(in, over, away)
Root wad presence	I	(yes, no, unknown)
Stream bank	I	Digitize
Stand density category	I	(sparse, medium, dense)
Stand composition	I	Proportion of conifer, hardwood, & mortality
Channel confinement	I	(confined, unconfined)
Tree genus	B	(e.g. Abies, Tsuga)
Tree species	B	(e.g. Abies procera)
Land form category	E	
Stand seral stage	B	(e.g. height or young, immature, mature)
Tree canopy class	B	(e.g. dominant., codominant, suppressed)
Stand size category	B	(e.g. tall, medium, short)
Recruitment category	E	
Stand structure	B	Stand initiation, stem exclusion, understory re-initiation, old growth (Oliver and Larson, 1996)

Table 2. Monitoring variables that are measured and were collected from aerial photography for the comparison of different photo scales (Status: I=included; B=briefly examined; E=excluded).

Variable name Measured	Status
Count	
Tree count (trees ≥20ft tall)	I
Seedling/sapling density	E
Distance	
Tree height	I
Down tree length	I
Tree diameter at breast height (DBH; estimated by equation)	I
Tree distance from stream (computed)	I
Stream length (computed)	I
Stream widths and their average (computed)	I
Tree diameter when down	E
Distance to other trees (computed)	E
Tree crown diameter	E
Area	
Tree crown area	I
Stand crown closure (computed from crown area)	I
Plot	I
Stream	I
Wind throw gap area	E
Percent debris/shrub cover	E
Spatial (relative or georeferenced)	
Tree position	I
Stream full bank	I
Azimuth for valley	E
Fall azimuth relative to stream (e.g. towards, parallel, away)	B

2.5 DATA COLLECTION STEPS FROM PHOTOS AND FIELD

2.5.1 Photo Procedures

The procedures for data collection from the aerial photography discussed below include orientation, interpretation, measurement, and data processing. Orientation relates the stereo photo pair to the photo measurement machine (i.e. an analytical stereoplotter), to each other, and to some reference system that provides scale. Interpretation involves viewing the 3D image and discerning natural objects such as tree tops, root wads, and stream banks. The natural objects are measured by placing a marker (called a "floating dot") upon them and computing distances and areas from their x-y-z positions. The data processing procedure transforms the analytical stereoplotter coordinate output into a rectangular American Standard Code for Information Interchange (ASCII) file for analysis and into geographic information system (GIS) shapefiles for display and spatial computations.

There are three methods of determining scale during the orientation procedure of the stereo photo pair on the analytical stereoplotter. They are: (1) ground control, (2) fixed-base, and (3) direct georeferencing. The ground control method, which has historically been used, utilizes a single camera and known ground coordinates to determine scale (Wolf, P.R., 1983). The fixed-base method is used mostly in special applications and makes use of the known distance between two cameras to determine scale without the need for ground control points (Veress, S.A., 1980), (Karara, H.M., 1967), (Konecny, G., 1965). The direct georeferencing method is a more recent development supplanting the ground control method, it uses a single camera and the known position and orientation of the camera lens to determine scale (Mostafa, M.M.R., 2003), (Schwarz, K.P., et. al., 1993), (Reutebuch, et. al., 2000), (Skaloud, J., 2002). The 1:2,000 and 1:6,000 scale photography was oriented by both the fixed-base and ground control methods. The latter method was used for the study's photo measurement data. Horizontal and vertical distances were measured from three objects each, respectively, to check if the differences between distances determined by the two scale methods were significant. The absolute average differences of the horizontal distances was 1.1% (minimum=0.6%, maximum=1.4%) and of the vertical distances was 1.4% (minimum=-2.2%, maximum=1.1%), see Table 3. These small differences were deemed acceptable for this study. The 1:12,000 and 1:32,000 scale photography was oriented by the ground control method.

Table 3. Horizontal and vertical distances from two different methods of determining scale on 1:2,000 fixed-base collected imagery from the Washington pilot study site #27.

Object identifier	Fixed-base distance	Geo. ref'd distance	% difference of fixed-base distance
pt.51 to pt.55	329.4 ft	333.2 ft	1.2
pt.51 to pt.56	253.2	254.7	0.6
pt.53 to pt.56	313.9	318.3	1.4
average	298.8	302.1	1.1
height a	94.6	92.5	-2.2
height b	75.1	75.7	0.8
top snag	92.9	91.9	1.1
average	87.5	86.7	1.4 (absolute avera

As described above in the photo population section, the aerial photography was collected by two methods: (1) a fixed-base camera system (two cameras taking stereo pictures simultaneously from a slow moving helicopter (< 3 knots)); and (2) a single camera taking sequential pictures from a fast flying (> 100 knots) fixed-wing aircraft. The effect of these methods affected the photography and its usefulness. In fact, because of the latter single camera methods, the 1:12,000 and 1:32,000 photography was unusable for riparian buffer interpretation. The stream banks and plot corners either had greatly limited visibility or were totally obscured. The fast airplane speed and the DOT camera's slow film magazine recycle rate resulted in distances between sequential photos of from approximately 3,600ft to 9,700ft, which for the most part prevented views down through the trees. The timing of the photography was also during hardwood leaf-out and bright skies so that dark shadows that limited views in gaps were prevalent. Obscured views due to hardwood leaf-out were not significant but could be in many riparian buffer areas, especially from shrubs (e.g. salmonberry) that would hide down tree trunks. The fixed-base 1:2,000 and 1:6,000 photography was usable because the short distance between the stereo photo pairs enabled viewing the forest floor down through the tree crowns and exposures were mostly with cloud cover so that shadows were minimized.

I devised a method to utilize the DOT photography so that as many variables from Tables 1 and 2 could be evaluated as possible, see Table 4. Clear, natural plot corner objects were identified on the 1: 2,000 scale photography after its orientation by fixed-base methods. The plot size was approximately 50 by 200ft long and the long side ran parallel to the stream. Then the 1:12,000 scale photos were oriented with aerotriangulation information provided by the DNR. Natural objects and their X, Y, and Z state plane coordinates were identified on the 1:12,000 scale photography that could also be seen on the 1:2,000 and 1:6,000 scale photography. The 1:2,000 scale photography was then re-oriented by bridging with the state plane coordinates and the plot corner state plane coordinates were recorded. The 1:32,000 scale photography was then oriented with the DNR aerotriangulation data and the plot corners were located with the coordinates from y 1:2,000 scale photos, even though their actual position could not be seen. The tops of the trees on the 1:2,000 and 1:32,000 were compared to ensure that the correct plot area was delineated. This step was repeated on the 1:12,000 and 1:6,000 scale photography, although the plot corners were visible on the 1:6,000 scale photography.

Table 4. Sequence of photo sample plot layout, photography orientation and bridging, and interpretation.

Step	Imagery used	Action
1	1:2,000	Orient with fixed-base control and determine plot corners.
2	1:12,000	Orient with DNR provided control and use to collect control for bridging to 1:2,000 and 1:6,000.
3	1:2,000	Orient, bridge control, and determine plot coordinates.
4	1:6,000	Orient and lay out plot.
5	1:12,000	Orient and lay out plot with 1:2,000 plot coordinates.
6	1:32,000	Orient and lay out plot with 1:2,000 plot coordinates and start interpretation.
7	1:12,000	Interpret.
8	1:6,000	Interpret.
9	1:2,000	Interpret.

2.5.2 Interpretation Procedures

The sequence of the interpretation of the four photo scales was selected to eliminate bias. The plot corners and their coordinates had to be determined first on the 1:2,000 scale photos so only clear natural objects that could function as plot corners were sought and little attention was paid to the plot contents. The purpose of this disregard was so that plot attributes noticed on the larger scale photos were not used when interpreting the smaller scales. The actual interpretation of plot details began with the smallest scale photography (i.e. 1:32,000). It was felt that interpretation decisions on the smaller scales were not influenced by previous orientation and plot layout work on the larger scales.

Softcopy photo measurement systems are computer versions of the photo measurement machine, an analytical stereoplotter (i.e. AP190, manufactured by Carto Instruments), used in this study. The softcopy stereo image is viewed on a computer screen instead of through optics. Discussions with DNR photogrammetrists put forth the idea that insufficient analytical stereoplotter magnification may cause interpretation errors, although softcopy resolution is admittedly also limited by the computer monitor pixel size. Although it is agreed that sufficient magnification greatly enhances correct photo interpretation, magnification of a low resolution object does not provide more information than less magnification of a high resolution object. It was felt that the lack of softcopy magnification did not limit correct interpretation of Tables 1 and 2 variables when the object was visible. The physical size of the tree images at the smaller scales are extremely minute and additional image content would not be visible at magnifications higher than the analytical stereoplotter used. For example, the actual film size covered by a 50ft by 200ft plot was 7.62 by 30.48mm, 2.54 by 10.20mm, 1.27 by 5.10mm, and 0.48 by 1.91 mm, respectively for photo scales of 1:2,000, 1:6,000, 1:12,000, and 1:32,000. Welch states that even 1:380,000 scale photos can be used to make "planimetric maps to 1:24,000 scale if adequate viewing magnification is available in the plotting instrument". He further qualifies this by saying "if image quality" is adequate (Welch, 1972). The mapping accuracy Welch refers to relates more to the geometric strength of even extremely small scale photography but not to the accuracy of natural resource object identification in this study.

2.5.3 Measurement Procedures

The operation of the analytical plotter's mechanical, optical, and computer components that were used for measurements is described as follows. Aerial photography negatives were made into diapositives (transparent positives made from the negatives) and a stereo pair was mounted on mechanical, moving image holders. Light was projected through the images and they are viewed in stereo or 3D through optics that have a zoom feature. Digital information was transmitted from the personal computer (PC) to micrometers that are mounted on the image holders, which in turn move the images to their proper position. The PC performs computations to determine the positions the two images should have relative to one another for clear 3D viewing. A mark in the form of a dot was superimposed on each of the two mounted stereo photos through the optical components. As the images were moved to view different areas the dots appear to move, and when each dot is placed on the same object (such as a tree top) the 2D coordinates of each dot's position is recorded. These coordinates were converted by the computer to a 3D real world coordinate system (e.g. state plane). These coordinates were used for the computation of distances and areas of objects, and for the determination of their positional relationship to each other, (e.g. distance of a tree to a stream bank edge) (Grotefendt, 2005).

Tree height measurement on the 1:12,000 and 1:32,000 scale was limited by a malfunction in the software that built the DEM. It was thought this was due to the very small area of the plot compared to the large area of the photography. This malfunction will need to be addressed if the small scales of photography are used in the future for tree height measurement. This malfunction caused errors of approximately 10 to 20 ft in tree heights so that there is no presentation of that data in the results section.

2.5.4 Photo Data Processing Procedures

The photo-collected riparian buffer data was in a form not compatible with analytical, statistical, or graphics software, such as ESRI's Arcview. Proprietary software was used to transform the analytical stereoplotter data into rectangular American Standard Code for Information Interchange (ASCII) files for analysis. This software also enabled the files to be input for additional transformation by geographic information system (GIS) proprietary scripts into shapefiles for display as maps and for computations such as distance of a tree to the full bank edge.

2.5.5 Field Procedures

The pilot study site that was selected for the field survey was chosen because of its accessibility and its possession of clear, natural photo targets that could be seen on the 1:2,000 scale photography and found in the field. All four scales of photography were interpreted prior to the field visit. All standing trees, down trees, and stumps were stem mapped. Three tape measures were used to locate objects. A baseline was formed by one tape extending down the stream between the two corner points that occurred in the stream centers. Two tapes were extended perpendicular from this baseline to the far plot edge. All tapes were kept horizontal. All objects were mapped and attributes collected within a 25ft wide strip that was perpendicular to the baseline and then the two tapes were moved to a subsequent strip. All mapping was done to scale on a field map which was digitized into an E.S.R.I. Arcview shapefile and transformed into the same state plane coordinate system as the photography so that all spatial data could be superimposed for display and analysis, Figure 4.

