COMPUTER-ASSISTED PHOTOINTERPRETATION AIDS TO FOREST INVENTORY MAPPING: SOME POSSIBLE APPROACHES

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ABSTRACT

Aerial photointerpretation is the mainstay of management forest inventories. Accuracy and consistency of this interpretation is a major concern. In addition there is a growing demand for these inventories to provide more quantitative information and data on new forest parameters. Incorporation of computer-assisted techniques to the interpretation process offers potential to improve forest inventories along these fronts.

Techniques must fit into the current infrastructure of mainly small or independent interpreter groups or individuals using 1:10 000 to 1:20 000 scale stereo photography. Computer-assisted interpretation therefore must be based on digitized photography and not necessitate large computers or costly display systems or analysis software. They must be simple to apply and not require inordinate fine tuning or trial and error by the interpreter.

Envisaged techniques are: 1) computer-based interpretation keys, 2) recall and display of ancillary data, 3) computer-assisted interpretation review where interpreters can quickly compare all stands they have interpreted as a given stand type, 4) automated single tree analysis including automated single tree isolation, delineation and species classification, plus estimations of stems/ha, crown closure, crown size, numbers of snags, and gap or patch size distribution , and 5) pixel and area based features such as conventional pixel classification and various texture measures for stands that could be presented visually or numerically to the interpreter as an aid. As well, visual or parametric comparison of current and past inventory photography presents a vast array of possible benefits to interpretation.

Keywords: forest inventory, photointerpretation, remote sensing, image analysis.

RÉSUMÉ

AIDES À LA PHOTO-INTERPRÉTATION ASSISTÉE PAR ORDINATEUR APPLIQUÉE À LA CARTOGRAPHIE DES INVENTAIRES FORESTIERS: DES APPROCHES À ENVISAGER

La réalisation des inventaires forestiers repose en grande partie sur l'interprétation des photos aériennes, laquelle doit être menée avec un degré de précision et d'uniformité élevé. En outre, on espère pouvoir tirer de ces inventaires de plus en plus d'informations quantitatives et de données sur de nouveaux paramètres

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forestiers. Dans ce contexte, l'intégration de techniques d'analyse assistée par ordinateur au procédé d'interprétation offre des possibilités intéressantes pour l'amélioration des inventaires forestiers.

Les techniques envisagées doivent pouvoir s'harmoniser à l'infrastructure actuellement utilisée par les groupes, principalement restreints ou indépendants, d'interprètes ou les individus qui travaillent avec des photos stréréoscopiques prises à une échelle variant entre 1/10 000 et 1/20 000. Par conséquent, la photo-interprétation assistée par ordinateur doit se fonder sur la photographie numérisée et doit pouvoir être réalisée sur de petits ordinateurs à l'aide de systèmes de visualisation et de logiciels d'analyse peu coûteux. Ces techniques doivent être faciles à appliquer et nécessiter un minimum de réglage fin ou de tâtonnements de la part de l'interprète.

Parmi les techniques envisagées, citons : 1) les clés d'interprétation par ordinateur, 2) le rappel et l'affichage de données auxiliaires, 3) l'examen de l'interprétation assistée par ordinateur, permettant aux interprètes de comparer rapidement tous les types de peuplements identifiés, 4) l'analyse automatisée d'arbres individuels, y compris l'isolation et la délimitation automatisées d'arbres, la classification des espèces, l'évaluation du nombre de tiges/hectare, la fermeture du couvert, la dimension du couvert, le nombre de chicots, la répartition des trouées ou des vides par superficie et 5) les fonctions d'analyse par pixel ou par zone, notamment la classification classique par pixel, et diverses mesures de texture des peuplements, présentées visuellement ou numériquement, en tant qu'aides à la photo-interprétation. De plus, la comparaison visuelle ou paramétrique des photos d'inventaires récentes et passées offre de nombreux avantages pour la photo-interprétation.

