

Estimating the Appropriate Resolution for the
Interpretation of Digital Images for Forestry Purposes
Using a Texture Algorithm


by

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B.Sc., Lakehead University, 1994
B.Sc., Lakehead University, 1994

A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of


MASTER OF SCIENCE


in the Department of Geography

 We accept this thesis as conforming
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ABSTRACT

The objective of this research is to determine the most appropriate resolution for viewing digital orthophotos and stereomodels for forestry purposes. Resolution and scale are critical variables in the interpretability of an image. A subjective analysis of interpretability as well as an objective analysis of local variance, are conducted on images of the Invermere Forest District, BC, at varying resolution. Determining interpretability from a subjective point of view involves the ranking of responses of certified photo interpreters who have viewed images of aggrading resolution. Determining the local variance of an image attempts to emulate the textural component of an image. The subjective and objective results are compared to reveal that calculating the local variance of various resolutions of an image can indicate the most appropriate resolution at which to view digital orthophotos and stereomodels for forestry purposes.

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ACKNOWLEDGEMENTS

Above all, thanks to God. Thanks to the Ministry of Forests and NSERC for funding, to Dr. Olaf Niemann, Dr. Gail Kucera, Dr. Mark Flaherty, Dr. Helena Kadlec and Mr. Michal Lodin (MoF) for advice, to my mom and a whole bunch of really good people at UVic.

CHAPTER 1

INTRODUCTION

1.1 Overview

In a rapidly advancing digital world, it is of critical importance that the techniques which are used to capture, store and transmit data, are efficient with respect to time and digital space, and yet, simultaneously, do not ignore the necessary requirements for the information in question. It is also of interest to determine if an objective measure of interpretability exists in order to facilitate the selection of resolution for a particular project. A review of the literature indicates that while many investigations have inquired into image interpretability (Caylor 1985, Congalton and Mead 1983, Hall 1981, Seeley et al. 1992) with respect to resolution, and many have inquired into the digital assessment of images (Woodcock and Strahler 1987, Marceau et al. 1994b), there has been no previous study which incorporates both subjective and objective measures of image resolution and determines the links between them.

This study investigates the most appropriate resolution for the interpretation of scanned black and white aerial photographs for forestry interpretation purposes. It also examines the use of average local variance as an indicator of image texture. Furthermore, this local image variance is examined as to its feasibility of estimating the most appropriate resolution for interpretability. Results indicate that the most appropriate resolution can be determined from subjective interpretation methods and that values of average local variance, which compute texture variations in an image, have the potential to be useful in resolution selection procedures.

1.2 Goals and Objectives

The goals of this research are to assess the interpretability of orthophotos and stereomodels produced at a variety of scales and resolutions using two approaches: a visual comparative analysis and a comparison of local image variance. The primary objectives of this research are: i) to subjectively determine the most appropriate resolution for viewing digital orthophotos and stereomodels for forestry purposes; ii) to conduct a texture analysis on the different resolution of imagery to determine maximum local variance and to assess the potential for using image texture as a measure of local variance; and, (iii) to determine if a relationship exists between the scale which was subjectively selected and the resolution at which peak local variance occurs.

The primary objectives of the investigation deal with the application of subjective and objective analyses in order to further the scientific approach to image interpretability. A secondary objective of this project is to promote the use of digital imagery for forestry applications by exposing photo interpreters to non-traditional methods of viewing imagery. Both the primary and secondary objectives promote the practical use and implementation of imagery in forestry.

CHAPTER 2

LITERATURE REVIEW

In order to set a suitable framework for comprehension, it is necessary to clarify the terminology and platform of investigation. In this light, definitions and related studies are reviewed. Definitions of resolution, scale, recognition units, interpretability with respect to forestry related issues, imagery formats and the learning factor, are given. These definitions are acquired from sources such as are suitable for the current investigation: from reputable textbooks, from Ministry of Forests publications and from the body of literature reporting related investigations. Not only are definitions extricated from the literature, but several related studies are reviewed with respect to methodology and results of subjective, quantitative and synergistic interpretations of digital imagery.

2.1 Definitions

In order to clarify the background for the appropriate resolution for the interpretation of digital images, the definitions of resolution, scale and the units defining feature and image recognition are presented. Photograph and image interpretability are discussed, focus given to those elements which are relevant to photo interpretation of forestry related features. Imagery formats and the factor of human learning in interpretation are presented.

2.1.1 Resolution, Scale and Recognition Units

The basis for this investigation lies in the interpretation of images. Scale and resolution are two factors which influence interpretability. The most suitable scale and resolution for interpretation are based on the degree of accuracy defined by the unit of recognition of the feature or image.

Scale is the expression of the relationship between the distance between two points on the image and the actual ground distance between those two points (Campbell 1987). The appropriate scale for images is controlled by the very nature of the interpretation project in question. Scale can be classified as small, medium or large. The smaller the scale, the greater the loss in interpretation. The larger the scale, the greater the interpretability of detail. Resolution between two objects is the minimum separation between them at which they appear separate and distinct on an image. Resolution can be defined as fine, medium or coarse. Coarser resolution will decrease the interpretability of detail, whereas finer resolution will increase detail interpretability. The necessary resolution for the interpretation of objects differs according to the objects' shape, size, arrangement and contrast view (Sabins 1978).

Information content relates to recognition, understanding and perception of the scene (Hall 1979). Recognition is a process which is contingent on the synthesis of photo interpretation elements. If the quality of the image is poor, then there may be an associated loss of information depending on the intention of the interpretation.

Caylor (1989) defined the difference between feature recognition unit (FRU) and image recognition unit (IRU), both terms of resolution which contribute to photo

interpretation accuracy. Image sharpness which influences photographic recording of shapes, edges, sizes and subtle texture properties, is related to photo interpretation. A critical FRU can be defined as the greatest spatial characteristic of an object that visually conveys all the information for the identification of the feature to a desired classification level (Caylor 1989). Levels of object classification depend on the information available. Feature detection requires less information than a partial characterization of the feature. A complete feature description requires more information than does a partial characterization. For the detection of a relatively equilateral object image, the object must be at least the size of the resolutional unit; for recognition, an 8X8 matrix is required; and, for complete identification, a 12X12 matrix is required (Hafemeister et al. 1985). Caylor exemplifies the above specifications in conjunction with the FRU: for characterizing the predominant tree species of a stand where tree crowns are of greater than 20 feet in diameter, the task would involve a partial characterization necessitating a 8X8 matrix for each of the 20 foot diameter objects. The appropriate FRU would be 30 inches wide. If the species of individual 6 foot diameter bushes were to be identified, the task would be analogous to the complete characterization requiring a 12X12 matrix, resulting in a 6 inch wide FRU (Caylor 1989). An IRU is defined as a unit on the image which has sufficient size to be interpreted correctly (Caylor 1989). The size of the IRU depends on the contrast of the object with the background as well as on the optical instruments used in the interpretation. The translation of the appropriate FRU size into the appropriate IRU size of suitable contrast on the film, occurs during photo scale selection. For example, an FRU of 30 inches wide, recorded for interpretation as a 62.5 micron wide IRU would require a photographic scale of

approximately 1:12 000 (Caylor 1989). The scale and resolution of the photograph or image is therefore dependent on the feature of interest and the unit at which this feature is interpretable.

2.1.2 Interpretability and Forestry Related Issues

The definition of interpretability is discussed and the various elements are examined. Focus is given to forestry-related interpretation. The factor of learning as images are viewed in a repetitive sequence is also discussed as it pertains to the viewing and subjective analysis of image interpretability.

Interpretability is the subjective measure of the degree of accomplishment to which the photo interpreter (PI) is able to observe, describe, measure and analyze the object space of the photograph (MacDonald 1958). The photo interpretation elements are size, shape, gray tone, texture, pattern, shadow and location (Ministry of Forests n.d.). Size refers to both relative and absolute size and is related to photo scale. Relative size compares one object to another. Shape refers to both two- and three-dimensional configuration. The shape of tree crowns is of paramount importance in the identification of tree species. Recognition of crown forms, such as dome, conical, irregular, etc., is useful in determining species type. Tone is affected by the spectral reflectance of the surface, film sensitivity, object colour, foliage surface, atmospheric conditions, topography, sun angle, age and health of the tree. These tonal influences are considered in species identification. Texture is the result of changes in tone which are caused when objects are too small to be discerned as individual objects. This important element in classification is influenced by scale, age,

crown closure, stand structure and sun angle. Texture is described as rough (coarse) or fine (smooth). Pattern refers to the repetition of objects in their spatial arrangement. Shadow is the resulting sun-projected profile of an object, such as a tree, onto the ground. Location and association can lead to species identification through knowledge of the habitat as well as of the geographic distribution (Ministry of Forests n.d., Lillesand and Kiefer 1979).

The PI uses these photo elements in the identification of tree species. In particular, crown forms, texture, tone and location are used to identify tree stands. Crown forms and texture are invariably lost if the spatial resolution of the image is too coarse. The trained human eye can discern up to 30 gray shades. Lower levels of radiometric resolution may lead to loss of information. Location and association reinforce the suitability of the need for manual interpretation as they are necessary for the deductive reasoning and convergence of evidence which results from the integration of all photo elements with knowledge of locale and ecological factors (Ministry of Forests n.d.).

Species classification and recognition in forestry is therefore dependent on the successful interpretation of tree crown shape, texture, tone and location. If the quality of the image is degraded, then the potential to interpret these elements and derive useful information decreases. Forest features used to evaluate image interpretability in this study are veteran (VET) component and multilayered stands, the distinction between forest and non-forested areas, the distinction between Class 1 Environmentally Sensitive Areas (ESA1) and Class 2 Environmentally Sensitive Areas (ESA2), the identification of logging roads and of logging road trails.

Resolution and scale influence the interpretability of the image. In the case of the forestry related features, the most appropriate resolution for the image exists where the important features for the given task are interpretable to the same level of interpreter confidence as would normally exist in the interpretation of analog photographs.

The element of learning is an accompanying factor of intuitive thinking which results from the repeated exposure to the same image features. Intuitive thinking is a result of the cognitive structure, or prototype, which has been encoded in an individual's memory through learning (Lloyd 1994). Lloyd (1994) found that spatial cognitive structures, also known as prototypes for spatial memory, are influenced and reaffirmed by increasing the frequency at which maps are encountered. Learning of the maps containing the prototypical characteristics is influenced by how the sequence of maps is presented: learning becomes more difficult when maps compared to the prototypical maps are clustered together (Lloyd 1994).

To minimize learning and to reduce any factors which may lead to the presence of a cognitive structure, images displayed to the interpreters in aggrading resolution sequences, until an increment in resolution does not facilitate the interpretation. This process is similar to the ascending method of limits procedure in optometry where the patient selects the lens which is most appropriate for his/her vision correction.

2.1.3 Imagery Formats

Digital images used in this study are stereomodels and orthophotos. Construction of the imagery is briefly discussed and orthophoto file size determination is addressed.

The large volume of conventional analog images presses limitations of economy on physical storage space. Digitally archiving the photographs saves physical space while preserving the original analog photographs. Once the photograph is in digital form, the pattern of brightness forms a numeric array whose values can be subjected to mathematical and statistical operations. A picture element, called a pixel, refers to the ground area represented by a single picture element of an image (Campbell 1987).

Digital stereomodels are photographic stereomates which have been scanned, geocorrected and are digitally interleaved on the viewing screen. The images are viewed with crystal lenses which alternate left and right eye viewing at the refresh rate of the screen. To the viewer wearing the lenses, the images appear to be three dimensional.

Orthophotos are digitally-corrected reproductions of aerial photographs. The ground-controlled corrections remove the effects of tilt, topographic displacement and camera lens distortion. Construction of orthophoto maps requires sound three-dimensional photo interpretation. An orthophoto is generally of lower resolution than the original because the final product has been digitally manipulated at least four times, losing resolution each time (Paine 1981).

The relative file size of a digital orthophoto can be calculated by the multiplication of the length times the width and, thereafter, the division of this number by the pixel size squared. Therefore, as the pixel size is doubled, the orthophoto mapsheet file size will

shrink by a factor of four (Manzer n.d.). For example, the length of time to screen display will be longer for an 80mB, 6 inch image pixel map sheet orthophoto than a 20mB, 1 foot pixel image. The temporal hardware and software delays in displaying an image can affect user aggravation as well as time costs. The final pixel size, which is expressed in ground units, affects the accuracy of digital orthophotos (Manzer n.d.).

2.2 Subjective Interpretation

Subjective methods can be used to assess the appropriate resolution for interpretation. Techniques to measure interpreters' consistency and correctness (Congalton and Mead 1983) and to assess image quality (Hall 1981) are reviewed. A study based on determining the most appropriate resolution for digital diagnostic images (Seeley et al. 1992) is examined. The assessment of these papers focuses on the subjective nature of determining the most appropriate resolution for interpretation purposes.

Congalton and Mead (1983) used a quantitative method to test for the correctness and consistency in photo interpretation. Error matrices were used to analyze using discrete multivariate techniques to facilitate the choices of the proper combination of film/filter, proper seasons and appropriate interpreters. The maximum likelihood estimate statistic, KHAT, is a measure of the difference in the change agreement and the actual agreement. Five experienced interpreters were tested; five different film and filter combinations were tested; and maximum skilled interpreters were tested against varying skilled interpreters.