2.6 DATA ANALYSIS

The photo and field collected data were subjected to comparative analyses. The accuracy of information collected by field methods alone has variability due to the field techniques employed. The basis used to determine the photo method's reliability was a comparison with the results of field techniques not the absolute truth or highest standard of measurement. The reporting of the measurement results by using the average of the absolute photo and field differences gave a better picture of their comparativeness. When no field plot existed, the 1:2,000 scale photography was the assumed standard. Scatterplots were used to examine relationships such as those between photo and field measured total tree height. The field-derived stem map was compared to the photo stem maps.

Part of the analysis was to refine measurement and detection criteria for comparisons of the different photo scales. The description of the standard system that was developed and the revised threshold values are in Appendix Tables 1, 2, and 3.

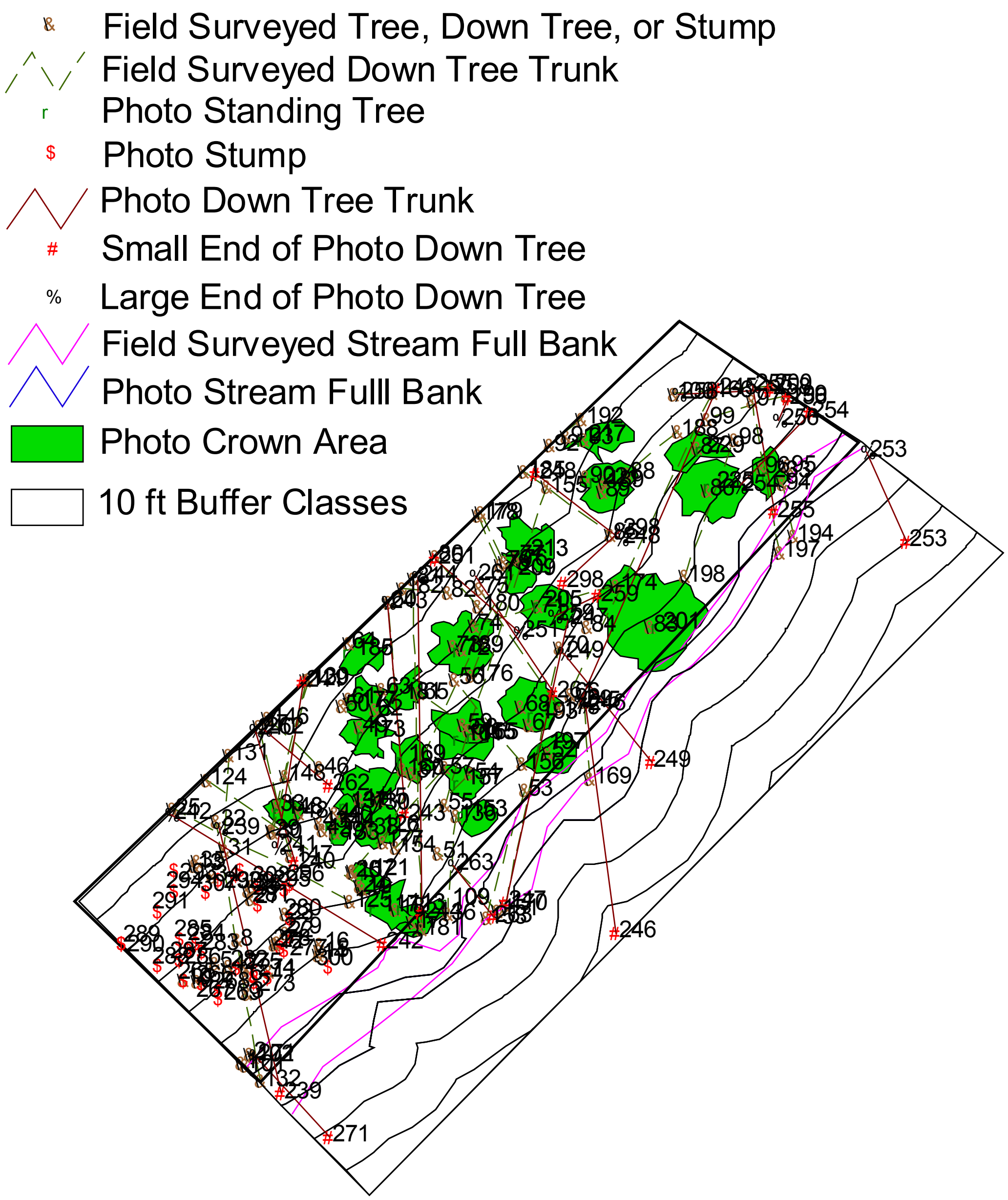

Figure 4. **An example map of superimposed field and 1:2,000 photo scale attribute data from the pilot study site #27 located west of Mt. St. Helens in southwestern Washington. Overlapping numbers are individual feature identifiers used to compare field to photo interpretation. The parallel contour-like lines are 10 ft distance classes from the photo stream full bank.**

3.0 RESULTS

3.1 PHOTO SCALE

The effectiveness of data collection is dependent on photo scale and the method of photo collection. Improvement of methods may improve future results but in particular, it was found that the two smaller scales (i.e. 1;12,000 and 1:32,000) would not have produced any useful data at all without the use of the large scale photos to determine plot corners and stream location. The ground surface also was not usually visible within the plot boundary on the two smaller scales. This also can occur on the larger scales (i.e. 1:2,000 and 1:6,000) but is much less frequent because fixed-base methods were used which provides views down through the tree canopy because of the small distance between the stereo photo pairs. Without a few visible ground points tree height measurement is not possible neither can a digital elevation model (DEM) be built which can also be used to measure tree heights. The ground elevation points from the larger scales were used on the smaller scales to build a DEM so tree heights could be collected.

3.2 DETECTION

The detection accuracy for selected variables is presented in Tables 5 through 12. A comparison of the counts of standing trees greater than 20 ft and down trees that were detected from the four scales of aerial photography (Table 5) shows that detection generally declines as the scale decreases. However, I also found two cases where there are higher tree counts at the smaller scales compared to the 1:2000 scale. These anomalies are assumed to be due to misidentification of standing or down trees.

Table 5. Tree counts by Washington study site and tree condition (standing, down, cut) from four scales of photography (note: There were no stumps found within the plots).

Study		Count from field and photos for different scales			
site #	Variable	1:2,000	1:6,000	1:12,000	1:32,000
24c uncut	trees >20ft	39	43	33	29
29 logged	trees >20ft	24	19	18	18
127c uncut	trees >20ft	38	37	40	30
24c uncut	down tree	6	0	0	0
29 logged	down tree	4	2	0	0
127c uncut	down tree	8	2	0	0

Misidentification of trees is shown by our results for Site 27 where we conducted the ground survey (Table 6). At site 27 we found that the actual count of standing trees, down trees, and stumps is 40, 35, and 22, respectively. The most accurate photo count of standing trees (31 of 40) and down trees (19 of 35) was from the largest scale of aerial photography (i.e. 1:2,000). The correct photo count of standing trees by the 1;6,000 scale (29 of 40) was almost as good as the 1:2,000 scale but 7 additional standing trees were also tallied that did not exist; presumably due to misidentification. The performance of both the 1:2,000 and 1:6,000 in the count of stumps was poor, over-counting by 55% and undercounting by 50% respectively. The count of standing trees, down trees, and stumps were poor for the 1:12,000 (20 of 40, 2 of 35, and 8 of 22, respectively) and for the 1:32,000 (15 of 40, 0 of 35, and 4 of 22, respectively), Table 6.

Table 6. **Washington pilot study site counts of standing trees, down trees, and stumps by four scales of photography and 100% field census (numbers in parentheses are the correct number out of those photo counted based upon the ground survey).**

	Pilot study site #27 count from field and photos by different photo scales				
Variable	**Field**	**1:2,000**	**1:6,000**	**1:12,000**	**1:32,000**
trees >20ft	40	31 counted (31 correct)	36 counted (29 correct)	20	15
down trees	35	22 (19 correct)	11 (10 correct)	2	0
stumps	22	34	11	8	4

To provide more context for validation, the Washington results (Table 6) are compared to field validation data from southeast Alaska 1:2,000 scale photo counts (Table 7; Grotefendt, 2005). The Alaska photo count of standing trees (12 of 11, 10 of 23, and 17 of 20) and stumps (2 of 2, 0 of 0, and 0 of 0) is closer to the field census than the Washington results. This may be because the Alaska stands are old growth forests and may have fewer suppressed trees or because the plot size was smaller by about 50%. The Alaska photo count of recent down trees was perfect at 2 sites (0 of 0 and 4 of 4) but fair at the high density site (3 of 5) (Grotefendt, 2005).

Table 7. **Washington pilot study site counts of standing trees, down trees, and stumps from Table 6 compared to three southeast Alaska photo count study sites with 100% field census (numbers in parentheses are the correct number out of those photo counted based upon the ground survey) (Grotefendt, 2005).**

			Counts from field and photos by different photo scales				
State/plot #	**Stand density**	**Variable**	**Field**	**1:2k**	**1:6k**	**1:12k**	**1:32k**
Wa 27	med	trees >20ft	40	31 (31)	36 (29)	20	15
Ak 679	low	trees >20ft	11	12	n/a	n/a	n/a
Ak 1071	med	trees >20ft	23	19	n/a	n/a	n/a
Ak 647	high	trees >20ft	20	17	n/a	n/a	n/a
Wa 27	med	all down trees	35	22 (19)	11 (10)	2	0
Ak 679	low	recent down trees	0	0	n/a	n/a	n/a
Ak 1071	med	recent down trees	4	4	n/a	n/a	n/a
Ak 647	high	recent and unknown down trees	5	3*	n/a	n/a	n/a
Wa 27	med	stumps	22	34	11	8	4
Ak 679	low	stumps	2	2	n/a	n/a	n/a
Ak 1071	med	stumps	0	0	n/a	n/a	n/a
Ak 647	high	stumps	0	0	n/a	n/a	n/a

(Note: The number in parentheses is the number that actually occurs in the field.)

* Decay class could not be photo interpreted because of high forest density.

Missed and misidentified objects and errors in height measurement and location contributed to errors in the 1:2,000 scale photo count. For example, 7 of the 9 missed standing trees in Table 6 were suppressed trees growing under taller trees or tall trees growing so close to a taller tree that their tops could not be distinguished. Photo measurement excluded two trees because they were less than 20 ft but actually were field measured to be 20 and 22 ft respectively, Table 8. The taper, tree top, and tree base of 3 down trees could not be photo viewed. This resulted in locating them within the plot, when actually they blew down from the opposite stream bank, Table 6.

There were 12 more photo counted stumps from the 1:2,000 scale photos than field tallied. A large, bright rock and a 2 ft chunk of a log lying up at an angle between two stumps were misidentified as stumps. Photo measurement did not detect that three included photo stumps were actually less than the 4 inch diameter inclusion rule. Misidentification of bright lumps and logging debris chunks likely accounted for the remaining over-count. Thorough examination of the field and 1:2,000 scale photos revealed that seven down trees field-mapped in 2006 had been standing at the time of the 2004 aerial photography but this did not result in any errors.

The error in photo counts from under-detection of small trees or trees that cannot reach the stream is a minor factor in riparian monitoring studies. Six of the 9 missed standing trees (Table 8) would not have reached the stream or contributed effective large woody debris (LWD).

Table 8. Reasons standing trees were missed by photo interpretation from the Washington pilot study site (#27) and their position relative to the stream which indicates the significance of missing them (e.g. their potential contribution as large woody debris (LWD)).

Field tree ID #	Field height (ft)	Distance to stream	Could hit stream?	Amount could extend past closest bank (ft)	Reason missed
39	37	29	yes	8	hidden under taller tree
40	41	31	yes	10	hidden under taller tree
50	69	48	yes	21	growing 2 ft from 74 ft tree
67	80	13	yes	67	top hidden under 94 ft tree
72	31	36	no	0	growing under 74 ft tree
76	28	38	no	0	hidden under taller tree
79	guess 30 ft based on dbh*	40	no	0	hidden under taller tree; blew down after photo was taken and extends outside of plot so no length available
93	20	46	no	0	under 65ft tree; photo ht likely < 20 ft
95	22	2	yes	20	visible; photo ht likely < 20 ft

* DBH=diameter at breast height or 4.5 ft above average ground level.