INTRODUCTION

Air photo interpretation is a basis of most management forest inventories. Stand delineation is a major component. For designation of stand attributes, accuracy, consistency, speed/cost, and level of detail are key factors. In addition, an ability to quantify interpretations to a finer level of detail (precision) and interpret new parameters is becoming increasingly important. There is a growing diversity of issues being addressed in forest management and urgency to make correct management decisions. A consequence is a need for more accurate information on the forest environment and for a much wider suite of data to be available. There would be interest among forest managers and inventory specialists in utilizing new techniques that would meet these demands in a cost effective manner. Automating some of the photointerpretation process and/or providing digital products to aid interpretation is a possible way of improving the effectiveness of an inventory. Recent developments in computer technology (especially reasonable cost display and storage capabilities), digital imagers, digitized photography and computer image analysis techniques make this possibility worth pursuing.

The general approach to developing computer-assisted interpretation aids, at least in the early stages, should be pragmatic. The simple objective should be to add tools that will help the interpreter, not replace any of their function. Expectation should not necessarily be to provide universally similar and correct parameters from the automated systems, just something that is useful and can be easily detected as poor when it does go awry. Initially quite a number of possible methods will have to be explored. Close interaction and suggestions from interpreters is essential. As these are vetted, more scientifically rigorous examination of the methods and results would be conducted. Techniques must fit well into the operational setting where they will be used. In the end, it is hoped that a suite of data processing and analysis techniques would be developed and available to the interpreter to use as they see fit. These would be applied to digitized photographs either by the interpreter groups or centrally. The interpreter would be presented results visually on the computer screen as layers on top of the imagery itself. This would augment the interpretation which may also be done on the screen or more likely on photographic prints of stereo pairs. For certain parameters such as crown closure, the quantitative information from the automated method could be incorporated as the final attribute. Special parameters such as the distribution of canopy gaps (openings) could be extracted at this time or later as needed.

This paper discusses the operational setting into which computer-assisted methods must fit and the consequences of these on system designs. The pros and cons of various general approaches are examined (e.g., single tree interpretation, traditional pixel-based classification, area based techniques, change detection, interpretation keys, review of interpreted stands and ancillary data display). Speculations are presented on expected capabilities and difficulties.

OPERATIONAL SETTING AND CONSIDERATIONS

Any techniques developed must be appropriate to the environment where they will be used. This discussion deals mainly with large inventory mapping projects. It must also be recognized that there is significant amounts of site specific and special purpose interpretation done outside the main inventory mapping environment.

Forest inventory is usually managed by government forest agencies or larger forest companies. Interpretation can be done by in-house experts, but more often than not it is done on contract usually by individuals or small companies. Since the interpretation must be digitized and input into a GIS, there is computer technology and expertise in the production loop. However, there is generally not a large technological infrastructure in place. In addition, the process of photointerpretation is time consuming and a significant cost component of inventory mapping at around 25% (Leckie and Gillis, 1995). As a consequence of this environment, automated interpretation solutions cannot necessitate large computer or costly display systems for the interpreter. They must also be simple and quick to apply, demand little training or additional specialized expertise and not require a lot of fine tuning or trial and error by the interpreter.

Stereo aerial photography at scales of 1:10 000 to 1:20 000 is the mainstay of management inventory. Much of this is black and white photography, although normal colour and colour infrared are not uncommon. At this time there are no other sensors available that can fulfill the full needs of management inventories. Therefore, digitized air photos near this scale must be a significant focus for computer-assisted photointerpretation systems. The absence of multispectral data on B&W photos and at best moderate quality (radiometrically and spectrally) multispectral information from colour films limits the analysis options. For example, species discrimination using spectral data alone especially on B&W photography will be limited. This context does not negate the value in developing systems based on digital multispectral imagery, but indicates that to receive widespread adoption in the current environment they must also be adaptable to get useful information from aerial photography.