The results included the observation of similarity of consistency and correctness between the skilled interpreters, the relatively poor application of one of the filters compared to the other four and the lack of consistency and correctness of the less skilled interpreters compared to those more experienced.

Hall (1981) used the "bubble sort" technique which involves a method of comparison between images. This subjective evaluation procedure requires that the viewer make a choice based on quality of one out of two images. The chosen image is retained and compared against another image. The image which is considered of better quality is always retained until all the test images have been viewed.

Seeley et al. (1992) discussed the "needed" spatial resolution for the accurate interpretation from radiological images. The goal of the project was to determine the optimal spatial resolution for the design of a Total Digital Radiology Department (TDRD). Lower resolution facilitates the acquisition, transmission, archiving and display of images in the TDRD. In order to be able to transmit images, the spatial resolution and grey level intensity are minimized to diminish the file size requirements; however, with the loss of resolution there may be a loss of accuracy of the diagnosis by the radiologist. The pilot study was followed up with a more intensive study. The results were not published due to the non-rigorous approach of carefully defining the data set (Roehrig 1996).

In the unpublished investigation by Seeley et al. (1992) the spatial resolution requirements for digital image archiving and communication while maintaining the same accuracy of diagnosis as in film screen systems was examined on a broader scale. For the study, 29 chest images of abnormal pulmonary cases were selected on the basis of findings

that would "most likely" be affected by changes in resolution. These findings included evidence of airspace disease, interstitial disease, small nodules or masses, etc. Another 29 images were selected because they were considered normal for the control group. The film images were digitized at 5.8 lp/mm with 12 bits of grey level and subsequently spatially degraded with a Gaussian blur function to produce spatial resolutions of 5.0, 3.75, 2.5, 1.875 and 1.25 lp/mm (Seeley et al. 1992).

The observers chosen to view the images were 19 certified radiologists. They were informed about the purpose of the experiment and the approximate number of cases to view. All the cases were viewed at the same spatial resolution. Four observers viewed the original analog images and the highest resolution (15.0 lp/mm). Each of the 5 different sets of images were viewed by 3 observers. For all the images, the viewers had two interpretation tasks: 1) the diagnosis (normal or abnormal), certainty (guess, relatively certainty, absolute certainty); 2) the subjective rating (not adequate, adequate, excellent) of contrast resolution, spatial resolution and visibility of seven intrathoracic structures. The viewers saw only one resolution set of images which were presented in random order. The viewing environment was unrestricted: in the radiologists' offices or reading rooms, using the accustomed amount of ambient light. No restrictions were placed on viewing distance or time (Seeley et al. 1992).

The subjective results indicate that on average, the viewers considered the images in each resolution set to be of "adequate" diagnostic quality with respect to spatial and contrast resolution. The ratings were all within one standard deviation of each other indicating that there is little variation across the six categories. For the specific intrathoracic structures, the

average visibility rating tended to improve with increasing spatial resolution. This trend was present for every structure. It was concluded that higher resolution does not necessarily indicate an improvement to the overall image quality, however, higher resolution may permit improved visibility of specific anatomic structures (Seeley et al. 1992).

Criticisms of the Seeley study are that there is an insufficient control of the variables. As aforementioned, the data set was insufficiently defined (Roehrig 1996). The interpreters viewed only one set of resolutions and there was no comparison between them. The difficulty in the application of the Seeley study to the photo interpretation for forestry purposes is not the varying of type of images. In fact, the type of image can be considered similar to those used in forestry, and therefore can be compared. The difference between the projects is that radiology studies consider the correct detection of an abnormality or the correct diagnosis of a clear image to be the factors on which to develop a statistical analysis. The inability to interpret the feature when it is there is considered an omission and is significant to the statistical analysis. The situation of faulty diagnosis does not exist in the same manner in the current interpretability study of forestry features in that the detection of abnormalities is not used as a measure of interpretability.

The subjective methods which have been reviewed are related to the effects of different film characteristics, image quality assessment, photo interpretation consistency and resolution selection. None of these studies has investigated an objective measure which might parallel, and be a surrogate for, the subjective results.

2.3 Quantitative Interpretation

Several investigations have been conducted to objectively assess the impact of the change of scale and resolution on remotely sensed photography and imagery. The early equation by MacDonald (1957), as well as maximum and minimum local variance (Woodcock and Strahler 1987; Marceau et al. 1994b) are examined as indicators of spatial resolution.

2.3.1 MacDonald's "Rule of Thumb"

MacDonald (1957) measured interpretability using resolution. He concluded that the level of interpretability of an analog photograph at resolution R at scale $1:n$ matches that of a photograph at resolution $2R$ at a scale of $1:\sqrt{2n}$. This conclusion was based on a lines-per-millimetre test and did not take into account the end use of the interpretation.

2.3.2 Maximum Local Variance

Woodcock and Strahler (1987) describe a model for the nature of a scene which is based on the assumption that the scene is composed of discrete objects. The scene objects are assumed to be either distributed on a continuous background, or, are arranged to completely cover the area. Abstractions of the real objects found in the ground scene are described as elements. In a forest scene, for example, the leaves, branches, trees and stands might be considered to be elements. Examples of common backgrounds in such an environment might include vegetative understorey, snow, soil. Scene models can be

simple, in which there is only one class of element and background, or complex, which include more than one class of element (Woodcock and Strahler 1987).

Woodcock and Strahler (1987) used the local image variance to determine the appropriate spatial scale at which to conduct a given investigation based on the spatial structure of the image. They reasoned that the spatial structure of the image is prevalently linked with the relationship between the spatial resolution and the objects in the scene. The manner in which the "images of a scene change as a function of spatial resolution is important" to the understanding of the spatial structure and thus, to the selection of a suitable scale of data (Woodcock and Strahler 1987, 313).

Local variance of a scene was used to indicate the most appropriate resolution for the image, based on the following reasoning: if the spatial resolution is finer than the objects in the scene, most of the pixel values will be correlated highly with the values of the adjacent pixels, resulting in a low measure of local variance; if the spatial resolution approximates the size of the objects then the value of a pixel is less likely to be similar to its neighbours; and, as spatial resolution increases, many objects are included in a pixel, which results in a decrease in the local variance (Woodcock and Strahler 1987).

Woodcock and Strahler graphed local variance as a function of spatial resolution to determine the appropriate spatial resolution for several test scenes. The value of local variance was computed as the mean value of the standard deviation of a 3X3 window moving across the image. The standard deviation of the values was computed. The resulting standard deviation value for each pixel was averaged over the entire image and assigned to the image as an indicator of local variance. The local variance was calculated

for degrading spatial resolution for the test scenes. The images were degraded by averaging the pixels to be combined in a larger, single pixel (Woodcock and Strahler 1987).

As the images were degraded, there were less pixels in the image. This decreases the reasonable number of values with which to compute local variance. Large images were used whenever possible in order that there would be sufficient leeway for degradation. As a rule-of-thumb, Woodcock and Strahler (1987) suggested that the minimum size of images in the computation of local variance is at least 60 pixels per side. Two limitations which were involved with graphs of local variance are: that the measure did not account for multispectral variation and that the values for one image could not be directly compared to those of another image. The latter limitation was due to the fact that the local variance is a global value for a given image and can only be compared to measurements from degraded derivations of the same image (Woodcock and Strahler 1987).

Woodcock and Strahler tested their hypothesis on forest, urban/suburban and agricultural environments. Of interest here are the results of the graphs generated from the forestry images. Two images were used: one of fine spatial resolution resulting from scanning a 1:15 000 aerial photograph to a 0.75 metre pixel and the other of a Thematic Mapper Simulator (TMS) image with 30 metre resolution. The purpose of the TMS image was to determine whether the graph of local variance would peak at a stand level of features.

The 1:15 000 photograph was of a forested area in South Dakota; the scene was constituted of trees on a relatively uniform background. The diameter of the tree crowns in this area of South Dakota are reported at approximately 8 metres. The results of the

analysis indicate that the peak of local variance occurs at a resolution of 6 metres. The forest stand scene of the TMS image does not have a peak at the conjectured stand level. Speculatively, this is explained by the poorly defined stands in the particular test image and by the inconsistencies in size of stand areas at this level. Simulated forest scenes of objects of known diameter were generated and results indicate that the maximum local variance occurs in the range of $1/2$ to $3/4$ of the size of the scene objects. This demonstrated that local variance is related to the size of objects and the spatial resolution. The reasoning for the maximum occurrence at a fraction of the size of scene objects is that high local variance take place predominantly around the perimeter of the tree and around the shadows, similar to an edge detector. As the image is degraded, the area covered by low variance values decreases. It is also necessary to maintain a pixel size of less than half the objects of interest in order to assure full contrast in the image measurements (Woodcock and Strahler 1987). The relevant conclusion from the investigation was that local image variance, that is, the mean of a 3×3 pixel window moving across the image, can determine the appropriate image scale. The required pixel size was concluded to be $1/2$ to $3/4$ the size of the objects of the scene.

2.3.3 Minimum Local Variance

Marceau et al. (1994) proposed a method for the identification of the "optimal spatial resolutions for detection and discrimination of coniferous classes in a temperate environment" (Marceau et al. 1994b, 105). Their study used airborne MEIS-II imagery of

eight spectral bands, acquired at 0.5 m pixel. Fourteen forest classes were defined and representative sites were selected. Using an averaging window algorithm, the spatial resolution of the original data was degraded from the centre of each site by 1 m increments to a maximum 29.5 metre pixel. Using the mean value derived from the resampling procedure for each site, the spectral variance was calculated for each forest class. The minimum spectral variance was used as an indicator of optimal resolution based on the argument that: if the spatial resolution is finer than the objects in the scene, individual pixel values selected from different sites on the image will have a lower probability of being similar resulting in high internal class variance; if the spatial resolution is greater than the objects of interest, the pixel values represent an aggregation of ground features similarly resulting in high internal class variance; however, if the spatial resolution approximates the optimal aggregation level for the objects of interest, then "the spectral variance of the pixels assumed to represent the object of investigation is at the lowest level" (Marceau et al. 1994b, 108). Therefore, a drop in class variance indicates the optimal level of aggregation. The method requires an a priori knowledge of the objects of interest (Marceau et al. 1994b). It was concluded that there exists no unique spatial resolution to be able to detect and discriminate all geographical entities in a complex environment such as a forest. The study by Marceau et al. (1994b), as well as the other studies which have been reviewed, primarily dealt with the digital assessment of remotely sensed images and did not focus on the interpretability of the images by an end user.

2.4 Synergistic Interpretation

The review of the literature indicated that many studies have been undertaken in subjective interpretation of resolution and in objective measures of resolution. Digital imagery has previously been available in a fixed number of resolutional choices. With advancements in digital imagery, are concomitant advancements in spatial data analysis. Will these techniques replace the interpreter? Can digital analysis stand alone? If not, can the interpreter benefit from digital advancements?

Spatial resolution is "analogous to the scale of the observations" (Woodcock and Strahler 1987, 311). Most scientific investigations allow for the selection of the scale at which the observations will be collected. Formerly, users of remotely sensed digital imagery were limited in the scale of investigation by the predetermined resolution of the space-born sensor. An increasing selection of resolutions due to the launching of new satellite platforms gives the investigator a greater choice for image scale, ranging from 10 m to 1 km. The selection of appropriate resolution is affected by several factors, including the information required from the scene, the methods of analysis which are used to derive the information and the spatial structure of the scene (Woodcock and Strahler 1987).

While digital analysis is at the forefront of remote sensing investigations, it does not replace the interpretation which can only be accomplished through skilled human observation. The most reliable and practical methods of acquiring information from remotely sensed data are through manual image interpretation. Computer analysis can automate some numeric tasks, but it does not replace the interpreter's ability to integrate

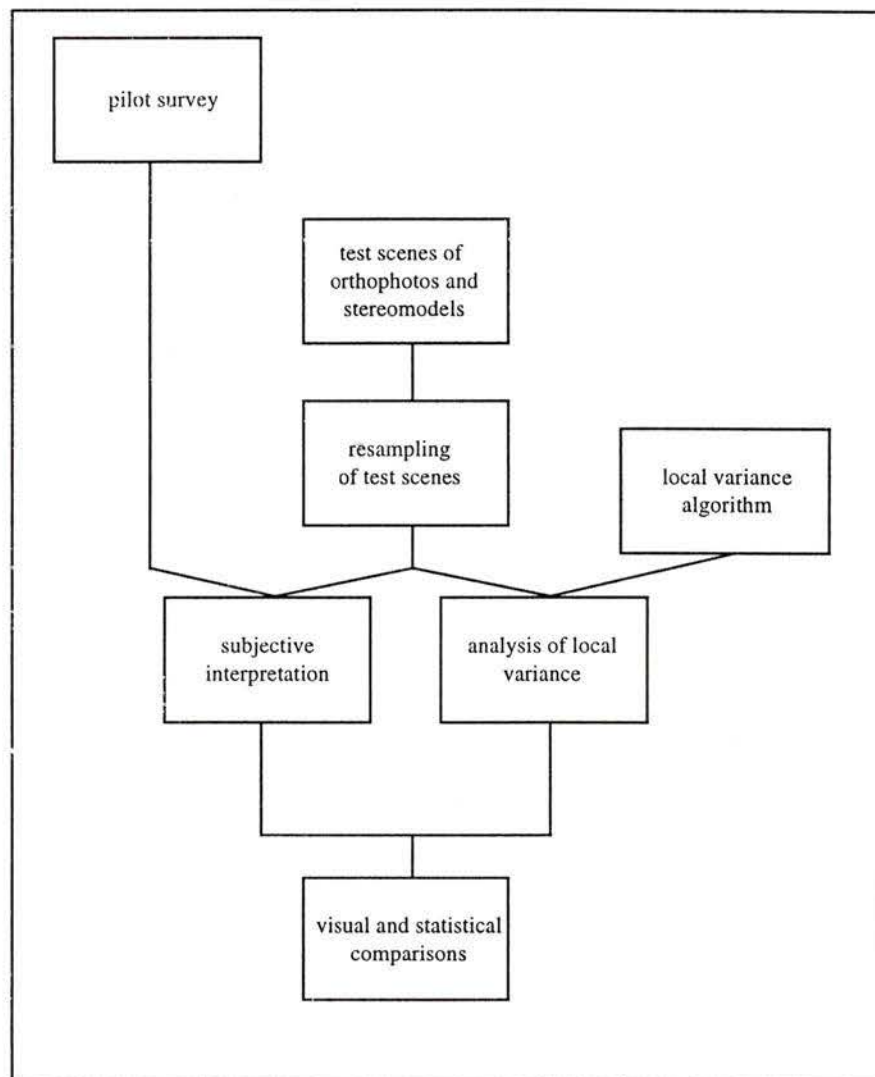
varied informational content and to differentiate less obvious elements of the image (Campbell 1987). According to Sayn-Wittgenstein, "interpretation is always a subjective procedure, even if one has the facilities and experience to rely on computer assisted pattern recognition and other methods for the classification of digital data, multivariate overlays and enhancements. None of these methods is so mechanical and objective that it can be successfully applied without the background knowledge and intuition of the interpreter" (Sayn-Wittgenstein 1978, 4). Therefore, even the best methods of computer-automated interpretations do not match the interpreter's ability to make accurate and precise interpretation.