The tree type (i.e. conifer, hardwood, snag) was correctly identified 100% of the time at the Washington pilot study site #27 on all scales of photography. Tree species was only detectable on the 1:2,000 scale photography, Table 9. The overall species identification error was 33% for thirty trees that were interpreted. Western hemlock, the most prevalent species, was correctly identified 82% of the time, Table 9. No field training with 1:2,000 photos was performed before this photo interpretation was done. For example, it was not known which species were most prevalent in that area. Previous experience was used to determine the species.

Table 9. The field count from the Washington pilot study site of the number and percent of erroneously classified species by super large scale photography and the species mistakenly called. The species codes are: WH=western hemlock *Tsuga heterophylla*; PSF=Pacific silver fir *Abies amabilis*; WRC=western redcedar *Thuja plicata*; DF=Douglas fir *Pseudotsuga menziesii*; SNAG=standing dead tree.

Species	Field count	Number erroneously classified	Percent erroneously classified	Species incorrectly called and their number (n)
WH	17	3	18%	DF(1), WRC(2)
PSF	10	6	60%	WH(4), WRC(2)
WRC	1	0	0%	n/a
SNAG	1	0	0%	n/a
DF	1	1	100%	WH(1)
TOTAL	**30**	**10**	**33%**	

I performed tree species interpretation of 176 trees in southeast Alaska where most species were similar to the study site except Douglas fir and Pacific silver fir, Table 10, (Grotefendt, 2005). The error of classification was 10% for all species with only a 2% error for western hemlock. Field work involving species identification was performed before the photo interpretation and improved the species recognition. Nonetheless, species with assumed highly distinguishing characteristics were still misidentified (e.g. spruce was called a western hemlock or Alaska cedar).

Table 10. The field count from southeast Alaska of the number and percent of erroneously classified species by super large scale photography and the species mistakenly called (Grotefendt, 2005). The species codes are: A= Sitka alder *Alnus sinuate* ; AKC=Alaska cedar *Chamaecyparis nootkatensis*; LP=lodgepole pine *Pinus contorta*; MH=mountain hemlock *Tsuga mertensiana*; SP=Sitka spruce *Picea sitchensis*; WH=western hemlock *Tsuga heterophylla*; WRC=western redcedar *Thuja plicata*.

Species	Field count	Number erroneously classified	Percent erroneously classified	Species incorrectly called and their number (n)
A	8	1	12.5	WH(1)
AKC	12	3	25.0	WH(1),WRC(2)
LP	3	0	0.0	n/a
MH	14	6	43.0	WH(5),WRC(1)
SP	25	5	20.0	WH(4),AKC(1)
WH	98	2	2.0	WRC(1),MH(1)
WRC	16	1	6.3	AKC(1)
TOTAL	**176**	**18**	**10.2**	

The down tree landing spot provides information about the potential function of the down tree in the stream. Down tree landing spot classifications were correctly assigned 89% (n=18) of the time, Table 11.

Table 11. Down tree land spot classification.

Position re: stream	Field count	Photo count
in	0	2
over	6	4
away	12	12
TOTAL	**18**	**18**

The presence of a root wad typically indicates windthrow unless bank undercutting or landslides are the cause of tree toppling. There were 78% of the down trees whose root wad presence or absence could be interpreted from the Washington pilot study site, Table 12. Four were unknown.

Table 12. Count of down tree bases (i.e. root wads) detected by field and photo scale 1:2,000.

Root wad type	Field	Photo 1:2,000
yes, root wad	16	13
not a root wad	2	1
unknown	0	4
TOTAL	**18**	**18**

3.3 MEASUREMENT

The effectiveness of photo measurement increased as the scale became larger but this was not due wholly to scale. The method of small scale photo collection limited measurement due to lack of visibility of objects, the ground, and the stream. If improved photo collection methods were followed (i.e. longer focal length; shorter distances between photos; leaf off; exposures optimized for ground surface visibility among riparian trees and shadow reduction) the usefulness of these smaller scales would likely improve. The smaller image size would still reduce the measurement accuracy. Over three-fourths of the variables in Table 2 could be measured satisfactorily with the larger photo scales (i.e. 1:2,000 and 1:6,000). A discussion of tree position is presented below as well as detailed results for field and photo tree heights collected from this study and southeast Alaska are presented in Tables 13 and 14 (Grotefendt, 2005).

The accurate location of tree position is relatively good for the 1:2000 scale. The distance from the field tree position to the photo tree position averaged 3.0 ft (std.dev.=1.7 ft, min=1.0 ft, max=9.0 ft, n=31) for photo scale 1:2,000. This accuracy of stem mapping was higher than a previous Washington, southern Olympic peninsula study reported in Grotefendt, 2005. That study reported the photo tree position average error was 2.6m (8.4ft) (s.d. =1.4m (4.5ft), range 0.1 to 4.6m (0.2 to 15.0ft), n=20). However, that study based its conclusions upon a comparison between a DEM projected tree base position from the tree top versus the base position that could actually be seen on the photo. No field mapped positions were used for comparison.

Tables 13 and 14 present the comparison between field and photo height from this study and a previous southeast Alaska study. Comparisons between photo and field tree height measurements are almost exclusively reported by other researchers as the average of their differences, not the average of their absolute differences (Aldred, A.H. and J.J. Lowe, 1978), (Kirby, C.L., and R.J. Hall, 1980), (Lyons, E.H., 1967). Therefore their results appear on the surface to be more accurate than if the average of the absolute differences were reported. The reason the average differences are usually lower is those differences have positive and negative sign which reduce their sum. This is illustrated in Table 13 where the average photo versus field height difference is 0.4ft (s.d.=8.0ft, n=26) and the average absolute photo versus field height difference is 6.0ft (s.d.=5.1ft, n=26).

Table 13. Washington summary statistics of tree heights from 1:2,000 scale photography and field measurements at the pilot study site #27 (n=26), (Grotefendt, 2005).

WA method	Range (ft)	Average difference from field (ft) (std. dev.)	Average (ft)	Std. dev. (ft)	Average of absolute difference from field (ft)	Std. dev. of absolute difference from field (ft)
1:2k photo	30-106	-0.4 (8.0)	69.1	15.5	6.0	5.1
field	34-107	n/a	69.6	18.6	n/a	n/a

The absolute average photo versus field tree height difference for southeast Alaska was 2.4m (7.8ft) or 10.6 percent from the average field height of 22.4m (73.4ft) for a sample of 376 trees, Table 14. Figure 5 illustrates that 88% of all photo estimated tree heights were within 5m (15ft) of field measured tree heights. The absolute average photo versus field height difference for Washington was similar to the Alaska difference, 9%, for the average field height of 69.6ft. Figures 6 and 7 are scatter plots for the field versus photo tree heights for Alaska and Washington, respectively.

Table 14. Southeast Alaska summary statistics of tree heights from 1:2,000 scale photography and field measurements at Control Lake and Upper Carroll (n=376), (Grotefendt, 2005).

Measurement method	Range (ft)	Average difference from field (ft) (std. dev.)	Average (ft)	Std. dev. (ft)	Average of absolute difference from Field (ft)	Std. dev. of absolute difference. from field (ft)
Super large scale photography	13-161	-4.8 (9.2)	68.6	27.9	7.8	6.8
Field	12-183	n/a	73.4	29.9	n/a	n/a

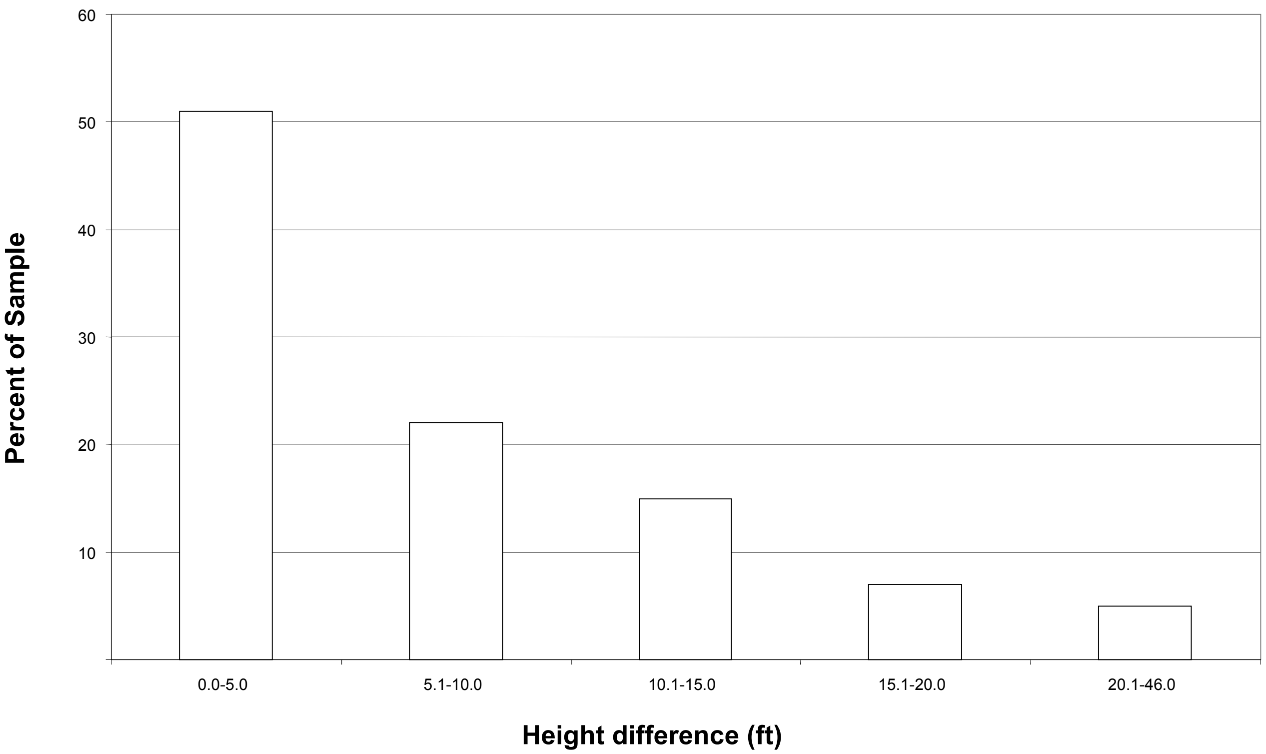

Figure 5. The percentage of southeast Alaska samples classified by absolute height difference in feet between field and photo measured tree heights from Control Lake and Upper Carroll (Grotefendt, 2005).