Another factor is the quantity of data. Over the areas involved in large inventory projects, data volumes are enormous. For digitized photography, the quantity of digital data depends on the resolution of the digitization. There are useful methods to assist interpretation at lower resolutions 1-3 m, but more sophisticated techniques can utilize high resolution to good benefit. It is the authors' belief that there is good reason, in terms of information content and interpretability, why inventory mapping has evolved to use 1:10 000 to 1:20 000 photography. To maintain the spatial detail of these photos, equivalent resolutions for digital imagery are 15 to 40 cm (Leckie, 1990), and Leckie(1993) showed that 70 cm data was sufficient for interpretation of digital multispectral imagery of a test site in Ontario. Therefore, digitizing in the order of 50 cm is a reasonable assumption for this discussion. Although the total volume of data is large the actual amount an interpreter views at one time is not. Generally 5 to 15 photos are interpreted per day. Reducing this to typical values, interpretation rates are roughly one photo per hour, 400 new hectares and 10 to 15 stands in an hour (Leckie, 1989; data of Leckie and Gillis, 1995). This does not put a strain on modern computer capabilities. Running some of the needed analysis algorithms over large areas is computer intensive, but, since the interpreter does not interpret large areas at a time or within one day, the processing load is almost assuredly amenable to preprocessing on small computers. It however should be noted that if one takes a typical high scan rate of most high-end digitizers (e.g., 7.5 microns which produces an approximately 11 cm pixel size for 1:15 000 scale photographs), a 30 000 by 30 000 pixel image is created and does result in significant processing requirements.

However, for a full interpretation capability "screen real estate" is an important issue. If one wants to duplicate the area seen on a photograph (assuming a 50 cm resolution) a screen of 7000x7000 would be needed. For say 400 ha of new land interpreted on each photo, the screen size is still problematic at (4000x4000). Even an 100 ha stand, which is a large stand but not unusual, needs a display over 2000x2000 pixels. In reality, the interpreter wants to see much more area than this to give context. Well thought out zoom, decimate, overview and double screen (dual monitor) systems need to be considered. Fortunately, in the computer-assisted interpretation application, "full out on-screen interpretation" is not necessary. Display of segments of a scene is sufficient. Regardless, screen real estate and manipulation is a major design factor. Stereo viewing of the data is essential for interpretation. This can be accomplished by stereo viewing of the paper prints of the photos as is traditionally done. However, display of stereo digital imagery for the computer-assisted methods is desirable but not absolutely necessary. There are various methods for displaying stereo imagery on a computer screen, each with pros and cons. None, however, precisely fits the need of full interpretation. Screen "real estate" is an even bigger issue for stereo display.

A key advantage in developing and implementing computer-assisted interpretation versus full interpretation systems is that a whole interpretation system does not need to be implemented at one time for it to be operationally useful. There is a good probability of success with incremental implementation of methods within the limitations of the setting.

ENVISAGED APPROACHES

This section describes possible general approaches and example suites of new interpretation aids and procedures. The operational framework consists of the following. The 1:15 000 scale inventory photography would be digitized to at least 1 m resolution. Interpretation would be done on the paper print photographs in stereo, but assisted by several types of computer based tools. Processing for these tools would be applied to the digitized photographs, most likely centrally, prior to interpretation. The interpreter would display results visually on the computer screen as layers on top of the imagery itself or on simple mylar overlays over the air photo prints. Parameters such as crown closure, gap distribution, number of snags and crown sizes could be extracted at this time as an aid to interpretation or later as needed. These tools will be integrated with on-screen interpretation as it comes into use. The types of tools can be categorized into six categories (1) computer-based interpretation keys, 2) recall and display of ancillary data, 3) computer-assisted interpretation review, 4) automated single tree analysis, 5) pixel and area based techniques, and 6) change detection. The first three essentially display example or ancillary data, the latter three analyze the imagery and provide the interpreter with quantitative data or relevant derived patterns in the imagery.

COMPUTER-BASED INTERPRETATION KEYS

Computer-based interpretation keys could be considered an on-line version of an interpretation manual. Examples of stand types and rules for resolving among difficult to interpret species would be stressed. Dichotomous, selective or elimination keys would be used. Elimination keys are useful to interpreters. They eliminate possibilities based on photointerpretation elements or contextual information such as ecological setting. One option for these keys would be within an expert system structure. The main advantage of the computer-based interpretation keys would be in ease of use. They are of most value in training or for inexperienced interpreters. Experienced interpreters rarely use keys.