Myers et al. (1989) studied the synergism between human interpretation and digital pattern recognition in preparation of thematic maps. It was suggested that the approach which should be taken is one of integrated manual/digital approach where the interpreter can intervene in the digital processes and can override any algorithmic designations. Therefore, approaches taken in subjective interpretation can be assisted by automated tasks, but caution should be taken that these tasks do not replace the interpretation which can only be accomplished with subjective approaches.

CHAPTER 3

METHODS

The literature revealed that there was no previous investigation that deals with both a subjective and objective approach to image interpretation, nor a comparison between the two. This current investigation was therefore undertaken to develop a method to investigate the most suitable resolution for image interpretation using two approaches: a subjective method and an objective method. The methods include a pilot study, the Invermere study area, as well as digital data acquisition and preparation which were funded and supported by the Ministry of Forests. The methods differ in the testing of the images: one is a subjective approach employing certified photo interpreters and the viewing environment at Triathlon Mapping Corporation, the other is an objective approach using a texture algorithm. A flow chart of procedures is given in Figure 3.1.

Figure 3.1 Procedures

3.1 Pilot Study

A pilot study was conducted to determine the features, photo interpretation elements and the scales which photo interpreters (PIs) use routinely in their work. The results of the survey were used as a basis for the formulation of the questions which relate to the subjective image viewing. Six certified PIs were surveyed.

The survey consisted of questions related to features, photo interpretation elements and scale. The first part queried the PIs as to which features they routinely identify at 1:70 000, 1:40 000 and 1:15 000 scales in their work (Table 3.1.1). One interpreter responded that, because of the nature of his particular daily tasks, he doesn't use the 1:70 000 nor the 1:40 000 scales routinely, thus, for these scales, the cumulative responses are from five interpreters. The collective responses are that the following features are distinguished at 1:70 000: roads, cut blocks (greater than 25 ha), significant water bodies, general locations of primary water courses, buildings, hydro/gas lines, landforms and landings. One interpreter also responded that the distinction could be made between fire and logging disturbances and also between forested and non-forested areas. All five interpreters specified "roads" as a feature distinguishable at this scale. Two interpreters specified cut blocks and buildings. The rest of the listed features were specified only once in all five responses. This indicates the extent to which the responses were varied and the diversity of the features which are routinely interpreted at 1:70 000.

Table 3.1.1 Features which can be interpreted at given scales

scale	feature
1:70 000	cut blocks (greater than 25 ha) significant water bodies general locations of primary water courses buildings hydro/gas lines landforms landings roads
1:40 000	all features listed above at 1:70 000 scale water bodies (greater than 5 ha) stocking/density variations height variations (greater than 5m) major infestations ephemeral creeks some individual tree details tree canopy pattern
1:15 000	all features listed above at 1:40 000 and 1:70 000 scales differences in species heights trails individual large conifer crowns greater than 30 meters

The collective responses for 1:40 000 are that the following features, including those distinguished at 1:70 000, are also distinguished: water bodies, (greater than 5 ha), stocking/density variations, height variations (greater than 5m), major infestations, ephemeral creeks, some individual tree details and tree canopy pattern. One interpreter responded that distinctions could be made between mature and immature stands, between coniferous and deciduous stands, and between pure pine stands and other coniferous stands. "Roads" were specified three times at this scale; all other features were mentioned only once.

The collective responses for 1:15 000 are the following features, including those distinguished at 1:70 000 and 1:40 000: differences in species, heights, trails and individual large conifer crowns greater than 30 meters. There was increased multiplicity of responses at this scale: roads were specified three times, permanent and ephemeral streams twice and individual tree crowns by five out of 6 PIs.

The second part of the survey queried which photo interpretation elements were most likely to be used in the interpretation of the features which the interpreter specified as distinguishable at each scale. Tone, texture and pattern were most frequently cited at all scales. For the delineation of forest cover polygons, tone was considered the most useful element. For the interpretation of Lodgepole Pine and of deciduous trees, texture was the most useful element. For the interpretation of Western Red Cedar, tone was the element of choice. Blowdown was most often interpreted by pattern, presence and absence of snags by size, boundary delineation of land use/land cover by tone.

The third part of the survey asked what the most useful scale was for several features: for the delineation of forest cover polygons, the most useful scale is 1:15 000; for the interpretation of crown forms, between 1:10 000 and 1:15 000; for the interpretation of crown closure, 1:15 000; for the detection of the presence or absence of snags, 1:5 000; for the interpretation of blowdown, between 1:15 000 and 1:20 000; and for the boundary delineation for land use/land cover, between 1:20 000 and 1:40 000.

The result of the pilot study is that no PI concentrates on the same features in the interpretation of forestry photographs. However, from the collective responses and with the aid of the study area inventory officer a question sheet was developed to examine the interpreters as to the interpretability of the images.

3.2 Study Area

The study area covers approximately half of a standard forest cover map sheet in the Invermere Forest District, British Columbia (Figure 3.2.1). This area is mountainous with steep slope gradients to provide a diversity of landscape in the analysis. Minimal change has occurred in the area of the orthophoto specifications over the past ten years with respect to logging and forest practices. The leading species in the area are Spruce, Lodgepole Pine and Fir (Ministry of Forests 1994). The airphoto coverage of the area was acquired at three different scales. The specifications of the airphotos are outlined in Table 3.2.1.

Figure 3.2.1 Study Area: Invermere Forest District, British Columbia



Ministry of Forests n.d.

Table 3.2.1 Specifications of airphotos

Scale: 1:15 000
Number of photographs: 6
Number of resulting models used for orthophoto production: 3
Date of acquisition: September 9, 1991
Time of Acquisition: 9:40 am
Photograph identification: BC91169 (112-117) south part
Camera: Zeiss 6 inch
Scale: 1:15 000
Number of photographs: 6
Number of resulting models used for orthophoto production: 3
Date of acquisition: September 24, 1991
Time of Acquisition: 12:20 pm
Photograph identification: BC91169 (245-250) north part
Camera: RC10 12 inch
Scale: 1:43 000
Number of photographs: 2
Number of resulting models used for orthophoto production: 1
Date of acquisition: September 15, 1981
Time of Acquisition: 11:40 am
Photograph identification: BC81122 (263-264)
Camera: Zeiss 6 inch
Scale: 1:80 000
Number of photographs: 2
Number of resulting models used for orthophoto production: 1
Date of acquisition: July 26, 1988
Time of Acquisition: 10:07 am
Photograph identification: BC88044 (105-106)
Camera: Wild 6 inch

3.3 Compilation of Stereomodels and Orthophotos

In this present investigation, digital stereomodels and orthophotos were used in order to investigate the query of resolution as an influence on interpretability. Stereomodels are routinely used by forest photo interpreters for visualizing stands and topography in three dimensions. Normally, pairs of analog photographs are viewed with a stereoscope. Information extracted from three-dimensional viewing include stand volume, species identification, topography, etc. and can be used to update forest inventory maps. Orthophotos are maps which show photographic detail with tilt and displacement removed (Campbell 1987). The stereomodel gives the viewer the advantage of three-dimensional visualization; the orthophoto map gives the user the benefit of positional accuracy.

The digital stereomodels and orthophotos were compiled by Triathlon Mapping Corporation, Burnaby, BC, to the specifications outlined by the Ministry of Forests. The stereomodels are epipolar resampled models in which the stereopairs are digitally interleaved on the viewing screen. The PIs viewed the images with crystal lenses which alternate left and right eye viewing at the refresh rate of the screen, providing a three dimensional view. The proposal requirements for the orthomap production for the Invermere Forest District required that the imagery cover the land base which is under the administration of the District. The objectives and deliverables of the proposal were as follows: sixteen diapositives of black and white aerial photographs were scanned at the varying scan sample rate of 7.5 microns; the orthophotomaps were compiled of the study area using control provided by the Ministry of Forests and compiled at pixel sizes of 0.625

and 2 metres for each photo scale; nine raster maps were plotted on paper at scales of 1:20 000, 1:10 000 and 1:5 000 of all three scales.

3.4 Viewing of Stereomodels and Orthophotos

Seven skilled photo interpreters were selected for assessing the images: six certified photo interpreters and the Invermere Forest District inventory officer. Before they viewed the images, they were given information as to the nature of the study as well as to the questions they would be asked concerning the different resolutions of images. During the image viewing session, they were given a verbal questionnaire for each image which they viewed, depending on the type of image (i.e. stereomodel or orthophoto) (Table 3.4.1.1). The PIs had approximately 10 minutes to view each image and answer the questions. The questions were designed based on the information from the pilot survey results, the interpretations which could be made from the type of image and on the knowledge of the area by the inventory officer. The PIs gave a verbal response on a scale of 1 to 5, including half values, such as 2.5 (Table 3.4.1.2). The verbal response was recorded. If the PI could not find evidence of the feature or element on the image, the response given was "n/e". If the feature or element was not interpretable or not applicable, the response given was "n/a". If a PI answered less confidently and gave a range, such as "2.5 to 3", the lower value was kept.

3.4.1 Stereomodel Viewing Methods

The PIs viewed 5 different equivalent pixel sizes of the epipolar resampled models in stereo, using crystal lenses. The models of BC91169248/9 at 1:15 000 (Figure 3.4.1.1) and of BC81122263/4 at 1:40 000 (Figure 3.4.1.2) were viewed at a distance at which PIs felt viewing was comfortable (approximately 75 cm). They viewed the images in a sequence of decreasing equivalent pixel sizes to avoid learning detail, a situation which might have occurred if the images were displayed in an ascending sequence. The images were enhanced using a contrast stretch after the initial overview. (The enhancement of each image was either an equalization over the full histogram or a straight linear clip followed by a gamma function.) After viewing all the equivalent pixel sizes, the PIs were asked to rate which equivalent pixel size was, in their opinion, best for over photo interpretation (mainly stratification). The equivalent scale which was awarded the highest rank by each interpreter was tabulated for each feature or photo interpretation element and the cumulative ranks were tabulated.

3.4.1.1 Questions for image viewing

STEREOMODELS

1. How well can you distinguish between VET component and multi layered stand?
2. How well can you distinguish between ESA1 and ESA2?
3. How well can you identify logging roads?
4. How well can you identify logging road trails?
5. How well is texture defined?
 - Tone?
 - Pattern?
 (i.e., do you lose texture, tone and pattern in this image because of blockiness?)

ORTHOPHOTOS

1. How well could you prestratify the area?
2. How well can you discriminate timber types?
 - PI (Pure Pine) vs. Mixed Pine (PI and Pa)
3. How well can you classify non-productive (NP) lands?
 - NPBu (Burn) vs NPOr (Open Range) vs Npurban vs NP with species?
4. How well can you see >10% differences in crown closure?
5. How well is texture defined?
 - Tone?
 - Pattern?

3.4.1.2 Ranking scale for question responses

1 - Extremely Well

2 - Well

3 - Adequately

4 - Poorly

5 - Extremely Poorly

n/e - No Evidence

n/a - Not Applicable or Not Interpretable.

3.4.2 Orthophoto Viewing Methods

Six orthophotomaps were used for the subjective viewing: two orthophotos were created from 1:80 000 imagery at ground pixel sizes of 2 metres and 0.625 metres; two orthophotos were also created from 1:40 000 at the above pixel sizes; and two orthophoto mosaics were created from 1:15 000 imagery at the same pixel sizes (Figure 3.4.2.1). The 2 metre pixel images were created from the 0.625 metre pixel images using a cubic convolution resampling algorithm. Cubic convolution is a popular, sophisticated and complex resampling algorithm which produces attractive images compared to other methods (Campbell 1987).