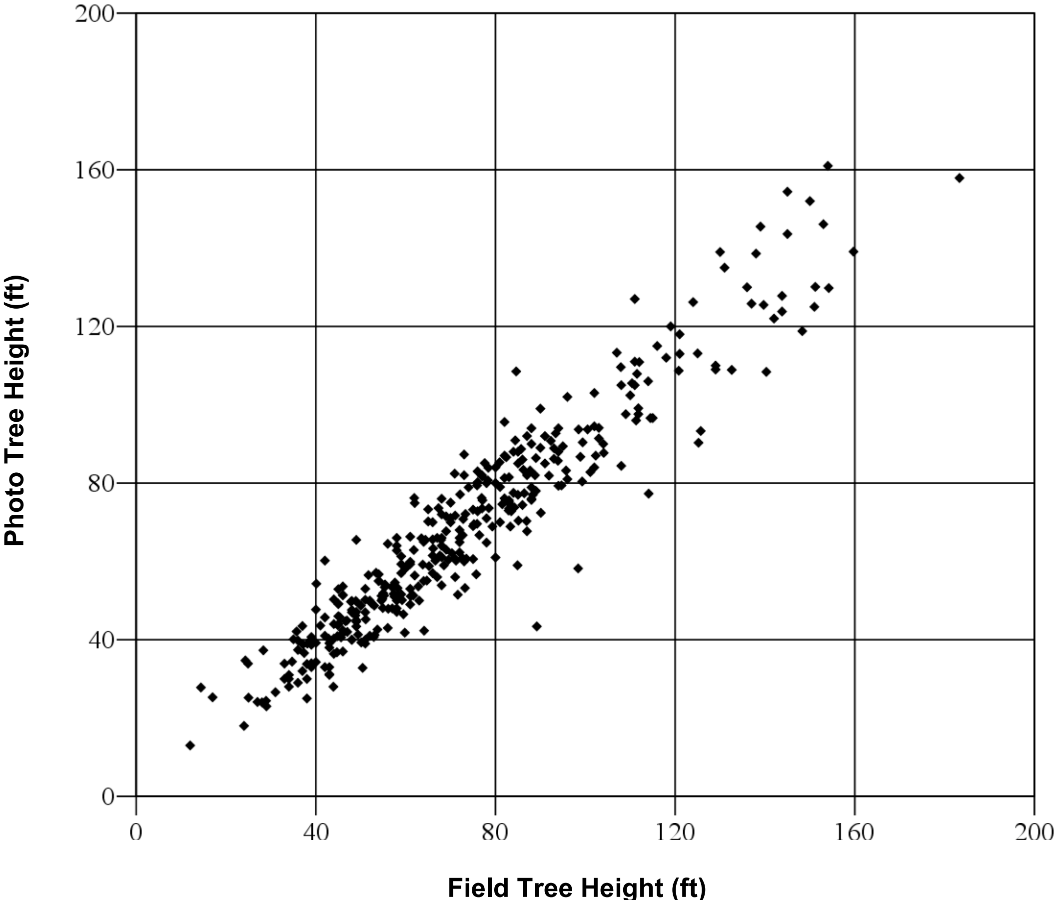

Figure 6. Scatter plot of photo and field tree heights from southeast Alaska at Control Lake and Upper Carroll (n=376).

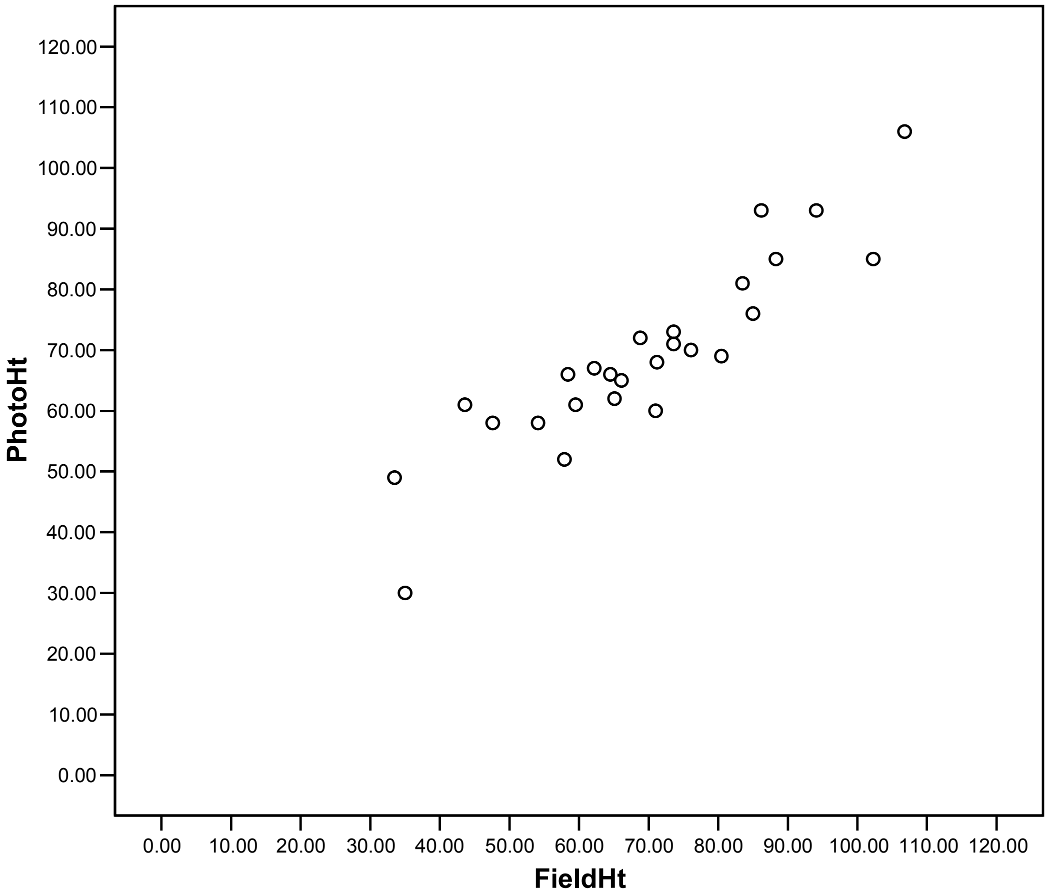

Figure 7. Scatter plot of photo and field tree heights from the Washington pilot study site #27 on the western slopes of Mt. St. Helens (n=26).

3.4 COST AND FEASIBILITY

The estimated cost for interpretation and collection of photography at four scales are reported in this section. The cost for collecting field validation data for this study is also reported below. Additional cost information from other larger studies is reported in the appendices to provide information for planning purposes. Note the field validation costs in this report are based on a high intensity survey (i.e., includes measuring all tree heights and the position of all standing and down trees and stumps) and may not reflect the cost for surveys of lower intensity.

3.4.1 Cost Differences Between Four Photo Scales

Photo Interpretation

The cost differences to interpret the four scales of photography were small and ranged from $104 to $195 per site per scale, Table 15. Smaller scales (i.e. 1:12,000 and 1:32,000) have lower interpretation costs because fewer variables are visible at these scales, resulting in less time spent in photo interpretation. All photo and field validation labor costs reported in this study are calculated at $45 per hour, regardless of photo scale.

Table 15. Labor costs to interpret and measure riparian variables on three study sites from four different scales of aerial photography.

	Photo scale			
Site	**1:32,000**	**1:12,000**	**1:6,000**	**1:2,000**
24C	$153	$104	$185	$173
27C	$150	$104	$174	$195
29	$140	$121	$168	$176

Photo Collection

The photo collection costs for this study's sites are presented in addition to those from other larger studies to provide a range of costs for planning purposes, Tables 16 and 17. The cost for photo collection are affected by the number of photos required to cover a study site in stereo, the aircraft and camera types, whether the site only or surrounding area must be photographed, the weather, and the travel time between sites and the airport of origin.

The cost in this study for collecting larger scale photos (i.e. 1:2,000 and 1:6,000) was $6,606 (Grotefendt, unpublished data) and for smaller scale photos (i.e. 1:12,000 and 1:32,000) was $5,655 (Potts, 2007). The number of photos collected was 15 for small scale and 146 for large scale. The photo collection cost per acre ranged from $0.08 to $20.53, Table 16.

The photo collection cost per acre is much less for the smaller scale photography (.i.e. 1:1,6000, 1:12,000, and 1:32,000), but the study site area (i.e. 10,000 sq. ft.) represents only 0.005 to 1.1% of the photo's stereo area, Table 16. A large portion of the smaller scale photos' area is not needed unless there are other study sites present.

Table 16. Cost to collect four scales of aerial photography for the four current study sites in the Willapa and Mt. St. Helens areas of southwestern Washington. Note these costs do not include aerotriangulation.

Nominal scale (actual scale**)	Total cost	Number of photos	Cost per photo	Stereo area coverage per photo pair (acres)	Photo collection cost per acre	Study site area in proportion to photo stereo area (study site = 10,000 sq. ft. or 0.23 acre)
1:2,000 (1:1,905)	$4,516[a]	100	$45.16	2.2	$20.53	10.5%
1:6,000 (1:5,716)	$2,090[a]	46	$45.43	20.1	$2.26	1.1%
1:12,000	$2,966[b]	8	$370.75	669.4	$0.55	0.03%
1:32,000	$2,689[b]	7	$384.14	4,760.3	$0.08	0.005%

[a] (Grotefendt, unpublished data)

[b] (Potts, 2007)

** Actual scale derived from focal length and known flying height. Actual scale used in stereo area coverage if known.

A larger riparian buffer study than this current study was conducted in 2002 in the central eastern and western Cascade mountains in Washington State (Grotefendt and Light, 2004). It included photo collection and riparian buffer photo interpretation and measurement from 31 sites covering 360 square miles of area. One scale of photography (i.e. 1:2,000) was actually collected and the cost to collect 1:12,000 scale photography by two methods was estimated by a Washington State Department of Natural Resources (DNR) employee experienced in contracting photo collection missions (Curtis, 2005), (Curtis, 2007). The estimated cost to collect 1:12,000 photography ranged from 5 to 10 times the cost to collect the 1:2,000 scale photography for the study, Table 17 and see Appendix Table 4 for more details.

The current study cost estimates were for four sites and the 2002 central Cascades study were for 31 sites or 7.75 times the number of sites. The 1:12,000 scale collection cost from Table 16 times 7.75 is $22,987 and is within 29% of the $17,790 1:12,000 photo scale collection cost in the third row of Table 17. Note the number of photos collected under this scenario would be 62 versus the 93 for the 2002 study.

Table 17. Cost to collect two scales of aerial photography for 31 riparian buffer study sites distributed over 360 square miles in the central eastern and western Cascade mountains in Washington state (Grotefendt, 2005), (Curtis , 2005), (Curtis, 2007). Note these costs do not include aerotriangulation. (See Appendix Table 4 for more details).

Photo scale	Number of photos	Cost to the State from private aerial photography vendor (Product: film & diapositives or scans) [cost/photo]	Cost to the State from private aerial photography vendors (Product: film & scans) [cost/photo]	Cost to non-State entities from private aerial photography vendors using a $1.5 million digital camera (Product: digital images) [cost/photo]	Cost to non-State entities from private aerial photography vendors: (Product: film & scans) [cost/photo]
1:2,000	232	$3,906 [$16.84]			
1:12,000[a]	720		$30,000 [$41.67]	$30,000 [$41.67]	$40,000 [$55.56]
1:12,000[b]	93		$17,790 [$191.29]	$17,790 [$191.29]	$19,790 [$212.80]

[a] Cost to collect photography over the entire 360 square miles (Curtis, 2007)

[b] Cost to collect photography with global positioning system (GPS) only over the sample sites (Curtis, 2007).

3.4.2 Cost Data for Planning Purposes

The field validation costs for this study and other larger studies are referred to here and included in Appendix Tables 4, 5, and 6 to provide more robust cost information for planning purposes. These field validation costs may not reflect the costs for other CMER field research efforts depending on survey intensity. The photo and field validation costs are based on the "included" status variables of Tables 1 and 2 for this study and a subsample for the larger studies. Note that diameter at breast height (dbh) is measured in the field, but estimated on the photo and crown area is measured on the photo, but not collected in the field.

The data from this study shows there is a large cost difference (11 times) between the photo measurement from 1:2,000 scale versus the field validation measurement for the same suite of variables (except dbh is estimated on the photo), Table 18. Comparable costs of photo versus field validation data were gathered in Alaska and the central cascades of Washington State where cost differences of field validation versus photo ranged from 1.2X to 17X, Table 18 and Appendix Tables 4, 5, and 6. The reason a forest inventory example is included is because the same type of data is collected as riparian buffer studies.

Table 18. Range of field validation versus photo data collection costs.