RECALL AND DISPLAY OF ANCILLARY DATA

Imagery would be referenced to existing data, such as the previous inventory map and stand attributes, history records of disturbance or silvicultural activities, any ground plots or observations, and key information such as elevation and ecological zone. The interpreter could recall and display this information over the digitized photography on screen. A key component might be example images easily accessed from an on-line library and displayed on a computer screen. This would include digitized representative images based on a variety of source data. For example, image chips around all stands known to be of a certain type via various field plots and visits. Ground photos for the field sites could be digitized, georeferenced and displayed. Large scale photographs of stands of that type could also be displayed when available. Eventually, other information such as that from airborne laser height estimation systems could be incorporated. As well, the old inventory photography could be digitized and displayed alongside an image of the same stand from the current inventory photography. The interpreter could better judge whether the stand has fundamentally changed and better utilize the old stand parameters in the new interpretation. These types of techniques could prove very useful in keeping the interpreter calibrated, accurate and consistent.

COMPUTER-ASSISTED INTERPRETATION REVIEW

The functionality of computer-assisted interpretation review would include capabilities to query and display concurrently all stands already interpreted as a given type. The interpreter could compare these stands and quickly identify anomalous interpretations. Use of stereo systems and techniques could be incorporated for viewing the stands on the screen. One could also envisage using comparisons of image based parameters (derived by the methods described below) among these stands to automatically identify potential outliers and questionable interpretations. This could considerably enhance consistency of interpretation and may indeed be the simplest but most powerful computer-assisted tool. There is, however, a logistical issue with this application. It implies that the interpretation (delineation and attributes), ostensibly on the paper version of the photograph, are routinely digitized and input into a database for access by the system.

AUTOMATED SINGLE TREE ANALYSIS

Automated single tree analysis is suitable only for high resolution imagery of approximately 1m meter or less. Algorithms would identify the presence of a tree, delineate its crown, and try to establish its species (Barbezat and Jacot, 1998; Brandtberg, 1998; Culvenor et al., 1998; Dralle and Rudemo, 1997; Dubé et al., 1998; Gougeon et al., 1998; Key et al., 1998; Larsen, 1998; Niemann and Adams, 1998; Pinz, 1998; Warner et al., 1998; Pollock, 1998). Additional information regarding its health may be extractable. In addition to spectral information, other image parameters used by photointerpreters could be algorithmically/mathematically expressed and used in automated methods (e.g., crown outline shape, branching structure, texture, etc.). Context information such as elevation and ecological setting extracted from various data bases could also be used for species determination. Automated single tree methods would also provide information on the distribution of stems, crown size, crown closure and gaps. Results could be presented visually or quantitatively to help the interpreter. Images of stand attributes such as crown closure could be displayed to aid interpretation (e.g., Figure 1). An important fact to remember is that these computer based methods are only being used to aid the interpreter with additional information. Certainly at this stage of development of automated interpretation it is not meant as the primary source of information and may often have to be ignored. Nevertheless, it may show some subtleties not identified by the interpreter or indeed provide quantitative attributes deemed suitable by the interpreter to use as the stand description. If producing good results the stand description will often be more precise than that which the interpreter could provide. Crown closure, species composition and if required stems/ha would be examples. In aspects of this application, again there is a logistics problem. If the interpreter wants a summary of the automatically derived stand parameters, it implies that the stand boundary just interpreted is digitized and georeferenced to the automatically interpreted image. As well, the interpreter is using the information provided to help delineate stand boundaries. Summaries on a stand basis to help this process cannot be generated until the boundary is determined. Automated segmentation or stand delineation can be incorporated as an aspect of the process.

The automated analysis, if deemed satisfactory by the interpreter, can lead to a new set of possible or optional attributes not necessarily mandated in the inventory (e.g., stems/ha, stand gap size distribution, numbers of snags or large trees, or crown size distribution). As well, stand delineation based on species composition, crown closure, gap sizes, and or stems/ha can be generated automatically (Gougeon, 1997). Other environmental strata based on the forest conditions needed, say, for nesting of a given important bird, can also be compiled.