The PIs viewed the six digital orthophotos on screen with zoom levels up to 4x, of which the equivalent scale is 1:7 200. The images were viewed at a distance which was comfortable for each interpreter (approximately 75 cm). The images were viewed in a sequence which began with the imagery derived from the smallest scale (1:80 000), and finishing with imagery derived from the largest scale (1:15 000). The sequence also included focus on the left, middle or right sides of the image in order to eliminate learning at that particular scale. The PIs were asked to rate the interpretability of certain forestry related features and of certain photo interpretation elements according to the portion of the image which was viewed. The ranks for the common were tabulated according to the original scale and also according to the output pixel size.

3.5 Texture Analysis of Stereomate Subscenes and of Orthophotos

Subscenes of the stereomodels and orthophotos were selected. A texture analysis of local variance, comparable to the method used by Woodcock and Strahler (1987) which used standard deviation as a texture measure, was performed on the subscenes and the results recorded.

3.5.1 Stereomate Subscenes

Four subscenes were cut out of the 1:40 000 and 1:15 000 stereomates which were viewed by the interpreters (Figures 3.5.1.1 and 3.5.1.2). The subscenes were selected as those which the PIs emphasized as areas of interest during the subjective procedures of interpretation. From the 1:15 000 stereopair, the BC91169248 photograph was used. From the 1:40 000 stereopair, the BC81122263 photograph was used. The 7.5 micron scans, which were used in the viewing of the epipolar resampled stereomodels could not be used, due to lack of disk space at the facility where the digital analysis occurred. The next available scan rate of 15 microns of the original scanned photographs was used. These digital images were not raw scans, but were spectrally normalized so that contrast was improved. The subscenes which were sectioned from the photographs were 800 lines by 800 pixels.

Each of the 8 subscenes was degraded progressively using an averaging image transfer to result in 5 different resolutions per subscene. A moving 3x3 kernel was then applied to each of the 40 subscenes in order to calculate the mean local variance for each subscene. The mean local variance was computed as

$$\sigma^2 = \frac{\sum (x - \bar{x})^2}{n - 1}$$

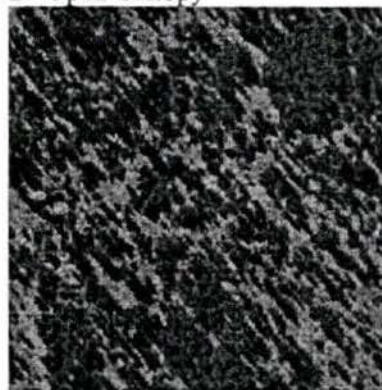
where σ^2 is the mean local variance (or sample variance as given by Freund 1988); x is the centre pixel of the 3x3 kernel; \bar{x} is the mean pixel value for the 3x3 kernel; and n is the number of pixels in the kernel (i.e. 9). For the edge pixels, a variance was not computed and therefore this null value was excluded from the calculation. The ground pixel size and image subscene size are given in Table 3.5.1.3.

Figure 3.5.1.1 Stereomate subscenes from 1:15 000 data used in texture analysis

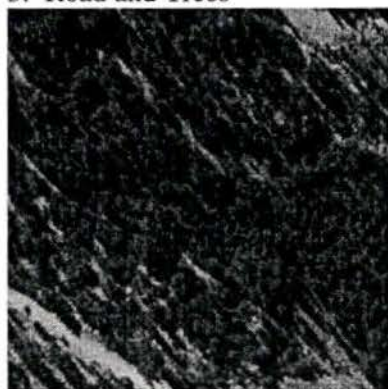
1. Dense Canopy



2. Open Canopy



3. Road and Trees



4. Streams and Trees

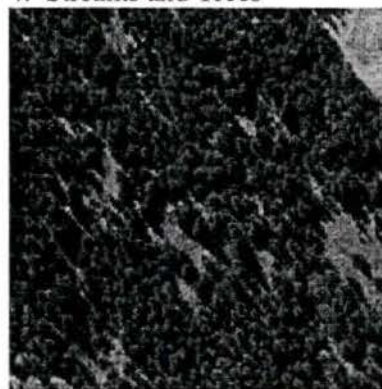
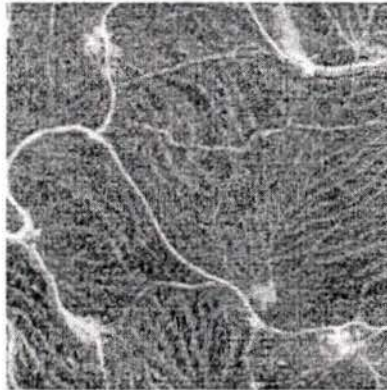


Figure 3.5.1.2 Stereomate subscenes from 1:40 000 data used in texture analysis

1. Cut Block



2. Treed Valley



3. Treed Valley



4. Treed Valley



Table 3.5.1.3 Subscene Details

Original Image Scale	Subscene Equivalent Pixel Size (microns)	Equivalent Scale	Ground Pixel Size (metres)	Image Subscene Size
1:15 000	15	1:750	0.225	800X800
	30	1:1 500	0.45	400X400
	60	1:3 000	0.90	200X200
	120	1:6 000	1.80	100X100
	240	1:12 000	3.60	50X50
1:40 000	15	1:2 000	0.60	800X800
	30	1:4 000	1.20	400X400
	60	1:8 000	2.40	200X200
	120	1:16 000	4.80	100X100
	240	1:32 000	9.60	50X50

3.5.2 Orthophotos

A subscene was selected by a PI from the orthophotos to facilitate image manipulation (Figure 3.5.2.1). The chosen subscene was considered to be representative of a variety of forest characteristics and included landmarks such as roads. Resolutional series for all three scales of orthophotos were created starting with the 0.625 metre resolution. Using a progressive resampling averaging algorithm, the resulting series were calculated as follows: 0.625 metre, 1 metre, 2 metres, 4 metres, 8 metres and 16 metres. There were therefore 18 different test scenes created. The averaging algorithm produced images whose pixel values are averages of the aggregated pixels. A variance image was computed for each of the resolutions of the orthophotos.

Polygon masks were created from buffered polygons of the Forest Cover Inventory digital file (FC1) of the Invermere area. The FC1 that was used was the 1981 coverage so as to relate to the least recently acquired imagery. The overlaid polygons were buffered to 60 metres to eliminate transition zone problems at the edge of polygons and to conform with the accuracy of the FC1 as defined by the Forest Inventory Manual (n.d.) (Figure 3.5.2.2). The average local variance was then calculated for each of the masked areas of forest cover for each resolution from the original scales. The values for the masks were then averaged to produce a value for each image.

Figure 3.5.2.1 Orthophoto subscene used in texture analysis (2 metre, 1:15 000 data)

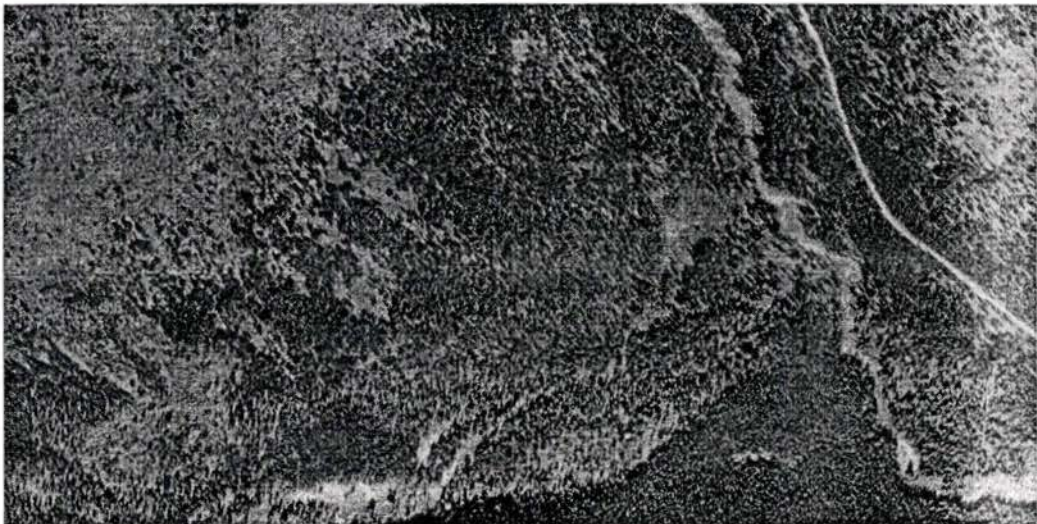
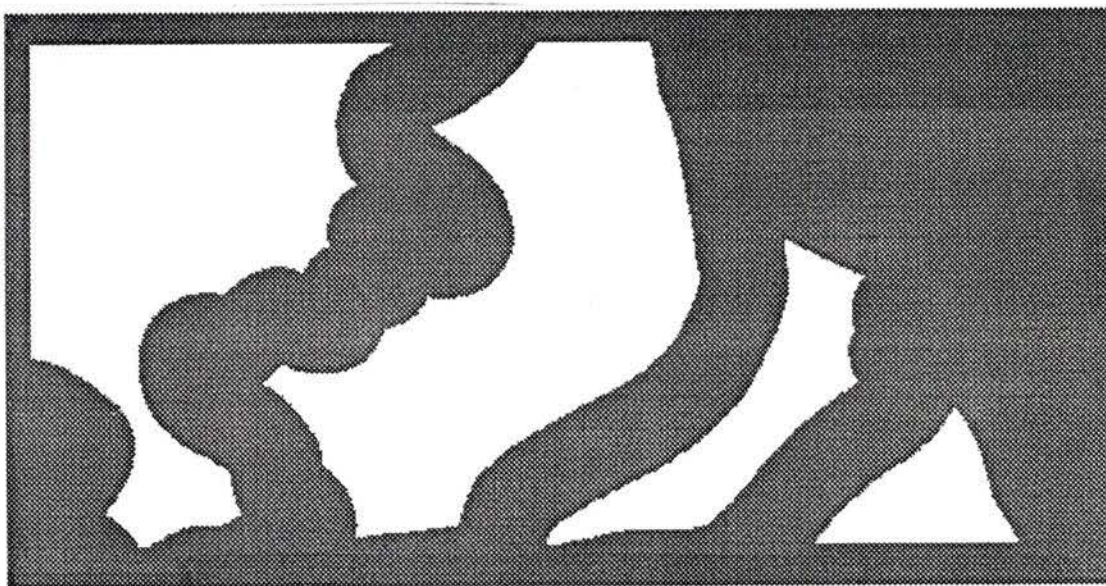


Figure 3.5.2.2 Buffered polygons



The methods which were used in this current investigation incorporated the preparation of images for viewing and for quantitative processing. Using various sets of resolutions, the photo interpreters determined which resolution was the most appropriate according to a subjective set of questions. By creating test scenes from the degrading resolutional sets, it was possible to determine the local image variance for each of the resolutions.

CHAPTER 4

RESULTS

The results of the implementation of the method for determining appropriate resolution are presented in three parts. The first part includes tables and graphs from the subjective image viewing procedures. The second part includes graphs from the texture analysis of the images. The last part involves the results of the statistical correlation measure between the subjective interpretation of the images and the texture analysis.

4.1 Results of the Subjective Image Viewing Procedures

The results of the subjective image viewing are presented for the stereomodel viewing and the orthophoto viewing. Both the stereomodel and orthophoto results are presented in tables where the number of times the highest rank was attributed to each equivalent scale for each feature or interpretation element.

4.1.1 Results of the Stereomodel Viewing

The results are presented in Tables 4.1.1.1 and 4.1.1.2. From Table 4.1.1.1, it is evident that an equivalent scale of 1:4 000 is consistently chosen as the best scale at which to view the features and at which to interpret the image elements from the 1:40 000 scale. This is an equivalent pixel size of 30 microns and an equivalent ground pixel size of 1.2

metres. For the 1:15 000 image, the most useful scale for the interpretation of features and the utility of the photo interpretation elements is in the range of 1:6000 to 1:1500 (Table 4.1.1.2). This range of scales includes 1:4000 scale with an equivalent ground pixel size of 1.2 metres. To view stereomodels, therefore, a 1:4000 scale is best for viewing the models on screen.

4.1.2 Results of the Orthophoto Viewing

The interpretability of the orthophotos was compared in two ways: (1) holding the pixel size constant and comparing original image scales, (2) holding the original image scale constant and comparing pixel size. These methods were employed to determine what was more influential to interpretability: output pixel size or original scale of the input images.

4.1.2.1 Scale-wise Comparison

The scale from which the orthophotos were made were compared maintaining constant pixel size. The scale which was awarded the highest rank by each interpreter was tabulated for each feature or photo interpretation element. The cumulative ranks are listed below (Tables 4.1.2.1.1 and 4.1.2.1.2).

Table 4.1.1.1 Number of times the highest rank was attributed to each equivalent scale for each feature or interpretation element. Original image was the 1:40000 stereomodel, scanned at 7.5 microns (BC81122263/4).