Study year and location	Study type and photo scale used	Field validation cost	Photo cost	Cost that field data collection is over photography
This study; 2006 Washington	Riparian buffer	$2,705/plot	$244/plot	11.0X
2002 central Cascades	Riparian Buffer 1:2,000 (photos only cover study sites)	$8.21/tree	$2.08/tree	4.0X
2002 central Cascades	Riparian Buffer 1:12,000 (photos cover all study area)	$8.21/tree	$7.04/tree	1.2X
2002 central Cascades	Riparian Buffer 1:12,000 (photos cover only study sites)	$8.21/tree	$4.68/tree	1.8X
2004 Southeast Alaska	Riparian Buffer 1:2,000 (photo cost based on 3 plots)	$69.80/ft of stream length	$4.08/ft of stream length	17.0X
2004 Southeast Alaska	Riparian Buffer 1:2,000 (photo cost based on 124 plots)	$69.80/ft of stream length	$8.72/ft of stream length	8.0X
1996 Southeast Alaska	Forest Inventory 1:2,000	$1,853/plot	$663/plot	2.8X

4.0 DISCUSSION

The reliability of riparian feature detection and measurement with aerial photos as compared to field methods decreased as the scale became smaller (i.e. 1:12,000 and 1:32,000 photo scale). The smaller scale photography was also severely limited by the methods of its collection (i.e. large air base, short focal length, underexposed riparian habitat, and leaf-on) and its performance may improve with improved photo collection methods. The results indicate that large scale photography (i.e. 1:2,000) can replace a substantial portion of the detection and measurement work normally done in the field. Field work though is still required for validation, an assessment of the degree to which riparian features are missed, and perhaps to collect field data in higher density forest stands. The ability of the larger photo scales (i.e. 1:2,000 and 1:6,000) is limited because of their small area of coverage. The smallest photo scale (i.e. 1:32,000) covers broad landscapes well but is limited by its resolution in detection. The 1:12,000 scale photos offer the best compromise between resolution and area covered for broad landscapes.

The feasibility to implement field and photo data collection has limitations. Field work is limited by the physical effort, terrain, timing, access, and travel time. The largest photo collection limitation is the sufficient availability of contractors or public agencies with the capability or willingness to take custom photography that is optimal for riparian feature detection and measurement.

The reduction in cost through the use of aerial photography is one of its key advantages. The aircraft platform (i.e. helicopter) may increase flight time across extensive areas but offers the flexibility of slower speeds during photography and the ability to sit and wait for optimal lighting conditions.

4.1 FEATURE IDENTIFICATION

The factors that promote good detection are: (1) good feature lighting with little difference in contrast between the tree crowns and forest floor; (2) exposure with leaf-off so shrub and hardwood foliage don't obscure feature details; (3) parallel camera axes between the stereo pair for comfortable 3D viewing; (4) stereo pair inter-distances that permit 3D views of the forest floor through the tree crown gaps; (5) camera focal lengths that mitigate tree layover (i.e. wide-angle lens effect); and (6) different sequential stereo views of the same location that permit interpretation of hidden features. Improvement in the detection of variables listed in Table 1 increased as the scale became larger. That is, as one would conclude intuitively, the ability to detect the variable of interest increased as the image size increased. The detection variables from Table 1 are grouped here into four major groups for this discussion: individuals (visible at crown surface); individuals (visible below crown surface); stand; and landform, Table 19. The detection of these groups is affected by forest density and photo scale. In this discussion it will be assumed that all scales of aerial photography (i.e. 1:2,000; 1:6,000, 1:12,000; and 1:32,000) would be optimally collected as described above (i.e. the resource photography, 1:12,000 and 1:32,000 scale, used in this study, would NOT be used).

4.1.1 Individuals Visible at Crown Surface

The detection of individual standing trees or snags and their identities (i.e. conifer or hardwood, genus or species) is least affected by forest density and photo scale because they protrude above the crown surface, Table 19. As the scale increases the accuracy of counts increases because tree leaders are more visible, although intermediate and suppressed trees will likely be missed, Table 6. The importance of these missed trees depends upon their perceived contribution to the objective of the riparian buffer assessment (e.g. will their omission cause incorrect conclusions). The type, genus, and species detection accuracy increases with increased scale but they are unaffected by different densities if in a dominant or codominant position. High density may reduce the amount of snag image visible and increase its oversight.

4.1.2 Individuals Below Crown Surface (i.e. those that require good forest floor visibility)

Forest density has a significant effect on the visibility and detection of individuals lying on the forest floor below the crown surface, Tables 8 and 19. Down trees may be detected even under dense crowns but their features such as decay class, landing spot, and root wad presence may be obscured. If those features are visible, their correct interpretation is enhanced as the image size or scale becomes larger. For example, fine branches, indicating 'recently blown down' are too small to be seen at smaller scales (1:12k and 1:32k). The landing spot classifications of 'in' or 'out' are often difficult to distinguish when a down tree is suspended at some height above the stream. In this case, a larger image often helps discern the down tree trunk position relative to the full bank.

4.1.3 Stand

The detection of stand variables is based mainly upon the synthesized views of many individuals. Even so, the absence from view due to high forest density or the small size of suppressed and intermediate trees may give an incorrect assessment of the composition, seral stage, canopy class, and size. The repeatability of stand variable detection between individual photo interpreters may also be difficult due to the judgment required in the synthesizing of views. Larger scales that provide more detailed views would improve consistency but sacrifice the amount of area covered. Irregardless of scale, the stand size is very difficult to assess without some form of measurement. Although seral stage may be discerned without measurement, forest density may falsely cause conclusions about size. Due to the false impression given by sparse forest density, I have mistakenly thought trees were shorter than they actually were when later measured.

4.1.4 Landform

The main landforms of interest are the stream and ground surface. The higher the forest density the more difficult these are to detect. When the forest density does not obscure the stream or the ground they are visible at all scales. The full bank edge or ground surface may be more accurately detected as the image size or scale increases. The fine branches of shrubs and blades of grasses may be indistinguishable at smaller scales and prohibit the correct detection of the ground and full bank at smaller scales, (i.e. 1:12,000 and 1:32,000).

Table 19. The effect of forest density and photo scale on grouped detection variables.

	The effect on variable detection from:	
Variable type	**Forest density**	**Photo scale**
Individuals (visible at crown surface) Tree condition (standing tree; snag) Tree type (conifer/ hardwood) Tree genus Tree species	Dominant and codominant trees visible at any density (suppressed and intermediate missed). The smaller amount of snag image visible at higher densities may reduce its detection. Tree type, genus, or species unaffected by density if dominant or codominant.	Conifer leaders not visible at smaller scales (1:12k, 1:32k). Type, genus, and species accuracy improves with increased scale.
Individuals (below crown surface) Tree condition (down tree; stump) Down tree decay class Down tree landing spot Root wad presence	Has big effect on all except stumps (e.g. when stumps are in the open, then film exposure and contrast, and ground vegetation and stump age affect stump discernment)	Ability to see and discern details decreases as scale is smaller. Decay class, landing spot, and root wads may be seen if visible on 1:2k, 1:6k, and 1:12k (except 'in' or 'over' on landing spot may not be distinguishable on 1:6k and 1:12k.
Stand Stand density category Stand composition Stand seral stage Tree canopy class Stand size category	Although stand variables are represented by the surface canopy, higher forest densities would reduce detection of shorter trees that contribute to composition, seral stage, canopy class, and size.	Stand density category and seral stage are least affected by scale. Proportion of mortality detectable decreases with smaller scales. Canopy class only detectable for surface and with smaller scales is less discernible. Size can be mistaken without measurements, irregardless of scale.
Landform Stream bank Ground surface Channel confinement	Higher densities reduce detection.	If visible, then detectable at all scales, except actual full bank edge less discernible at smaller scales.

4.2 FEATURE MEASUREMENT

There are constraints between the optimal geometry and visibility for riparian feature measurement. The geometry is stronger for vertical and horizontal measurements when the distance is longer between sequential photos. This excessive length though prohibits views through tree crown gaps of the forest floor. As the altitude of the photography increases, the distance between sequential photos may increase up to some limit and still permit viewing through tree gaps. The geometry of the fixed-base camera system used to collect the 1:2,000 and 1:6,000 scale photography used in this study was optimized for 1:2,000 scale which is taken at 500 ft of altitude. The accuracy of horizontal and vertical 1:2,000 scale photo measurements of distinct artificial targets was less than 1% and 3% respectively in previous studies (Grotefendt, 2005). The 1:6,000 scale photography was collected mainly to provide an overview of the 1:2,000 scale photography and was pressed into use for measurements for this study. The 1:6,000 photo scale measurements were therefore less accurate than the 1:2,000 scale photos because the fixed-base distance was not increased. The 1:2,000 scale photo measurements (e.g. tree height and position) were better than the other photo scales. The 1:12,000 and 1:32,000 photo scale geometry was strong, yet poor visibility of the ground and other features made measurements unusable.

Improvement in the measurement of variables listed in Table 2 increased as the scale became larger primarily due to better image visibility. The measurement variables from Table 2 are grouped here into four major groups for this discussion: individuals (visible at crown surface); individuals (visible below crown surface); stand; and landform, Table 20. The measurement of these groups is affected by forest density and photo scale. In this discussion it will be assumed that all scales of aerial photography (i.e. 1:2,000; 1:6,000, 1:12,000; and 1:32,000) would be optimally collected as described in the preceding 'feature identification' section (i.e. the resource photography, 1:12,000 and 1:32,000 scale, used in this study, would NOT be used).

4.2.1 Individuals Visible at Crown Surface

Higher forest density mainly affects the measurement of tree height, crown area, and crown diameter variables for individuals visible at the crown surface because of the lack of ground visibility and reduction of crown details. Counts, position, and density are not affected by higher densities except for missed intermediate and suppressed trees. The counts are more accurate with larger scales (i.e. 1:2,000 and 1:6,000), Table 6. This occurs because of the small image size of tree leaders with smaller scales (i.e. 1:12,000 and 1:32,000). Tree height and dbh estimated using height and crown area are also affected by smaller image size because the tree leaders and crown details are less visible. Smaller image size, not geometry, also reduces the accuracy of distances and position. The error in tree height measurement was 3% larger with 1:15,840 scale photography than 1:2,000 scale photography in southeast Alaska (Grotefendt, 2005). Crown area and diameter are believed to be under- or over-estimated on 1:15,840 scale photography compared to 1:2,000 scale photography based on studies in southeast Alaska (Grotefendt, 2005) and unreported research I have conducted with large scale photography from the Cedar River watershed in Washington.

4.2.2 Individuals Below Crown Surface (i.e. those that require good forest floor visibility)

The higher the forest density the more difficult it is to measure individual variables that occur below the crown surface, such as down tree length. There are though, improved opportunities for visibility and measurement when stereo pairs of photos have shorter distances between them because better views occur between tree crowns. The photo scale has less effect on measurement accuracy if the variables are visible. The image size may be less visible for smaller scales though, such as the down tree trunk bark blending with surrounding soil and vegetation, and this can introduce measurement errors.

4.2.3 Stand

As the stand density increases the ground visibility decreases and it is more difficult to delineate plot boundaries. There may be small gaps due to single tree blowdown but with higher densities these may be missed and the windthrow gap area variable won't be measured. When the ground is visible plot areas may be delineated well at any scale. As the scales become smaller it is more difficult to view and measure crown closure and windthrow gap areas.

4.2.4 Landform

High forest densities often may make the stream indistinguishable if it is small in width. Then its length, width, area, gradient, and full bank position cannot be measured. If the stream is visible differences in scale have less effect on measurement. The smaller scales (i.e. 1:12,000 and 1:32,000) may have greater positioning errors due to the reduction in image distinctness because of its smaller size. Vertical distances are in general less accurate than horizontal using normal aerial photogrammetry methods. Larger scales and stronger geometry (i.e. greater distances between stereo pairs and shorter focal length distances) would provide better measurements of stream gradient. Medium to high forest densities may prevent views when this stronger geometry is employed.

Table 20. The effect of forest density and photo scale on grouped measured variables.