Zoom Level	32	8	4	2	1
Equivalent scale	1:32000	1:8000	1:4000	1:2000	1:1000
Equivalent pixel size (microns)	240	60	30	15	7.5
Equivalent ground pixel size (metres)	9.6	2.4	1.2	0.6	0.3
VET component			3	4	
ESA1 vs. ESA2	2		3	2	
Logging roads		5	2		
Logging road trails		2	4	1	
Texture			4	3	
Tone		2	3	2	
Pattern		1	5	1	

Table 4.1.1.2 Number of times the highest rank was attributed to each equivalent scale for each feature or interpretation element. Original image was the 1:15000 stereomodel, scanned at 7.5 microns (BC91169248/9).

Zoom Level	16	8	4	2	1
Equivalent scale	1:6000	1:3000	1:1500	1:800	1:400
Equivalent pixel size (microns)	120	60	30	15	7.5
Equivalent ground pixel size (metres)	1.8	0.9	0.45	0.225	0.1125
VET component		3	2	2	
ESA1 vs. ESA2	3			3	
Logging roads	3	3			
Logging road trails		1	3	3	
Texture		2	4	1	
Tone	1	3	2		
Pattern	2	2	2	1	

Table 4.1.2.1.1 Number of times the highest rank was attributed to each original scale for each feature or interpretation element. The pixel size was constant at 2m.

	1:80000	1:40000	1:15000
PRE		2	3
TIMBER TYPES	1	3	
NP LNDS	1	2	1
>10 DIFF CC	1	3	
TEXTURE		6	1
TONE		4	
PATTERN		4	1

Table 4.1.2.1.2 Number of times the highest rank was attributed to each original scale for each feature or interpretation element. The pixel size was constant at 0.625m.

	1:80000	1:40000	1:15000
PRE	1	4	
TIMBER TYPES	1	4	1
NP LNDS	1	3	
>10 DIFF CC		3	1
TEXTURE		3	1
TONE	1	3	1
PATTERN		2	2

4.1.2.2 Pixel-wise Comparison

The pixel sizes were compared maintaining constant the scale from which the image was derived. The pixel size which was awarded the highest rank by each interpreter was tabulated for each feature or photo interpretation element. The cumulative ranks are listed below (Tables 4.1.2.2.1 to 4.1.2.2.3).

The results of the scale-wise comparison indicate that the orthophoto created from the 1:40 000 imagery is the most interpretable based on the responses of the PIs (tables 4.1.2.1.1 and 4.1.2.1.2). The original 1:40 000 scale airphotos, however, differs significantly from the original 1:80 000 and 1:15 000 scale airphotos. The 1:40 000 airphotos are the oldest of the set of the three scales, acquired at 11:40 am, 15 September 1981, using a Zeiss 6 inch camera. The 1:80 000 airphotos were acquired 10:07 am, 26 July 1988 using a Wild 6 inch camera. The 1:15 000 airphotos were acquired in two sets with a Zeiss 6 inch camera. The photos of the southern flight line were acquired at 9:40 am, 9 September 1991; the photos of the northern flight line were acquired at 12:20 pm, 24 September 1991. The explanation for the preference of the 1:40 000 scaled orthophoto over the 1:80 000 orthophoto is linked to the scale factor. The PIs complained that the 1:80 000 was fuzzy and washed out. The 1:40 000 scale orthophoto was considered sharp and clear for the interpretation of the features and elements under consideration.

Table 4.1.2.2.1 Number of times the highest rank was attributed to pixel size for each feature or interpretation element. The scale from which the image was derived was constant (1:80 000)

	2m	0.625m
PRE		6
TIMBER TYPES	1	1
NP LNDS	4	3
>10 DIFF CC	5	
TEXTURE	1	5
TONE	3	3
PATTERN	2	1

Table 4.1.2.2.2 Number of times the highest rank was attributed to pixel size for each feature or interpretation element. The scale from which the image was derived was constant (1:40 000).

	2m	0.625m
PRE		5
TIMBER TYPES	3	2
NP LNDS	3	3
>10 DIFF CC	1	2
TEXTURE	4	3
TONE	2	
PATTERN	4	3

Table 4.1.2.2.3 Number of times the highest rank was attributed to pixel size for each feature or interpretation element. The scale from which the image was derived was constant (1:15 000).

	2m	0.625m
PRE	5	2
TIMBER TYPES	2	3
NP LNDS	3	2
>10 DIFF CC	1	3
TEXTURE	1	2
TONE	4	3
PATTERN	2	3

Based on this explanation, it was expected that the 1:15 000 orthophoto would be considered even clearer and sharper than the 1:40 000 orthophoto, and thus be ranked higher for the interpretability of features and elements. This is not the result, however, as the 1:40 000 orthophoto was considered superior to the 1:15 000 orthophoto. These results can be explained by the differences in the 1:40 000 orthophoto, which is a true orthophoto, versus the 1:15 000 orthomap, which is an orthomosaic. The compilation of the 1:15 000 orthomap required the mosaicking of 12 airphotos, as opposed to 2 for the 1:40 000 orthophoto and 2 for the 1:80 000 orthophoto. For the 1:15 000 orthomap, the compilation was based on 6 models in the upper half of the orthomap and 6 models in the lower half. The mosaicking resulted in almost imperceptible join lines between images. Since the airphotos for the northern half of the orthophoto were acquired at a different time of day than the southern half, the shadows in the image fall in inconsistent angles, creating confusion in the interpretation. To overcome this problem, the airphotos should be acquired as temporally close together as possible. Even if this were feasible for this study, the join lines might add difficulty to the interpretation.

Although an orthomosaic created from 1:15 000 scale imagery would have increased detail due to the original larger scale, the compilation is more time and labour consuming and there is increased displacement of the height of surficial features at larger scales which is not removed in the correction for terrain displacement. It is more economical to compile an orthophoto from one stereomodel, but if the scale is too small, however, as in the case of the 1:80 000 orthophoto, there is an accompanying loss of interpretability. It is hypothesized that a threshold exists where the number of airphotos

used is minimized as the scale of acquisition is maximized. This threshold would be the appropriate height at which to acquire the air photos.

To combine the results from the scale-wise and pixel-wise comparison, an image with interpretable timber type differences and with highly rated photo interpretation elements is the 1:40 000 at the 2 metre pixel size. For prestratification and for greater than 10% differences in crown closure, the 0.625 metre pixel is given a higher rating more frequently. The results indicate that there is a greater consensus on the differences between the images derived from different scaled imagery than from the output pixel size.

From this preliminary synthesis of the data which was collected from the viewing of the images, it is concluded that the issue of interpretability is dependent on original scale. The utility of the scale is not as critical when dealing with output pixel sizes at the given pixel resolutions.

4.2 Results of Texture Analysis

The results of the texture analysis are presented for the stereomates (Figure 4.2.1.1) and the orthophotos (Figure 4.2.1.2). Both the stereomodel and orthophoto results are presented in graphs of local variance against ground pixel size. The trend of the graphed data follows the trends which Woodcock and Strahler (1987) observed in the results of their studies of local variance. There is a peak for the local variance around 2 metres for the orthophotos and around 1.5 metres for the stereomodels.

Figure 4.2.1.1 Results of Stereomates Local Variance Analysis

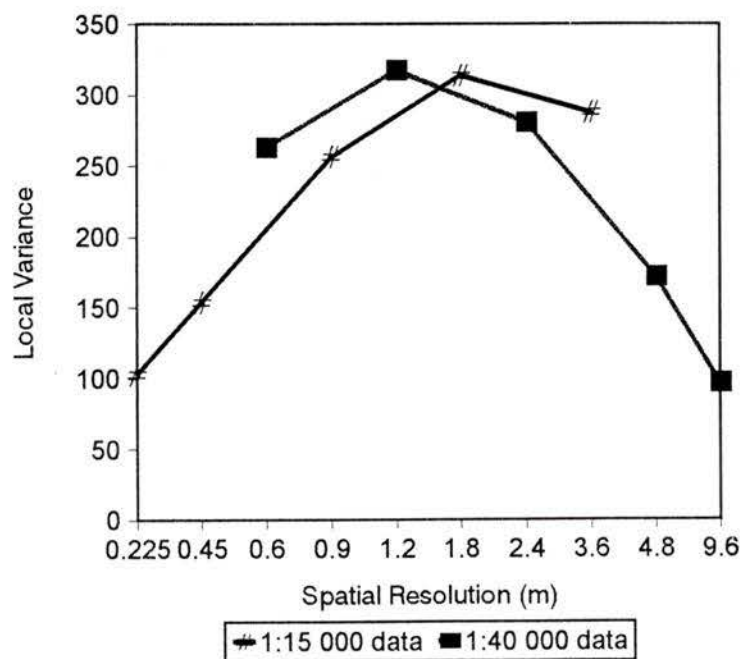
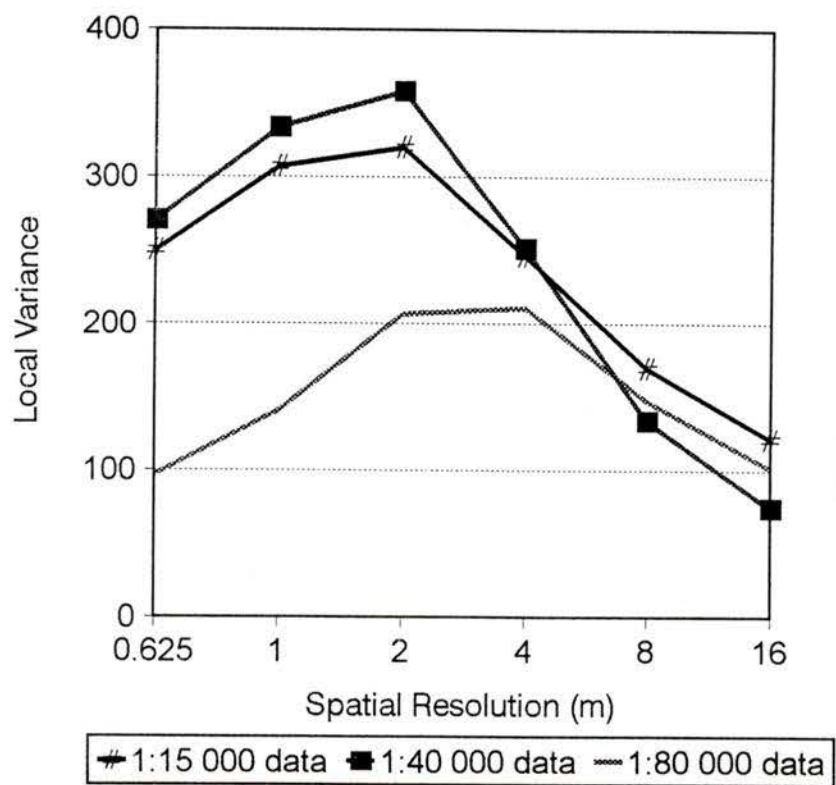


Figure 4.2.1.2 Results of Orthophotos Local Variance Analysis



CHAPTER 5

STATISTICAL ANALYSIS AND DISCUSSION

The results of the subjective analysis and the texture analysis were compared in two ways. The first is a visual comparison of the ground pixel size at which there is maximum interpretability and maximum local variance. This was done for both the stereomodels and the orthophotos. The second is a correlation analysis of the direction of interpretability and local variance trends with respect to increasing ground pixel size. This was done for the stereomodels only as the statistical analysis proves unfeasible for the subjective orthophoto data since only two resolutions were viewed.

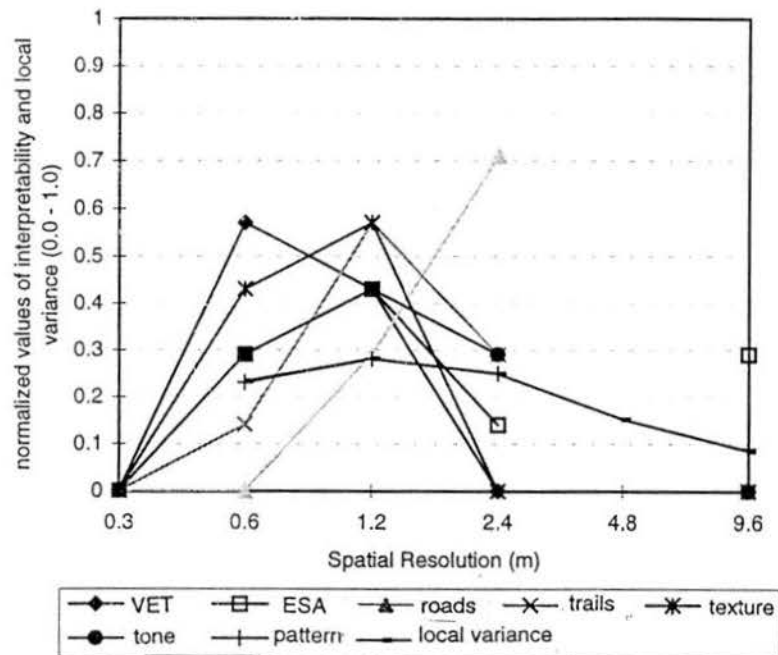
5.1 Visual Comparison

The results of the subjective analysis of interpretability and local variance against ground pixel size are presented in Figures 5.1.1.1 and 5.1.1.2 for the stereomodels. The values for the subjective interpretation and local variance were normalized by dividing by the category totals, to create values between 0.0 and 1.0, and plotted against ground pixel size. From the results, it appears that the most appropriate range of resolution of viewing stereomodels for the forestry purposes in this study, is between 0.9 and 1.8 metres, or an average equivalent scale of 1:4 000. The local variance has a maximum at 1.8 metres. There is more variation in the results from the 1:15 000 image, mainly due to the

increased internal variability in the scenes. For the 1:40 000 stereomodels, there are maxima of interpretability in the range of 0.6 to 2.4 metres. Variance also peaks at 1.2 metres, a clearly following the tendency of interpretability. The 1:40 000 results are much more successful due to the lower internal variance within the scene at this scale.

For the orthophotos, a re-examination of Tables 4.1.2.2.1 and 4.1.2.2.2 reveal that there is little difference between the preference of 0.625 metre resolution for the interpretability of the orthophotos compared to a 2 metre resolution. From the results, of the local variance as it is presented in Figure 4.2.1.2, it appears that the mean local variance generally has a maximum in the range of 1 to 2 metres resolution. This partially explains the interpreters' indecision about which resolution was the best to view the orthophotos; at any coarser resolution, it is hypothesized that interpretability would also decrease.

Figure 5.1.1.2 Stereomodel results of the subjective analysis of interpretability and local variance against ground pixel size (1:40 000). Both interpretability values and variance values have been normalized by dividing by their respective category totals to give values between 0.0 and 1.0.



5.2 Statistical Comparison

The results of the subjective viewing and of the local variance analysis were statistically compared for the stereomodels to determine the strength of a linear relationship. The orthophoto results were not be compared in this way since only two values were derived for the subjective viewing: one at 0.625 metres and the other at 2 metres. A comparison would not measure the strength of relationship in the same way.

For the stereomodels the subjective and mean local variance results were correlated with Spearman's non-parametric correlation coefficient to measure the strength of the linear relationship between variables. The coefficient ranges from -1 to +1. A value of +1 indicates a perfectly positively related linear relationship, a value of -1 indicates a perfectly negative linear relationship and a value of 0 indicates that there is no linear relationship between the variables (Freund 1988). Spearman's correlation is a non-parametric measure and was used in this study since the original subjective data are ordinal. Spearman's is based on the ranks of the data values rather than the actual numeric values. A one-tailed test of significance was conducted where the null hypothesis was that the coefficient was not greater than zero. The values for the subjective interpretation were normalized by dividing each by the total number of responses in that category and correlated individually with the local variance values. The results of the statistical assessment are presented in Table 5.2.1.

From Table 5.2.1, it is evident that for the 1:40 000 scale, there is a strong degree of positive correlation between the subjective interpretability and the local variance at

each ground pixel size. Of interest are the relatively high values for the interpretative elements of texture (0.6325), tone (0.9487) and pattern (0.9487). This reinforces the premise that local variance is an estimator for image texture and pattern. For the 1:15 000 scale, the consistency of correlation decreases. For tone and pattern, the correlation is positive at 0.400 and 0.7746, respectively. However, for texture, there is a negative correlation value of -0.400. This is explained by the fact that most interpreters chose 0.45 metre ground pixel as preferable for interpretation rather than 1.8 metres where local variance is at a maximum.

Table 5.2.1 Correlation of local variance with interpretability of features and elements

feature or element	local variance at 1:40 000 (level of significance)	local variance at 1:15 000 (level of significance)
VET component	0.2108 (0.395)	-0.3162 (0.342)
ESA1 vs. ESA2	0.3162 (0.342)	0.0000 (0.500)
Logging roads	0.7379 (0.131)	0.8944 (0.053)
Logging road trails	1.0000 (0.000)	-0.9487 (0.026)
Texture	0.6325 (0.184)	-0.4000 (0.300)
Tone	0.9487 (0.026)	0.4000 (0.300)
Pattern	0.9487 (0.026)	0.7746 (0.113)

The high positive correlation between subjective and objective measures for the 1:40 000 scale is indicative of the potential for automated tasks to aid in the processing and preparation of digital images for interpretation. If texture can be emulated by a local variance indicator, as seen with the strong positive relationship of the 1:40 000 stereomodel subscenes, then scales of interpretable texture can be selected automatically. This can efficiently decrease time consumed in manually selecting appropriate resolution. It was also help predict a resolution at which images can be confidently captured, stored and transmitted without loss in interpretability. This is to say that if the appropriate resolution for interpretability is known, then images can be acquired at a greater scale or finer resolution, bearing in mind that the particular processing techniques relating to the project at hand will cause some loss in resolution. The method developed here of verifying local image variance as an indicator of subjective image interpretability at various resolutions, is of value to the applications research in digital imagery.

5.3 Limitations and Avenues of Future Research

Limitations of this research are observable in the data and the subjective viewing procedure. These limitations underscore the concepts of research validity and reliability but also indicate avenues of further investigation.

Validity can be examined through the construct of the research, and the internal and external correctness and credibility of the research (Mitchell and Jolley 1988, Maxwell 1996). Construct validity questions the variables which are involved in an investigation; internal validity questions whether one variable actually had effect on the other; external validity questions whether the change in one variable would have the same effect outside of a study. Reliability refers the degree to which the same score would result if the subject were re-tested (Mitchell and Jolley 1988).

Research constructs included measuring interpretability as a function of resolution. For the series of images where only resolution was a changing factor, the measured variables maintain the internal validity, however, for the orthophotos, the introduction of changing scale as a variable which controls interpretability had a source of error introduced by the fact that the data was multi-temporal: there was a discrepancy in the dates of the photos of different scale.

Internal validity was limited with respect to the photo interpreters: an issue that was not addressed was the consistency between photo interpreters and within photo interpreters. Additionally, one of the photo interpreters was not certified. Reliability was not measured as to the results of photo interpretation ranking. Ideally, consistency between photo interpreters and within interpreters would be measured before the image viewing procedure. It should be noted that one of the difficulties which exists in measuring consistency within interpreters is that if the same image is viewed then a cognitive structure develops (Lloyd 1995).

External validity was limited to the study area and the particular group of photo interpreters. No extension was made beyond the study area to test the results. The subjective viewing procedure was limited by the number of viewers and also by the available viewing time of the digital images. Only a handful of certified photo interpreters was available under the budget for the project. Certainly, in an improved study, as large a sample number of interpreters as possible would be employed: the theoretical ideal being all photo interpreters. These factors are obvious limitations to the subjective viewing of the images and to its applications beyond the area of the study.

Avenues of future research therefore include a more comprehensive approach to subjective image viewing as well as an extension of the method to other land use areas. Would testing and controlling the differences between photo interpreters lead to significant differences in the results? What results would precipitate if the imagery were of the same date? The method has reasonable results for the study area, but can it be used for other land uses such as urban areas and agricultural lands?

The limitations of time, finance and image availability constrained the investigation. These limitations, however, signal great potential for areas of future research.

CHAPTER 6

CONCLUSION

With recent advances in the capture, storage and transmission of digital imagery, it is of paramount importance that the information which the image is purported to convey is not conceded. Although lower resolution imagery increases the efficiency of the image viewing and manipulation procedures, an appropriate resolution exists at which image features are sufficiently interpretable, and yet which dismisses unnecessary excess of finer resolution for the application at hand.

This study investigated the most appropriate resolution for digital orthophotos and stereomodels for forestry purposes through a subjective interpretation procedure. It also examined the use of average local variance as an indicator of texture. Additionally, the use of the average local variance was examined as its suitability to aid in the selection of the most appropriate resolution.

Results of the subjective viewing indicate that for viewing epipolar resampled models, the most appropriate range of resolution is 0.9 to 1.8m, or average equivalent scale of 1:4 000. The local variance has a maximum within this range. Results from the subjective viewing of the orthophotos indicate that there is little difference in on-screen interpretability of equivalent scales of 0.625 and 2m pixels. The local variance peaks at 2m or beyond, indicating that maximum scene variance is attained at a greater pixel size than those viewed by the interpreters.

It is therefore recommended that image viewing, whether as on-screen digital orthophotos or as epipolar resampled stereomodels, that the equivalent pixel size be less than or equal to 2m. For 1:15 000 imagery, a scan rate of 120 microns would result in a ground pixel size of 1.8m; for 1:40 000, a rate of 45 microns would result in a 1.8m ground pixel size; and for 1:70 000 imagery, a scan rate of 22.5 microns would result in a 1.575m pixel. It is always advisable to scan at rates slightly lower than the recommended rate, particularly if there is to be any significant image manipulation thereafter.

Comparison of the results of the textural algorithm to the subjective results indicate that a local variance computation can roughly emulate subjective interpretation and therefore can be used as an indicator of appropriate resolution selection based on a textural approach. This finding is valuable in the world of digital imagery. It points to the ability of the researcher to select a likely resolution of suitable interpretability based on the local variance of an image. The indication of the most appropriate resolution will by-pass the need for the production of unduly large file sizes which press limitations on storage, transmission and retrieval processes.

The method developed in this study using local variance as a surrogate for defining the suitable resolution has potential to aid the researcher in the selection of image resolution, but does not replace the invaluable skills of the photo interpreter. This underscores the synergistic approach of the human role in the rapidly advancing digital world.

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APPENDIX A
GENERAL INFORMATION GIVEN TO PHOTO
INTERPRETERS PRIOR TO IMAGE VIEWING

Triathlon File: _____

MoF File: _____

UVic File: thesis3

Research Project - Digital Imagery

Here is a package that will be distributed again on the day of image viewing hosted by Triathlon Mapping Corporation for the Ministry of Forests. The schedule of events is detailed below. Please review it before arriving at Triathlon so that you will be familiar with the schedule. This will facilitate the operations so that there will be no delays (and you will get back to the Island on time!) Please be familiar with it and **DO NOT HESITATE TO CALL BEFORE WEDNESDAY** if any element is unclear to you.

PROJECT OBJECTIVE:

The main objective of this project is to determine which scale and scan rate is the most appropriate for the interpretation of forestry related features. The prints and images which you will view are created from different scales. As experts in your field, we appreciate your participation and quality interpretations as part of the project. The prestratification aims to enhance your ability to interpret the images at various scales as well as to provide a set of lines which can be compared for accuracy. Your verbal responses to the questions we will ask will provide for us a subjective indication of the most useful scale. Not all questions will be asked for all images; only questions which are relevant to the area covered by the image will be asked. Your responses will be limited to:

- 1 - Extremely Well
- 2 - Well
- 3 - Adequately
- 4 - Poorly
- 5 - Extremely Poorly

This scale can also be considered your *confidence in your interpretation* with respect to the subject of the questions. Example questions are as follows:

How well could you prestratify the area?

How well can you discriminate timber types?

PI (Pure Pine) vs. Mixed Pine (PI and Pa)

How well can you classify non-productive lands?

NPBu (Burn) vs NPOr (Open Range) vs NPurban vs NP with Species

How well can you see >10% differences in crown closure?

How well can you see 50 year differences between stand age?

How well can you identify evidence of disturbances (logging, insect, disease, etc)?

How well can you distinguish between VET component and multi-layered stand with respect to crown closure, age and height?

How well can you identify trails and logging roads?

(Note: For digital images, you will also be asked to specify which zoom factor is most appropriate.)

INTERPRETER TASKS:

You will be asked to:

- (1) Interpret a 1:70 000 stereomodel print with a stereoscope and pens (10 minutes).
- (2) Prestratify orthophoto prints and respond to questions (1.5 hours).
- (3) Digitally prestratify orthophoto images and respond to questions (1.5 hours).
- (4) Digitally prestratify stereomodels and respond to questions (1.5 hours).
- (5) Take home and complete a comment form.

APPENDIX B
SAMPLE SHEET OF QUESTIONNAIRE FOR VIEWING
DIGITAL ORTHOPHOTOS FOR A PHOTO INTERPRETER

IMAGE: 1:20k (from 1:80k)

AREA: left side

- | | |
|--|--------------|
| 1. How well could you prestratify the area? | 1 2 3 4 5 ne |
| 2. How well can you discriminate timber types?
Pl (Pure Pine) vs. Mixed Pine (Pl and Pa) | 1 2 3 4 5 ne |
| 3. How well can you classify non-productive lands?
NPBu (Burn) vs NPOr (Open Range) vs NPurban vs NP with Species | 1 2 3 4 5 ne |
| 4. How well can you see >10% differences in crown closure? | 1 2 3 4 5 ne |
| 5. How well is texture defined?
Tone? | 1 2 3 4 5 ne |
| Pattern? | 1 2 3 4 5 ne |

MOST USEFUL ZOOM LEVEL TO INTERPRET THIS IMAGE ____

IMAGE: 1:20k (from 1:40k)

AREA: centre

- | | |
|--|--------------|
| 1. How well could you prestratify the area? | 1 2 3 4 5 ne |
| 2. How well can you discriminate timber types?
Pl (Pure Pine) vs. Mixed Pine (Pl and Pa) | 1 2 3 4 5 ne |
| 3. How well can you classify non-productive lands?
NPBu (Burn) vs NPOr (Open Range) vs NPurban vs NP with Species | 1 2 3 4 5 ne |
| 4. How well can you see >10% differences in crown closure? | 1 2 3 4 5 ne |
| 5. How well can you see 50 year differences between stand age? | 1 2 3 4 5 ne |
| 6. How well can you identify evidence of disturbances
(logging, insect, disease, etc)? | 1 2 3 4 5 ne |
| 7. How well is texture defined
Tone? | 1 2 3 4 5 ne |
| Pattern? | 1 2 3 4 5 ne |
| | 1 2 3 4 5 ne |