	The effect on variable measurement from:	
Variable type	**Forest density**	**Photo scale**
Individuals (visible at crown surface) Tree or snag count Tree height Tree DBH (computed) Object distance from stream Distance to other trees Tree crown diameter Tree crown area Tree position	At large scale (1:2k) counts not affected by high density in AK old growth. Heights less reliable as density increases because ground visibility reduced. (affects DBH estimation). Position and distances not affected. Crown diameter and area visibility reduced with higher densities.	Counts more accurate when scale larger (1:2k, 1:6k). Less conifer leader visibility at smaller scales increases count, height, and dbh estimation error (1:12k, 1:32k). Distance and position errors at smaller scales due mostly to smaller image size not geometry. Crown diameter and area very unreliable at 1:6k, 1:12k, and 1:32k scales.
Individuals (below crown level) Down tree or stump count Down tree length Down tree diameter Fall azimuth relative to stream	Higher density reduces ability to reliably measure, however larger scale (1:2k) fixed-base improves opportunities for visibility and measurement.	When visible a reduction in scale has less effect, but reduced image size at 1:12k and 1:32k scale may decrease object extremity visibility (i.e. tree leader may be indistinguishable, trunk bark may blend with surrounding soil and vegetation.

Table 20. (continued).

Variable type	The effect on variable measurement from: Forest density	Photo scale
Stand Stand crown closure area Plot area Windthrow gap area	Higher density greatly reduces details needed to discern small windthrow gaps and delineate plots.	At lower densities plot area reliable at any scale. Other areas unreliable at smaller scales (i.e. 1:12k, 1:32k)
Landform Stream length Stream width Stream area Stream full bank position Stream gradient	Higher densities that obscure stream visibility reduce measurement accuracy. Higher densities obscure stream surface and make gradient measurement difficult.	When visible a reduction in scale has less effect but smaller image size with smaller scales (i.e. 1:12k and 1:32k) reduce accurate positioning. Gradient requires strong geometry at all scales.

4.3 CAPTURE SPATIAL PATTERNS OF VARIABILITY

The resolution of the imagery and the size of the riparian feature to detect, affect the effectiveness of air photos to capture spatial patterns of variability. The current project's 1:12,000 photo scale and past projects where I worked with 1:15,840 photo scale provide the best compromise. The larger scales (i.e. 1:2,000 and 1:6,000) do not cover large enough areas and the smallest scale in this study (i.e. 1:32,000) does not have high enough resolution to detect down trees reliably. The mid-scale photos (i.e. 1:12,000) from this study did not detect down trees very well at all. But my research with the U.S. Forest Service's 1:15,840 photo scale revealed down trees although it was likely that half to two-thirds were missed in large gaps and when there were only single down trees or gaps were small (i.e., a brief examination of 1:2,000 scale photography from the same area provided an estimate of down trees missed).

4.4 FEASIBILITY TO IMPLEMENT

There is only one known contractor available to collect the larger scale photography (i.e 1:2,000 and 1:6,000) optimally for riparian plots at this time. Private contractors (e.g. Aero-Metric, Seattle) and the DOT with 9x9inch cameras can collect 1:3,000 and 1:6,000 scale photography but it will be from fixed-wing aircraft with long distances between sequential photos which greatly limits its usefulness for riparian study. Helicopters are required to ensure correct exposure and spacing, unless fixed-wing aircraft can be used that fly slower or the cameras' film advancement rate is increased. Contractors and the DOT have been approached to use helicopters but due to FAA restrictions and their own inclinations they have been reluctant to make these investments. Despite this current limited availability of contractors, their number would likely increase as requests for riparian buffer specific aerial photography jobs rise. Currently the main market of aerial photography is mapping and orthophoto production.

It was recently learned that the DNR will not consistently continue to collect 1:12,000 scale imagery and that their funds have been diverted to support a National Aerial Photography Program (NAPP). The NAPP will collect photography of the entire United States every five years, covering the area of Washington State at a smaller scale than the 1:32,000 scale that was to be collected this year. It is unknown if this will affect the consistent collection of 1:32,000 scale aerial photography in the future.

4.5 COST

The cost to collect riparian data with the 1:2,000 scale photo method is at least one-half to one-fourth the cost of field methods based on past southeast Alaska and Washington studies and the current Washington study. The cost of travel to field sites is less in Washington because vehicle travel and hiking is most often possible instead of helicopter or float plane use as in Alaska. Field visit costs are still required when using riparian photo data collection but the overall total cost is less than if just field plots were taken. The cost to collect minimal riparian data by 1:12,000 scale photos is approximately one-half of the field cost. The landscape cost of photo data collection compared to field visits is still unknown because the 1:32,000 scale photography did not provide much useful information due to its method of collection. Additional cost and accuracy of data collected by satellite imagery (i.e. Quikbird) would be useful in determining costs and feasibility for its landscape data collection use. Once the four scales used in this study are oriented, the interpretation effort for the same area is very similar. The labor used in interpretation, data management, and analysis is usually significantly greater than or at least equal to the cost of aerial photo collection based on over ten large studies I have conducted. It is counterproductive to invest large amounts of labor in interpretation, data management, and analysis using resource photography that does not meet riparian data collection needs, rather than taking custom photography.

5.0 RECOMMENDATIONS

1. Use large scale photography (1:2,000) to replace or supplement field riparian plots for collection of: (a) the individual variables visible at crown surface (Tables 19 and 20); (b) the individual variables below crown level (Tables 19 and 20); (c) landform variables (Table 19 stream bank only and Table 20 all variables); and (d) stand variables (Table 20) but still continue to collect some proportion of field plots for validation, to assess the degree to which riparian features are missed, and to collect data when forest density is high. Integrate light detection and ranging (LIDAR) in the collection of the 1:2,000 scale photography so that digital elevation models (DEM) may be created in dense forest stands. Note that collection of stream gradient will depend upon orientation of the aerial photography to a geographic coordinate system.

2. Collect custom and improved small scale (i.e. 1:12,000) photography with methods that ensure measurement potential and the optimum visibility of riparian features (i.e. appropriate airbases, longer focal length, leaf-off, and proper lighting conditions). Use 1:12,000 or 1:6,000 scale photography to collect the stand variables except the stand size category variable and the landform variable channel confinement (Table 19). Use larger scales to validate measurements made with the 1:6,000 or 1:12,000 scale photography.

3. Integrate multi-scale remote sensing with field plots. A method is needed to make inferences across broad or landscape areas.

   Determine a multi-scale approach by evaluating how well riparian features on 1:32,000 aerial photography or satellite imagery (i.e. Quikbird) can be correlated to larger scale photography (i.e. 1:2,000, 1:6,000, and 1:12,000) and field plots.

   Link this multi-scale approach with other remote sensing data extraction techniques such as auto crown detection.

4. Field validation is required for all the above to ensure accuracy of methods are sufficient to detect change.

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APPENDICES

MEASUREMENT AND DETECTION CRITERIA

A standard system was developed to compare differences in object detection and measurement among the photo scales. The relative power to identify, categorize, count, and measure each object on a photo is ranked from 1 to 5, with 5 being the highest object resolution power (ORP; Table 1). The ORP provides a relative number for evaluating which scale of aerial photography will provide sufficient accuracy for a particular monitoring study.

Appendix Table 1. Data collection method evaluation criteria or object resolution power (ORP) number and criteria. The ORP are ranged from 1 to 5, with 5 being the highest ORP. If the Error Percent column is blank, it means the error percent is variable.

ORP number	Definition	Error %
1	Distinguish between plant and geomorphological features (i.e. fluvial landforms)	0%
2	Distinguish coarse plant (i.e. count of individuals and tree versus shrub) and geomorphological features (i.e. fluvial landforms with riparian versus other)	> 20%
3, 4, 5	Able to quantify with counts or measurements and/or identify qualities	
3A	Distances, areas, and spatial positions (spatial is a relative or georeferenced coordinate system)	< 20%
3B	Identity is general (e.g. tree, but not down tree or stump; less than 3 ground points visible; not tree type (e.g. conifer); < 20% stream visible)	
3C	Able to count individuals within 20%	< 20%
4A	Distances, areas, and spatial positions (spatial is a relative or georeferenced coordinate system)	< 10%
4B	Identity is more specific (e.g. can distinguish down trees and stumps; tell conifer vs hardwood vs snag; see 30% or less of stream; see full banks; 3 or more ground points visible; in or over or away from stream discernible)	
4C	Able to count individuals within 10%	<10%
5A	Distances, areas, and spatial positions (spatial is a relative or georeferenced coordinate system)	< 5%
5B	Identity is very specific (e.g. distinguish genus (e.g. Abies), decay class, crown condition)	
5C	Able to count individuals within 5% (able to distinguish visible individual tree leaders)	< 5%

Appendix Table 2. Variable final threshold values.

			ORP # $^{\text{see Appendix Table 1}}$ (expected error percent) by scale of aerial photography			
Type	**Variable name**	**Variable definitions or codes**	**1:2,000**	**1:6,000**	**1:12,000**	**1:32,000**
Detect						
	Tree condition	(live, snag, down, cut) cut may be higher	4B (5)	4B (10)	3B (30)	3B (60)
	Tree type	(conifer or hardwood)	4B (1)	4B (5)	4B (10)	3B (20)
	Tree decay class (when down)	(foliage [needles or leaves] recent [i.e. green or brown], twig [i.e. secondary or tertiary branches], or unknown)	5B (5)	4B (10)	3B (30)	n/a
	Down tree landing spot	(in, over, away)	4B (5)	4B (10)	3B (60)	n/a
	Root wad presence	(yes, no, unknown)	5B (5)	4B (10)	3B (30)	n/a
	Stream bank	Digitize	4B (20)	4B (30)	3B (60)	n/a
	Stand density category	(sparse, medium, dense)	4C (10)	3C (15)	3C (20)	3B (30)
	Stand composition	Proportion of conifer, hardwood, & mortality	5C (5)	4C (10)	3C (20)	2 (30)
	Stream confinement	(confined, unconfined)	5B (5)	5B (5)	4B (10)	n/a
Measure						
Count	Tree count (trees 20ft +)	Digitize each individual	4C (10)	3C (15)	3C (20)	2 (35)
Distance	Tree height		4A (10)	3A (20)	n/a	n/a
	Tree length	(when down)	4A (10)	3A (20)	n/a	n/a
	Tree DBH	(estimated by equation)	3A (20)	n/a	n/a	n/a
	Tree distance from stream	Computed	5A (5)	4A (10)	2(30)	n/a
	Stream length	Computed	5A (5)	4A (10)	2(30)	n/a
	Stream widths and their average	Computed	4A (10)	3A (20)	n/a	n/a
Area	Tree crown area		3A (20)	2 (30)	n/a	n/a
	Stand crown closure	(computed from crown area)	3A (20)	2 (30)	n/a	n/a
	Plot		4A (10)	3A (20)	n/a	n/a
	Stream		4A (10)	3A (20)	n/a	n/a
Spatial	Tree position	Relative or georeferenced	4A (10)	3A (20)	2 (30)	n/a
	Stream full bank	Relative or georeferenced	4A (10)	3A (15)	2 (40)	n/a

n/a is non-applicable.

Appendix Table 3. **Final threshold accuracy levels for variables whose feasibility of detection from smaller photos scales will be briefly examined.**

			ORP # see Appendix Table 1 (expected error percent) by scale of aerial photography			
Type	**Variable name**	**Variable definitions or codes**	**1:2,000**	**1:6,000**	**1:12,000**	**1:32,000**
Detect						
	Tree genus	(e.g. Abies, Tsuga)	4B (10)	3B (20)	2 (40)	n/a
	Tree species	(e.g. Abies procera)	4B (10)	n/a	n/a	n/a
	Stand structure	Stand initiation, stem exclusion, understory re-initiation, old growth (from Oliver and Larson 1996)[a]	4B (10)	4B (15)	3B (20)	n/a
	Stand seral	(e.g. height or young, immature, mature)	5B (10)	5B (10)	4B (20)	3B (30)
	Tree canopy class	(e.g. dominant., codominant, suppressed)	4B(10)	4B(10)	2(30)	n/a
	Stand size category	(e.g. tall, medium, short)	4A (10)	3A (20)	2 (30)	n/a
Measure						
Spatial	Fall azimuth relative to stream	(e.g. towards, parallel, away)	4A (10)	3A (20)	2 (30)	n/a

[a] Oliver, Chadwick. D. and Larson, Bruce C. 1996. Forest stand dynamics, New York, Wiley, 520 p.