MOST USEFUL ZOOM LEVEL TO INTERPRET THIS IMAGE ____

IMAGE: 1:20k (from 1:15k)**AREA: right**

- | | | | | | | |
|--|---|---|---|---|---|----|
| 1. How well could you prestratify the area? | 1 | 2 | 3 | 4 | 5 | ne |
| 2. How well can you discriminate timber types?
Pl (Pure Pine) vs. Mixed Pine (Pl and Pa) | 1 | 2 | 3 | 4 | 5 | ne |
| 3. How well can you classify non-productive lands?
NPBu (Burn) vs NPOr (Open Range) vs NPurban vs NP with Species | 1 | 2 | 3 | 4 | 5 | ne |
| 4. How well can you see >10% differences in crown closure? | 1 | 2 | 3 | 4 | 5 | ne |
| 5. How well can you see 50 year differences between stand age? | 1 | 2 | 3 | 4 | 5 | ne |
| 6. How well can you identify evidence of disturbances
(logging, insect, disease, etc)? | 1 | 2 | 3 | 4 | 5 | ne |
| 7. How well can you distinguish between VET component
and multi-layered stand with respect to crown closure,
age and height? | 1 | 2 | 3 | 4 | 5 | ne |
| 8. How well is texture defined?
Tone? | 1 | 2 | 3 | 4 | 5 | ne |
| Pattern? | 1 | 2 | 3 | 4 | 5 | ne |

MOST USEFUL ZOOM LEVEL TO INTERPRET THIS IMAGE _____

IMAGE: 1:10k (from 1:80k)**AREA: left side**

- | | | | | | | |
|--|---|---|---|---|---|----|
| 1. How well could you prestratify the area? | 1 | 2 | 3 | 4 | 5 | ne |
| 2. How well can you discriminate timber types?
Pl (Pure Pine) vs. Mixed Pine (Pl and Pa) | 1 | 2 | 3 | 4 | 5 | ne |
| 3. How well can you classify non-productive lands?
NPBu (Burn) vs NPOr (Open Range) vs NPurban vs NP with Species | 1 | 2 | 3 | 4 | 5 | ne |
| 4. How well can you see >10% differences in crown closure? | | | | | | |
| 5. How well is texture defined
Tone? | 1 | 2 | 3 | 4 | 5 | ne |
| Pattern? | 1 | 2 | 3 | 4 | 5 | ne |

MOST USEFUL ZOOM LEVEL TO INTERPRET THIS IMAGE _____

IMAGE: 1:10k (from 1:40k)**AREA: centre**

- | | | | | | | |
|--|---|---|---|---|---|----|
| 1. How well could you prestratify the area? | 1 | 2 | 3 | 4 | 5 | ne |
| 2. How well can you discriminate timber types?
Pl (Pure Pine) vs. Mixed Pine (Pl and Pa) | 1 | 2 | 3 | 4 | 5 | ne |
| 3. How well can you classify non-productive lands?
NPBu (Burn) vs NPOr (Open Range) vs NPurban vs NP with Species | 1 | 2 | 3 | 4 | 5 | ne |
| 4. How well can you see >10% differences in crown closure? | 1 | 2 | 3 | 4 | 5 | ne |
| 5. How well can you see 50 year differences between stand age? | 1 | 2 | 3 | 4 | 5 | ne |
| 6. How well can you identify evidence of disturbances
(logging, insect, disease, etc)? | 1 | 2 | 3 | 4 | 5 | ne |
| 7. How well is texture defined?
Tone? | 1 | 2 | 3 | 4 | 5 | ne |
| Pattern? | 1 | 2 | 3 | 4 | 5 | ne |

MOST USEFUL ZOOM LEVEL TO INTERPRET THIS IMAGE _____

IMAGE: 1:10k (from 1:15k)**AREA: right**

- | | | | | | | |
|--|---|---|---|---|---|----|
| 1. How well could you prestratify the area? | 1 | 2 | 3 | 4 | 5 | ne |
| 2. How well can you discriminate timber types? | | | | | | |
| Pl (Pure Pine) vs. Mixed Pine (Pl and Pa) | 1 | 2 | 3 | 4 | 5 | ne |
| 3. How well can you classify non-productive lands? | | | | | | |
| NPBu (Burn) vs NPOr (Open Range) vs NPurban vs NP with Species | 1 | 2 | 3 | 4 | 5 | ne |
| 4. How well can you see >10% differences in crown closure? | 1 | 2 | 3 | 4 | 5 | ne |
| 5. How well can you see 50 year differences between stand age? | 1 | 2 | 3 | 4 | 5 | ne |
| 6. How well can you identify evidence of disturbances | | | | | | |
| (logging, insect, disease, etc)? | 1 | 2 | 3 | 4 | 5 | ne |
| 7. How well can you distinguish between VET component | | | | | | |
| and multi-layered stand with respect to crown closure, | | | | | | |
| age and height? | 1 | 2 | 3 | 4 | 5 | ne |
| 8. How well is texture defined? | 1 | 2 | 3 | 4 | 5 | ne |
| Tone? | 1 | 2 | 3 | 4 | 5 | ne |
| Pattern? | 1 | 2 | 3 | 4 | 5 | ne |

MOST USEFUL ZOOM LEVEL TO INTERPRET THIS IMAGE _____

IMAGE: 1:5k (from 1:80k)**AREA: left side**

- | | | | | | | |
|--|---|---|---|---|---|----|
| 1. How well could you prestratify the area? | 1 | 2 | 3 | 4 | 5 | ne |
| 2. How well can you discriminate timber types? | 1 | 2 | 3 | 4 | 5 | ne |
| Pl (Pure Pine) vs. Mixed Pine (Pl and Pa) | | | | | | |
| 3. How well can you classify non-productive lands? | 1 | 2 | 3 | 4 | 5 | ne |
| NPBu (Burn) vs NPOr (Open Range) vs NPurban vs NP with Species | | | | | | |
| 4. How well can you see >10% differences in crown closure? | 1 | 2 | 3 | 4 | 5 | ne |
| 5. How well is texture defined? | 1 | 2 | 3 | 4 | 5 | ne |
| Tone? | 1 | 2 | 3 | 4 | 5 | ne |
| Pattern? | 1 | 2 | 3 | 4 | 5 | ne |

MOST USEFUL ZOOM LEVEL TO INTERPRET THIS IMAGE _____

IMAGE: 1:5k (from 1:40k)**AREA: centre**

- | | | | | | | |
|--|---|---|---|---|---|----|
| 1. How well could you prestratify the area? | 1 | 2 | 3 | 4 | 5 | ne |
| 2. How well can you discriminate timber types? | | | | | | |
| Pl (Pure Pine) vs. Mixed Pine (Pl and Pa) | 1 | 2 | 3 | 4 | 5 | ne |
| 3. How well can you classify non-productive lands? | | | | | | |
| NPBu (Burn) vs NPOr (Open Range) vs NPurban vs NP with Species | 1 | 2 | 3 | 4 | 5 | ne |
| 4. How well can you see >10% differences in crown closure? | 1 | 2 | 3 | 4 | 5 | ne |
| 5. How well can you see 50 year differences between stand age? | 1 | 2 | 3 | 4 | 5 | ne |
| 6. How well can you identify evidence of disturbances | | | | | | |
| (logging, insect, disease, etc)? | 1 | 2 | 3 | 4 | 5 | ne |
| 7. How well is texture defined? | 1 | 2 | 3 | 4 | 5 | ne |
| Tone? | 1 | 2 | 3 | 4 | 5 | ne |
| Pattern? | 1 | 2 | 3 | 4 | 5 | ne |

MOST USEFUL ZOOM LEVEL TO INTERPRET THIS IMAGE _____

IMAGE: 1:5k (from 1:15k)

AREA: right

- | | | | | | | |
|--|---|---|---|---|---|----|
| 1. How well could you prestratify the area? | 1 | 2 | 3 | 4 | 5 | ne |
| 2. How well can you discriminate timber types?
Pl (Pure Pine) vs. Mixed Pine (Pl and Pa) | 1 | 2 | 3 | 4 | 5 | ne |
| 3. How well can you classify non-productive lands?
NPBu (Burn) vs NPOr (Open Range) vs NPurban vs NP with Species | 1 | 2 | 3 | 4 | 5 | ne |
| 4. How well can you see >10% differences in crown closure? | 1 | 2 | 3 | 4 | 5 | ne |
| 5. How well can you see 50 year differences between stand age? | 1 | 2 | 3 | 4 | 5 | ne |
| 6. How well can you identify evidence of disturbances
(logging, insect, disease, etc)? | 1 | 2 | 3 | 4 | 5 | ne |
| 7. How well can you distinguish between VET component
and multi-layered stand with respect to crown closure,
age and height? | 1 | 2 | 3 | 4 | 5 | ne |
| 8. How well is texture defined? | 1 | 2 | 3 | 4 | 5 | ne |
| Tone? | 1 | 2 | 3 | 4 | 5 | ne |
| Pattern? | 1 | 2 | 3 | 4 | 5 | ne |

MOST USEFUL ZOOM LEVEL TO INTERPRET THIS IMAGE _____

**APPENDIX C
COPY OF PRELIMINARY RESULTS
SUBMITTED TO MINISTRY OF FORESTS**

UVIC file: Geogthes3

PRELIMINARY RESULTS OF DIGITAL IMAGE VIEWING

G. Bergmans

Monday, March 25, 1996

Introduction and General Methods

1. Stereomodel Viewing
2. Digital Orthophoto Viewing
3. Enhancements of Digital Orthophotos
4. Prestratification of Stereomodels

Conclusions

INTRODUCTION AND GENERAL METHODS

This is a preliminary report to synthesis the results of the image viewing which took place at Triathlon Mapping Corporation, Burnaby on March 13 and 14, 1996. Six certified photo interpreters (PI's) and one non-certified PI attended the interpretation sessions.

The PI's were asked the following questions as they viewed the images. They gave a verbal response on a scale of 1 to 5. This response was recorded. If the PI could not find evidence of the feature or element on the image, his response was n/e. If he could not interpret the feature or element, or considered it no applicable, he answered n/a. If a PI answered less confidently and gave a range, such as "2.5 to 3", the lower value was kept.

QUESTIONS:

1. How well can you distinguish between VET component and multi layered stand?
2. How well can you distinguish between forest and non-forested areas?
3. How well can you distinguish between ESA1 and ESA2?
4. How well can you identify logging roads?
5. How well can you identify logging road trails?
6. How well is texture defined?

Tone?

Pattern?

(i.e., do you lose texture, tone and pattern in this image because of blockiness?)

RANKING SCALE:

- 1 - Extremely Well
- 2 - Well
- 3 - Adequately
- 4 - Poorly
- 5 - Extremely Poorly
- n/e - No Evidence
- n/a - Not Applicable or Not Interpretable.

The results of stereomodel viewing, digital orthophoto viewing, orthophoto enhancements and prestratification of stereomodels is described in this report.

1. STEREOMODEL VIEWING

Methods:

The PI's viewed 5 different equivalent pixel sizes of the epipolar resampled models in stereo, using the crystal lenses. They viewed the images in a sequence of decreasing equivalent pixel sizes. The images were enhanced using a contrast stretch after the initial overview. The enhancement was either an equalization over the full histogram or a straight linear clip followed by a gamma function. After viewing all the equivalent pixel sizes, the PI's were asked to rate which equivalent pixel size was, in their opinions, best for over photo interpretation (mainly stratification).

Results:

The equivalent scale which was awarded the highest rank by each interpreter was tabulated for each feature or photo interpretation element. The cumulative ranks are listed below.

Table 1.1 Number of times the highest rank was attributed to each equivalent scale for each feature or interpretation element. Original image was the 1:40000 stereomodel, scanned at 7.5 microns.

Zoom Level	32	8	4	2	1
Equivalent scale	1:32000	1:8000	1:4000	1:2000	1:1000
Equivalent pixel size (microns)	240	60	30	15	7.5
VET component			3	4	
Forest vs. Non Forest		2	3		
ESA1 vs. ESA2	2		3	2	
Logging roads		5	2		
Logging road trails		2	4	1	
Texture			4	3	
Tone		2	3	2	
Pattern		1	5	1	

Table 1.2 Number of times the highest rank was attributed to each equivalent scale for each feature or interpretation element. Original image was the 1:15000 stereomodel, scanned at 7.5 microns.

Zoom Level	16	8	4	2	1
Equivalent scale	1:6000	1:3000	1:1500	1:800	1:400
Equivalent pixel size (microns)	120	60	30	15	7.5
VET component		3	2	2	
ESA1 vs. ESA2	3			3	
Logging roads	3	3			
Logging road trails		1	3	3	
Texture		2	4	1	
Tone	1	3	2		
Pattern	2	2	2	1	

Discussion:

From Table 1.1, it is evident that the 1:4000 scale is consistently chosen as the best scale at which to view the features and at which to interpret the image elements from the 1:40 000 scale. This is an equivalent pixel size of 30 microns. For the 1:15 000 image, the most useful scale for the interpretation of features and the utility of the photo interpretation elements is in the range of 1:6000 to 1:1500 (Table 1.2). This range of scales includes 1:4000 scale, which is the scale which was derived from the Table 1.1. To view stereomodels, therefore, a 1:4000 scale is best for viewing the models on screen.