PHOTO DATA AND FIELD VALIDATION DATA COLLECTION COSTS

The small sample size from this study limited its utility for a true measure of economy so comparisons from studies with larger sample sizes are presented in Appendix Tables 4, 5, and 6. They represent comparisons between photo data and field validation data collection costs of tree heights, riparian plot data, and forest inventory from experiments conducted in Alaska and Washington. These comparisons reflect the collection costs of two scales of photography in this study, 1:2,000 and 1:12,000, for tree heights and one scale, 1:2,000 for riparian plot data and forest inventory. The field validation costs for the riparian plot data reflect a 100% inventory and mapping effort and may not reflect the costs for other CMER field research efforts, depending on survey intensity. The forest inventory costs are included because of data collection similarities with riparian buffer plots, for example the type of data (e.g. tree heights, diameters, and condition) and remoteness of plot location.

The cost to collect tree heights was based on a riparian buffer study in June of 2002 in Washington that covered 360 square miles. In this study a sample of 31 sites was required to measure windthrow in different buffer width treatments. These 31 sites contained 5,912 visible trees which required 186 hours to measure at $45 per hour on an analytical stereoplotter and process their data. The cost to collect the imagery by helicopter and process the film was $3,906. These figures resulted in a total photo cost excluding overhead of $12,276 to measure the visible trees. An average of 10 minutes per tree is needed to field measure tree height based upon field experience with tape and clinometer or laser range finder. For this particular application 985.5 hours of field time would be required in addition to 3 hrs per site for travel and hiking in and out. This resulted in a total field cost of $48,532.50 to measure the tree heights excluding overhead, Table 15. The use of 1:2,000 scale photography to measure tree heights resulted in a savings of 75% over field methods and the measurements are comparable to field tree heights (i.e. within 2.4m (7.8ft) of the average of the absolute difference, see Table 14). The costs were also estimated to collect the 5,912 tree heights from small scale photography (i.e. 1:12,000 scale) (Curtis, 2005). The 1:2,000 scale photo collection and measurement was 30 to 44% of the small scale photography cost, Table 15 (Grotefendt, 2005).

Appendix Table 4. **A cost comparison between 1:2,000 and 1:12,000 scale photo and field methods to collect tree heights from a riparian buffer monitoring application in Washington (n of plots=31; n of trees measured=5,912) (Grotefendt, 2005).**

Scale	Total photo cost ($)	Total field cost ($)	Photo cost per tree ($)	Field cost per tree ($)	Photo cost per sq. mi ($)	Field cost per sq mi ($)	Photo cost per acre ($)	Field cost per acre ($)
1:2,000	12,276	48,532	2.08	8.21	34.10	134.81	.05	.21
1:12,000	39,870 [a]	48,532	7.04	8.21	115.59	134.81	.18	.21
1:12,000	27,660 [b]	48,532	4.68	8.21	76.83	134.81	.12	.21

[a] Cost to collect photography over the entire 360 square miles, perform aerotriangulation, and measure trees (Curtis, 2005).

[b] Cost to collect photography with global positioning system (GPS) only over the sample sites, perform aerotriangulation, and measure trees (Curtis, 2005).

The second example occurred near Hoonah, Alaska and presents a comparison of the costs (Table 16) to conduct riparian buffer validation tests. The field costs included labor costs of $11,070 and fixed costs of $3,657 for airfare, lodging, food, supplies and equipment costs to conduct a 100% inventory and mapping effort. The field labor costs included time in the field plus the time to process the field data and hand draw maps. Approximately 2.5 field days of 10 hours each were required for a 3 person crew to complete each plot. Each plot was approximately 60ft in length along the stream and 66 to 99ft in depth from the stream or approximately half of the area of the plots in this current study. The photo cost to collect the same information was $861, which included the fixed costs of $231 to collect the photo pairs and $630 for labor costs that included measuring and interpreting the photos, processing and analyzing the data, and making maps. Labor was fixed at $45 per hour for both methods. The per photo collection cost was reached by cumulating the total costs to collect super large scale photos for a riparian study from 4 geographic regions from Petersburg to Hoonah and dividing by the number of photos collected. The costs per plot, per acre, and per foot of stream length are given in Table 16. The field cost per foot of stream length was $69.80 versus $4.08 for the photo method or 17 times as much. The cost to collect super large scale photography of 24.8 miles of stream from Petersburg to Hoonah and photo measure the same riparian data as this validation test from a sample of 124 plots was $8.72 per foot of stream length. Using this higher photo cost reduces the ratio of field to photo cost to 8 times (Grotefendt, 2005).

Appendix Table 5. **A cost comparison between 1:2,000 scale photography and field methods to collect the riparian buffer data of standing tree, down wood, and stump and their spatial position in southeast Alaska near Hoonah (Grotefendt, 2005).**

Plot type	# plots	Total photo cost ($)	Total field cost[a] ($)	Photo cost per plot ($)	Field cost per plot[a] ($)	Photo Cost per acre ($)	Field cost per acre[a] ($)	Photo cost per ft of stream length ($)	Field cost per ft of stream length[a] ($)
validation	3	861	14,727	287	4,909	34.10	134.81	4.08	69.80
stream study	124							8.72	

[a] Field costs were based on a 100% inventory and mapping effort. This included measuring the height of all standing trees and the position of all standing trees, down trees, stumps, and the stream bank.

The third example is a forest inventory application at Control Lake on Prince of Wales Island due east of Ketchikan, Alaska that covered an area of approximately 53,370 acres and required the sampling of 200 plots for volume. The field method per plot cost of $1,853 used was determined from a larger study during the same time period funded by the Forest Service to compare the accuracy of various remote sensing methods to field methods. The total field cost of $370,600 to collect 200 plots for volume was based upon labor costs at $50 per hour and direct costs of helicopter, air travel, room and board, vehicles, survey equipment, and other direct costs. Forty plots were actually field visited and data collected to arrive at these cost estimates. The super large scale photo total cost estimate of $132,510 to photo sample 200 plots for volume with 40 plots field visited to develop photo-volume relationships was based upon 51 sites actually photographed and 10 field plots actually visited. These costs included labor costs at $50 per hour for photo measurement training, photo handling and measurement, data processing, and reporting as well as the direct costs for instrument use, film, helicopter, air travel, room and board, vehicles, and other incidentals. The average cost per plot to collect and measure 200 photo plots was $229.75 and the average cost per plot to measure 40 field plots was $2,164. This resulted in an average cost per point of $663 (Table 17). The use of super large scale photography resulted in a savings of 64% over field methods and the photo estimates were within 10.9 to 13.4% of field estimates (Grotefendt, 2005).

Appendix Table 6. A cost comparison between super large scale photography and field methods for the collection of plot volumes (gross board foot 32 feet log scale) from a forest inventory application in southeast Alaska (Grotefendt, 2005).

Study #	Field method number of field plots	Photo method number of field and photo plots	Total field method cost ($)	Total photo method cost ($)	Field cost per plot ($)	Photo cost per plot ($)	Field cost per acre ($)	Photo cost per acre ($)
K15	200	40 field 200 photo	370,600	132,510	1,853	663	6.94	2.48

SUPPLEMENTAL REPORT

The Potential of Softcopy or Digital Photogrammetry for Riparian Buffer Data Collection

Final Report

Prepared for:

Cooperative Monitoring, Evaluation, and Research
(CMER)

State of Washington Forest Practices Board
Adaptive Management Program

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INTRODUCTION

This report is a supplement to results reported to the Cooperative Monitoring, Evaluation, and Research committee (CMER) in "Suitability of Aerial Photography for Riparian Buffer Monitoring" by Richard A. Grotefendt, Dec. 7, 2006. That report's purpose was to compare and evaluate the capability of collecting riparian vegetation monitoring data from four different scales (1:2,000, 1:6,000, 1:12,000 and 1:32,000) of aerial photography that have varying degrees of resolution, accuracy, and cost. If aerial photography is to be used for riparian buffer data collection, some photogrammetric system must be utilized to measure and interpret the features on the photos. Photogrammetry is "the art, science and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting images and patterns of electromagnetic radiant energy and other phenomena" (Slama, et. al., 1980)

For the main study cited above, an analytical stereoplotter (i.e. an analytical optical-mechanical system) was the photogrammetric system used. This system and add-on post-processing software has limited availability and support although its effectiveness and accuracy have been demonstrated. No comparable system is known. In the photogrammetric industry softcopy or digital photogrammetry system's utilization has greatly increased and large companies exist that provide support. Because of the increased use and support this paper examines softcopy's current status and applicability for riparian buffer data collection. This may illustrate its potential for CMER and Washington State Department of Natural Resources (DNR) staff use but does not rule out analytical optical-mechanical system's use although their availability and support would require development. Funds were available to characterize the advantages and disadvantages of softcopy by interviews with two or three photogrammetry professionals and from my own experience.

Mapping from aerial photography is the major use of softcopy photogrammetry. Public agencies and private entities such as timber companies have a responsibility to know the location and attributes of objects within their administration, such as roads, bridges, light poles, manholes, and river channels. The principles of photogrammetry permit reliable positioning of these objects by remote means that are more cost-effective and efficient than field surveys, although field surveys are often required for accuracy verification. Historically this mapping was conducted using optical-mechanical components and mathematical methods for photo orientation (i.e. analytical photogrammetry). Softcopy systems replace film with digital imagery and the analytical optical-mechanical components are replaced by high-end computers and monitors (Maalouli, 2007).

The processes of photo orientation, aerotriangulation, and orthophoto production are more efficient and cost-effective with softcopy systems than analytical optical-mechanical systems. Therefore the use of analytical optical-mechanical systems, such as the analytical stereoplotter (i.e. AP190) used in the photo scale CMER study that this report supplements, has been declining in the mapping industry. Software and custom programs have been developed on analytical optical-mechanical systems to process, analyze, and display the riparian buffer data collected from film (e.g. Grotefendt, 2005). Currently softcopy systems do not have this interface highly developed for riparian buffer data and also have other limitations, such as lower resolution than provided by film (pers. comm., G. Maalouli, 2006).

The use of imagery collected from satellites reduced the use of small scale photography for natural resource data collection for management purposes (.e.g. timber volume type maps; forest type maps; Meyer and Werth, 1989). The photogrammetric mapping companies found this satellite imagery inadequate for their accuracy requirements and continued their use of small scale photography. Yet, the use of small scale photography for natural resource assessment is needed because regulatory requirements are increasing the complexity of forest management and planning in the United States and require data that are timely and accurate for monitoring to ensure compliance with regulations. Monitoring determines the status and trends of key plant and animal populations and characterizes their habitat conditions. Rare plant species (Schreuder and Goebel, 2001) and riparian tree height are examples of management variables that must be monitored. An understanding of the physical environment (e.g. stream, wetland, or hill slope) and plant position within that environment (e.g. distance to stream) is also required. Public and private landowners and users monitor to ensure compliance with these regulations and still utilize the forest and its environment in a productive manner, for example, for timber production, fish production, or recreation (Wright, et. al., 2002), (Grotefendt, 2005).

This demand has renewed interest in the use of small and large scale aerial photography for the remote collection of natural resource data. Since the mapping industry is dealing with non-natural features in general its systems and tools are not optimally developed for natural resource characterization and measurement. Natural objects such as trees and shrubs do not have distinct edges and individuals may be difficult to distinguish on normal scales of photography routinely collected for the mapping industry. The mapping industry generally uses shorter camera focal lengths to achieve mapping accuracy standards (personal communication, G. Maalouli, 2006) whereas longer focal lengths are better for viewing between forest tree crowns to assess ground conditions. Methods of measurement may also be different. For example, tree height measurement requires knowing the spatial position of the top and the bottom of the tree. This measurement has been automated on an analytical optical-mechanical system but not in softcopy (Grotefendt, 2005).

The methods, results, and discussion sections indicate the status of softcopy relative to natural resource data collection and improvements that will increase its usefulness.

METHODS

The focus of the methods was on the cost, hardware and software, and operation of softcopy for only riparian buffer data collection not other applications. This report does not examine all available softcopy products. The main products reviewed were BAE Systems SOCET SET (SOCET SET) and Intergraph (formerly Zeiss/Intergraph). These are in current use at the Washington State Department of Natural Resources (DNR) and Department of Transportation (DOT), and Aerometric - Walker Division. Two other packages were also examined or used: Leica Geosystems ERDAS IMAGINE with its stand-alone version Stereo Analyst and DAT/EM of Systems International.

COST

Cost data was collected from interviewees and past experience. Software companies were not contacted. The cost of operating softcopy includes the initial purchase, software maintenance agreements, hardware, labor, and overhead. Scanning of film is required to convert the aerial photography into a digital form. Approximate costs of optical-mechanical systems are included for cost comparisons.

HARDWARE AND SOFTWARE

Softcopy requires digital images, high end computers and monitors, scanning equipment, large amounts of data storage devices, and software. Information on hardware and software was provided by the interviewees and past experience.

OPERATION

Operation of GIS software packages such as ArcInfo (by ESRI) often require months and years of experience to gain familiarity with complex functions and an understanding of limitations. This is similar with all photogrammetric systems, including softcopy. Interviews were conducted from a small sample of photogrammetry professionals to provide a synthesis of softcopy's operation with respect to natural resource interpretation rather than compare all the various vendor's softcopy feaetures. The digitizing and viewing features that provide object delineation and interpretation were reviewed.

The following questions were used as a basis and starting point in the interviews:

1. What is the cost of one workstation and software?

2. What is the caliber of technical support provided by the softcopy vendor?

3. Have you ever done vegetation interpretation and if so what kind?

4. What field verification have you done of photo identification and measurements made?

5. Have you been in charge of the scanning of the aerial photography that you use?

6. Have you used digital imagery collected by the new digital metric cameras?

7. Have you interpreted imagery with shadows?

8. How easy is it to adjust the contrast and brightness within shadows?

9. Have you ever compared the amount of detail in shadows between original film and the scanned or photographed digital image?

10. What digitizing tools are available in softcopy to collect the commonly collected riparian buffer variables?

11. Are you able to translate the softcopy data into a rectangular American Standard Code for Information Interchange (ASCII) format?

12. Are the softcopy system data files interchangeable with other softcopy or analytical optical-mechanal systems and have you successfully done those interchanges?

13. Are you able to compute variables from the softcopy data?

14. Assuming softcopy is the current platform you primarily use have you ever worked on an analytical stereoplotter and if so what would you say are the disadvantages to using softcopy that may affect the quality of riparian vegetation monitoring data collection?

RESULTS

The responses from the fourteen questions are in Tables 1 and 2. These results plus my own experience are incorporated into the following sections on cost, hardware and software, and operation of softcopy.

Table 1. Responses by photogrammetric professionals to questions on cost, hardware and software, and operation of softcopy systems* (SS=Socet Set; INT=Intergraph; DE=DAT/EM). Responses are sometimes conflicting because respondents have experience with the same package but different assessments.

Question	Responses
1. Costs.	See Table 2 in the Cost section.
2. Technical support caliber.	Using a scale of 1 to 10: SS=3; SS=9; INT=6; DE=9.
3. Experience interpreting & measuring vegetation.	Not much, only conifer versus hardwood, spartina, kelp; not tree types, only area of vegetation or conifer versus hardwood.
4. Any field verification of vegetation identification?	No, mainly field verification of mapping standards or client conducts field verification.
5. Scanning experience	Yes, both were responsible for scanning.
6. Digital camera imagery use	No; yes.
7. Shadow interpretation	Both yes.
8. Image adjustment ease	Easy with both SS and INT. Older version of Zeiss/Intergraph cumbersome (my experience).
9. Film vs. digital shadow detail comparison	Yes; only a little.
10. Digitizing tools available	Both have point, line, and area. Neither can measure tree heights using digital elevation model (DEM).
11. Data translation to ASCII	SS has no specialized output; INT has none readily available but possible if know tricks.
12. Softcopy to softcopy translation	Yes for both, but receiving softcopy systems may have limits.
13. Variable computation	Not readily available with SS or INT, requires specialized tool development.
14. Comparison optical-mechanical to softcopy	No disadvantages of softcopy; The quality of film and analytical stereoplotter optics exceed digital imagery and computer monitor displays as of today, but these differences may disappear with improvements in softcopy hardware.

* Contains responses from two respondents that are active in the field of photogrammetry. One respondent uses Socet Set and the other Intergraph but also has experience with Socet Set and DAT/EM.

COST

The total cost of softcopy packages ranged from $11,500 to $33,000, Table 2. Optical-mechanical systems (i.e. analytical stereoplotters) used to range from $42,000 to at least $150,000, but may now be found second-hand for much less since companies and government agencies have replaced them in lieu of softcopy systems.

Table 2. The hardware, software, and additional costs associated with the four softcopy packages reviewed.

Package	Hardware* Cost	Software Cost	Additional Costs
Socet Set	$10,000	$20,000	$1,500 + (ArcGis)
Intergraph	$8,000	$20,000	$5,000 (Microstation)
Stereo Analyst	$8,000	$3,500	none
DAT/EM	$8,000	$10,000-12,000	$1,500 + (ArcGis)

* Hardware includes a special graphics card, two high refresh-rate computer monitors, a computer with dual processors, a "Z" screen, and a specialized mouse with eleven buttons.

HARDWARE AND SOFTWARE

The hardware used by softcopy systems are essentially the same. A fast computer with dual or quad processors is required to re-display two one-gigabyte aerial photo images as the photo interpreter enlarges and reduces the image while moving around the landscape. Analytical optical-mechanical systems provided binocular type systems for viewing the left and right photos in stereo or 3D. Softcopy systems provide these 3D views by alternatively displaying the left and right digital image onto a high refresh-rate computer monitor. These alternating images are viewed with either a passive or active viewing system (VRLogic, 2006).

Softcopy systems require a digitizing package to delineate features. These are either additions to the system or built-in. Microstation is one of the most robust computer-aided drawing (CAD) packages but it is specialized for the mapping industry and not well developed for attributing riparian buffer data, Table 2. ArcGIS from ESRI is suited for attributing although it does not possess some features useful for riparian buffer data collection such as automatic tree height measurement by recording the tree top and computing the distance to the digital elevation model (DEM) surface directly below it. Stereo Analyst includes a digitizing suite but my past experience using it at the University of Washington found that the tools were insufficient to collect riparian buffer variables well.

The large amount of data management and storage space required for active use as well as archival of digital aerial photography must be considered with softcopy. Firms and agencies in the business of digital photogrammetry invest in the equipment to support this data management, but this could be problematic for small firm or agency use unless planned for. The file size of a 9x9 inch scanned aerial photo at 12 micron's pixel resolution is approximately 1 gigabyte. The data storage required to cover the state of Washington once is approximately 100 terabytes (i.e. with 1:12,000 scale aerial photography that has 60% end overlap and 30% side overlap).

Photogrammetric scanners are required to scan the aerial film collected by metric cameras and not lose the imagery's geometric integrity. These scanners cost upwards of from $60,000. A company or agency must consider either the purchase of this equipment or payment of scanning charges to convert a photograph to a digital image. Some firms utilize metric digital cameras, eliminating the need for a scanner, but at their current cost of $1.5 million, film cameras are still in high use. The scanning process involves some loss in image resolution as does the production of diapositives from negative film (diapositives are used on analytical optical-mechanical systems). This loss may be critical to the interpretation of shadowed areas between standing trees in riparian buffer areas. That is, if the imagery was collected under conditions to properly expose the film for those conditions. Image integrity must be considered when using any photogrammetric system, analytical optical-mechanical or softcopy. (personal communication, G. Maalouli, D. Petermann, 2006). If these conditions are accounted for it will likely not prevent the usefulness of softcopy for riparian buffer photo interpretation.

OPERATION

Orientation Certain geometric procedures (i.e. interior, relative, and absolute orientation) must be followed to view photography in stereo and make measurements whether softcopy or analytical optical-mechanical systems are used. One of the major advantages of softcopy is its efficiency in this operation. When an analytical stereoplotter is used the common orientation points are found by the operator. Softcopy automatically detects these points. The aerotriangulation and orthophoto production processes are also automated. Visual checks are required, but the time required to manually find and mark common tie and pass points is greatly reduced.

Tools Analytical stereoplotters and softcopy both provide tools to record positional data in some computer data file (i.e. points, lines, polygons). The AP190 analytical stereoplotter provides four different fields to store a multitude of attribute codes of the positional data. Softcopy CAD systems (e.g. Microstation) do not provide as broad a suite of attribute fields. ArcGIS (ESRI) which is used by DAT/EM has more attribute features but testing was not done to verify its utility compared to the heads-down digitizing and attributing of the AP190. Based on the interviews and my own experience, softcopy is not as efficient as the AP190 for heads-down digitizing and attributing. However, these tools are assumed possible through custom software development.

Viewing differences Softcopy is sufficient for interpretation and measurement if the digital imagery has been exposed and scanned optimally for the object of interest (e.g. shaded ground surface among standing trees) even though the resolution and view of analytical optical-mechanical systems is better. Softcopy can often magnify more than analytical optical-mechanical systems and this feature would help in distinguishing object differences and their identity.

Data translation The data that is collected from aerial photography must be in a form usable for statistical and spatial analysis. Statistical software packages require the data to be in a spreadsheet or some fixed format where each line provides a complete record of information. GIS packages require positional data with attributes for identification when displayed. In addition, GIS packages may perform spatial computations such as areas of polygons, distances from one feature to another, and subdivision of polygons into distance categories (e.g. 0-10m from stream bank, 10-20m from stream bank, and so on). Some type of data post-processing from analytical optical-mechanical or softcopy systems is requisite. I have not found these completely developed for softcopy but it is assumed it is possible. Allowance must be made for this data translation development. It has already been done for the analytical stereoplotter used in the photo scale CMER study cited above.

DISCUSSION

My interchanges with other professionals indicate that softcopy is a valuable resource and the trend of the future for photogrammetric collection of data. There is a caveat that neither softcopy nor analytical optical-mechanical systems exist as turn-key systems for riparian data collection at this date, except for the analytical optical-mechanical system used in the photo scale study cited above. The second caveat is that as with any sophisticated science, the support of professional photogrammetrists is needed to orient aerial photography, customize software, train users, and trouble shoot applications to ensure correct application.

For natural resource softcopy work I found DAT/EM is the optimal package of those reviewed at a cost of a little under $22,000. There may be other suitable packages such as VR1 that are not reviewed in this report. Past and recent experience and review of Stereo Analyst have not been favorable. This product is still considered in the beta test stage. Also Stereo Analyst does not possess the photogrammetric features to orient and form stereo models. These must be performed by other packages in ERDAS Imagine's software suite. Socet Set and Intergraph are not my primary recommendation due to their cost and the process required for software modification although they are excellent packages. DAT/EM is believed to be the easiest to obtain software customization.

Softcopy has great potential for increasing the amount of riparian buffer data collected from aerial photography. Its use has mainly been confined to the mapping industry. Investment in software modification and post-processing software will be required for its utilization for natural resource data collection. Softcopy tools that are used to record positional data have less developed attributing features. Geographic information systems (GIS) that have well developed systems for attributing spatial data have poor photogrammetric features. The bridging between these two systems plus development of spatial computational algorithms and the outputting of spatial data in a form for statistical analysis are needed.

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