2. ORTHOPHOTO PRINT VIEWING

Two orthophotos were created from 1:80 000 imagery at ground pixel sizes of 2m and 0.625 m. Two orthophotos were also created from 1:40 000 at the above pixel sizes. Two orthophoto mosaics were created from 1:15 000 imagery at the same pixel sizes. The photo interpreters viewed the six digital orthophotos on screen with zoom levels up to 4x, of which the equivalent scale is 1:7200. The photo interpreters were asked to rate the interpretability of certain forestry related features the interpretability of certain photo interpretation elements. The orthophotos were compared in two ways: (1) holding the pixel size constant and comparing original image scales, (2) holding the original image scale constant and comparing pixel size.

Scale-wise comparison:

The scale from which the orthophotos was made were compared maintaining constant pixel size. The scale which was awarded the highest rank by each interpreter was tabulated for each feature or photo interpretation element. The cumulative ranks are listed below (Tables 2.1 and 2.2).

Table 2.1 Number of times the highest rank was attributed to each original scale for each feature or interpretation element. The pixel size was constant at 2m.

	1:80000	1:40000	1:15000
	2m	2m	2m
PRE		2	3
TIMBER TYPES	1	3	
NP LNDS	1	2	1
>10 DIFF CC	1	3	
TEXTURE		6	1
TOPE		4	
PATTERN		4	1

Table 2.2 Number of times the highest rank was attributed to each original scale for each feature or interpretation element. The pixel size was constant at 0.625m.

	1:80000	1:40000	1:15000
	0.625m	0.625m	0.625m
PRE	1	4	
TIMBER TYPES	1	4	1
NP LNDS	1	3	
>10 DIFF CC		3	1
TEXTURE		3	1
TOPE	1	3	1
PATTERN		2	2

Pixel-wise comparison:

The pixel sizes were compared maintaining constant the scale from which the image was derived. The pixel size which was awarded the highest rank by each interpreter was tabulated for each feature or photo interpretation element. The cumulative ranks are listed below (Tables 2.3 -2.5).

Table 2.3 Number of times the highest rank was attributed to pixel size for each feature or interpretation element. The scale from which the image was derived was constant (1:80 000)

	1:80000	
	2m	0.625m
PRE		6
TIMBER TYPES	1	1
NP LNDS	4	3
>10 DIFF CC	5	
TEXTURE	1	5
TONE	3	3
PATTERN	2	1

Table 2.4 Number of times the highest rank was attributed to pixel size for each feature or interpretation element. The scale from which the image was derived was constant (1:40 000).

	1:40000	
	2m	0.625m
PRE		5
TIMBER TYPES	3	2
NP LNDS	3	3
>10 DIFF CC	1	2
TEXTURE	4	3
TONE	2	
PATTERN	4	3

Table 2.5 Number of times the highest rank was attributed to pixel size for each feature or interpretation element. The scale from which the image was derived was constant (1:15 000).

	1:15000	
	2m	0.625m
PRE	5	2
TIMBER TYPES	2	3
NP LNDS	3	2
>10 DIFF CC	1	3
TEXTURE	1	2
TONE	4	3
PATTERN	2	3

Discussion:

From Table 2.1 and 2.2, it is evident that the 1:40 000 scale is consistently chosen as the best scale from which to create orthophotos, whether the final pixel size be 2m or 0.625 m.

From Table 2.3, it is concluded that, for prestratification, a pixel size of 0.625 is rated more interpretable more frequently at the 1:80 000 original scale. Texture interpretation is likewise rated higher more often at a 0.625 metre pixel size. In contrast to this finding, for the interpretation of non-productive lands, of greater than 10 % differences in crown closure, and of pattern, a 2 metre pixel size is consistently rated higher in interpretability.

From Table 2.4, the highest rank for 1:40 000 was more often attributed to photo interpretation elements of texture, tone and pattern and for the interpretation of timber type differences at the 2 metre pixel, but for prestratification and the interpretation of greater than 10 % differences in crown closure, a 0.625 metre pixel was more often given a higher rating.

From Table 2.5, the highest rank was more often attributed to the 0.625 metre pixel image for interpretation of timber type differences, greater than 10 % differences in crown closure and for the photo interpretation elements of texture and pattern. In contrast to this, the 2 m metre pixel is ranked higher more frequently for prestratification, the interpretation for distinguishing between productive and non-productive lands and for the interpretation of tone.

To combine the results from the scale-wise and pixel-wise comparison, an image with interpretable timber type differences and with highly rated photo interpretation elements is the 1:40 000 at the 2 metre pixel size. For prestratification and for greater than 10% differences in crown closure, the 0.625 metre pixel is given a higher rating more frequently. The results indicate that there is a greater consensus on the differences between the images derived from different scaled imagery than from the output pixel size.

Conclusion:

From this preliminary synthesis of the data which was collected from the viewing of the images, it is concluded that the issue of interpretability is dependent on original scale. The utility of the scale is not as critical when dealing with output pixel sizes at the given pixel resolutions.

3. ENHANCEMENTS OF DIGITAL ORTHOPHOTOS

The interpreter was asked to view the effect of enhancements on orthophoto images.

i. Three orthophotos with pixel ground sizes of 0.625 metres, were displayed on screen at a scale of 1:12 000. Each orthophoto had been generated from of a different scale: 1:80 000, 1:40 000 and 1:15 000. As a full equalization stretch was applied to each orthophoto, the interpreter reported what level of contrast was best for the interpretability of that image. The results are reported below (Table 3.1). Once the all the images were enhanced to maximize interpretability, the interpreter was asked to rank which image he preferred.

Table 3.1 Image ranking of preference of original image scale.

original image	pixel size (m)	contrast value	rank
1:15 000	0.625	c = 0.28	1
1:40 000	0.625	c = 0.29	2
1:80 000	0.625	c = 0.03	3

(Display at 1:12000)

The PI ranked the image which was mosaicked together from 1:15 000 imagery the highest, followed by the orthophoto created from the 1:40 000 imagery. The last ranked image was that one created from the

1:80 000 imagery.

ii. Two orthophotos were displayed on screen at a scale of 1:12000. Both orthophotos had been generated from 1:80 000 imagery. Full equalization stretches were performed as in the previous experiment and the images were compared.

Table 3.1. Image ranking of preference of pixel size.

original image	pixel size (m)	contrast value	rank
1:80 000	2	c = 0.08	1
1:80 000	0.625	c = 0.03	2

(Display at 1:12 000)

The results indicate that the interpreter preferred the enhanced 2 metre pixel size over the enhanced 0.625 metre pixel size (Table 3.2).

iii. Three orthophotos with pixel ground sizes of 2 metres, were displayed on screen at a scale of 1:12 000. Each orthophoto had been generated from of a different scale: 1:80 000, 1:40 000 and 1:15 000. As a full equalization stretch was applied to each orthophoto, the interpreter reported what level of contrast was best for the interpretability of that image. The results are reported below (Table 3.3). Once the all the images were enhanced to maximize interpretability, the interpreter was asked to rank which image he preferred.

Table 3.3 Image ranking of original scales at 2 meter pixels.

original image	pixel size (m)	contrast value	rank
1:15 000	2	c = 0.09	1
1:40 000	2	c = 0.08	2
1:80 000	2	c = 0.04	3

(Display at 1:12 000)

The PI ranked the image which was mosaicked together from 1:15 000 imagery the highest, claiming more detail, followed by the orthophoto created from the 1:40 000 imagery. The last ranked image was that one created from the 1:80 000 imagery.

iv. Two 1:80 000 orthophotos were redisplayed on screen at a scale of 1:12 000. Full equalization stretch was performed on the imagery with 2 metre pixel, and a linear clip (34 minimum, 250 maximum) followed by a gamma was performed on the 0.625 metre image. Subscenes were compared a scale of 1:12 000 (upper right hand corner = 745, 835; lower left hand corner = 1781, 2316). The images were compared Table 3.4).

Table 3.4 Image ranking of pixel sizes from 1:80 000 imagery.

original image	pixel size (m)	contrast value	rank
1:80 000	2	gamma = 1.13	1
1:80 000	0.625	c = 0.04	2

(Display at 1:12 000)

The results indicate that the interpreter consistently preferred the 2 metre pixel size over the 0.625 metre pixel size.

v. The two orthophotos (1:80 000 @ 2m and 1:80 000 @ 0.625m) were compared in subscenes of increasing scale to determine where the threshold of hypothesised increased interpretability in the 0.625m image lay

(Table 3.5).

Table 3.5 Determining threshold of image interpretability with respect to pixel size.

<i>scale</i>	<i>1:80000@2 m</i>	<i>PI comments</i>	<i>1:80000@0.62 5m</i>	<i>PI comments</i>
1:9700	same		same	
1:8600	1	clearer tree crowns on 2m image	2	crowns appeared fuzzier
1:7600	same		same	
1:6000	same		same	
1:5700	same		same	
1:4900	same		same	PI was looking for finest detail, i.e., crowns, to determine interpretability
1:3600	2	PI started to lose fine features such as creeks		
1:3300	2		1	
1:2600	2		1	Both images started to lose interpretability
1:2200	2		1	
1:1900	2	Blockiness of pixel evident	1	Both images "useless for stands"
1:1500	2		1	Overall, 0.625 was preferred image

Results indicate that the interpreter could detect the difference in pixel size as it influences interpretability at the 1:3600 equivalent scale. This sub-study, along with parts 2 and 4 above, indicate that the 2 metre pixel output is sufficient for orthophoto production, as the difference is not detected until the equivalent scale is 1:3600.

vi. Interpretability enhancement for features in shadow:

Three orthophotos which had all been generated from 1:15 000 imagery were displayed on screen. Each orthophoto had differing ground pixel sizes: 2m, 1m and 0.625 metres. Subscenes of shadowed areas were generated. These subscenes were displayed at 1:4500, followed by smaller scales. At the smallest scale, enhancements directed by the PI were performed. The interpreter reported what scale was best for the interpretability of features in shadow. The results are reported below (Table 3.6).

Table 3.6 Comparison of enhancements in shadow.

<i>equivalent scale</i>	<i>Pixel Size</i>		
	<i>0.625m</i>	<i>1m</i>	<i>2m</i>
@1:4500	no visibility	no visibility	no visibility
@1:2200	no visibility	no visibility	pixels visible
@1:1100	ranked 1	ranked 2	blocky; no recognition

At 1:1100 and at greater than 1:1100, the interpreter could make distinctions in the shadowed area on the 0.625m pixel and 1m pixel image (Table 3.7). With linear clips enhancements, the PI

claimed that he could interpret bare rock, low shrubs and moss.

Table 3.7 Comparison of enhancements in shadow at greater than 1:1100 scale.

ground pixel size	enhancement description	Interpretability comments
0.625m	211 max. linear clip. No gamma stretch.	Can see in shadows. Preferred, but for forestry related information content, tones were too similar
1m	210 max. linear clip. No gamma stretch.	Bare rock - white. Low shrubs and lichen - "Probably identifiable"
2m	211 max. Gamma = 1.04	Seen in shadow: moss, rock, shrubs

(Display at 1:1100 or greater)

These results indicate that the use of enhancements in shadowed areas is useful for interpretation of features in these areas.

4. PRESTRATIFICATION OF STEREOMODELS

The interpreter was asked to delineate a prestratification between two stand types. At a scale of 1:12000, the interpreter felt "too far back". He could not distinguish between species, but could still prestratify on the basis of texture and crown closure. At a scale of 1:6000, the interpreter felt more confident in his ability to prestratify on the basis of texture, tone and pattern. At 1:3000, the interpreter felt the most confident in his delineation. His approach in this particular delineation at this scale was to draw the edge of the fine texture rather than coarse texture. At 1:1500, he began to see the edge of transition between fine and coarse texture. He lumped the coarse texture together and the outside polyline defined the inside stand. The interpreter felt much less confident at this scale as the edges of the stands became more convoluted and therefore less immediately interpretable.

Table 4.1. Confidence level ranking in which prestratification would generate the best map.

ranking	scale	equivalent pixel size
1	1:3000	60 microns
2	1:6000	120 microns
3	1:1500	30 microns
4	1:12000	240 microns

Results indicate that the best scale at which to prestratify is 1:3000. The second ranked scale is 1:6000. This is consistent with the results found in Part 1, where the interpreters' consensus was that 1:4000 is the best overall scale for working with digital stereomodels.

CONCLUSIONS

This preliminary report summarizes the results of the image viewing of digital stereomodels, digital orthophotos and enhancement of digital orthophotos as well as the prestratification of stereomodels. The results indicate that interpretability of certain features is scale dependent and that the most appropriate resolution is one in which the 1:1 screen resolution of the pixel reflects an approximate 1:4000 scale. Additionally, enhancements are useful to derive interpretability from shadowed areas.

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President's Award, Lakehead University	1994
NSERC University Undergraduate Student Research Award	summer 1993
Canada Scholar	1990 - 1992
Academic All-Canadian Athlete	1990 - 1992

Figure 3.4.2.1 Orthophoto (1:15 000 data)



North part
RC 10 12 INCH

Photo Scale 1:15000 Final Scale 1:20000 Scan Res. Microns - 30 Pixel Size Metres 2

South part
RC 10 12 INCH
© 1991 0 40

Figure 3.4.1.2 Stereomates of BC81122263/4 (1:40 000)



Figure 3.4.1.1 Stereomates of BC91169248/9 (1:15 000)



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Title of Thesis:

Estimating the Appropriate Resolution for the Interpretation of Digital Images for Forestry Purposes Using a Texture Algorithm

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April 23, 1997