PIXEL AND AREA BASED TECHNIQUES

Traditional pixel based image classification techniques are best applied on medium and low resolution data; they generally do not perform well with high resolution data. At lower resolution there are many mixed pixels of tree and stand components (e.g., sunlit or shaded trees and open areas, different species). They will be problematic in consistently providing stand attributes appropriate for management inventories. Exceptions would be simple uniform single species units. It also must be remembered that, for the most part, systems will be analyzing only panchromatic or low quality multispectral data from aerial photos. Such techniques, whether applied to low or high resolution data, may, however, provide patterns of forest vegetation useful to the interpreter at a secondary level. For example, one could match the texture, Fourier Transform or variogram of a stand to that of a known stand of a known density to estimate stand density. Area-based characteristics such as texture and other image parameters based on the basic photointerpretation elements could be calculated. The techniques are best used if stands are already delineated. They can be applied without this requisite, for example, areas of homogeneous image parameters such as texture could be automatically outlined and presented to the interpreter. Again the interpreter could use both pixel based classifications and area based parameters as a visual aid to objectively recognize similar interpretation elements or to statistically match the parameters of different stands to identify potentially similar stands.

Because of the large number of component parts of a forest stand that contribute to its overall reflectance pattern and innumerable ways they can be arranged, pixel and area based analysis techniques have generally not met with success over anything but select conditions. A stand with the same inventory attributes can have a wide variety of possible reflectance characteristics and patterns. A given set of spectral characteristics can result from different stand types. However, there are possibly area based methods that could provide information or patterns useful for interpretation. As well, because the human interpreter is controlling decisions, a method is valuable even if it helps only occasionally or only differentiates one specific problem condition.

CHANGE DETECTION

Having previous and current images, plus the interpretation from the past inventory expands the number of possible computer-assisted techniques. It requires that both sets of photography be digitized and massaged. It is expected that benefit could come from comparing image parameters or automated single tree results from an image taken say at the time of the last inventory with current inventory image parameters. If these parameters have not changed then it can be assumed the stand has not fundamentally changed and use the old inventory attributes (grown over time) would be appropriate. The old stand boundary could also be used leading to potentially very significant efficiency gains. Digitizing of stand boundaries is a major cost of an inventory (Leckie and Gillis, 1995). One could also build a projection of what the image parameters would look like under normal stand development over the time period and compare current parameters to expected image parameters. Where there is change detected, other automated interpretation techniques could be used or a comparison made of image parameters with those expected under a given change. Of course, these methods gain most benefit when there is confidence in the previous inventory. It is not anticipated that registration between images would, under normal circumstances, be sufficient to conduct tree for tree comparisons, but area based change detection techniques would be useful.

It should also be noted that with such change detection methods a whole new inventory approach is possible. Change detection techniques would be used to determine areas that have undergone changes beyond normal stand development. Only these areas would actually be interpreted by the photointerpreters, vastly reducing the interpretation task. Digitizing and analyzing the photography from the previous inventory is onerous but if one does an automated interpretation on the new inventory, it would be available to use with the next inventory interpretation, be it a new inventory cycle or an update.

CONCLUSION

The goal of computer-assisted interpretation methods should be to improve the inventory in terms of quality, add additional quantitative parameters and do this at little or negative cost impact without significantly altering the current framework of inventory production. The methods, although having sophisticated underpinnings, therefore, should be designed to be used with minimal computer equipment (e.g., PCs) and computer expertise. They should be based on using digitized 1:10 000 to 1:20 000 B&W, normal colour or colour infrared photographs, while still recognizing that fully digital systems are gradually becoming an increasingly viable option for some applications. These requirements are based on the current operational setting and state of relevant technologies. They will all evolve together over time. In addition, this paper has discussed the computer based techniques in terms of 'assisting' the interpreter. As methods are developed and become mature, one must recognize the potential role of such techniques to provide spatially explicit quantitative information that can be compiled not only on a traditional stand basis but into spatial units to meet specific forest management needs. For example, the habitat for an important bird species, or presence of trees of a specific species and size. The role for providing data on new types of information not traditionally interpreted will also be important.

Use of on-line interpretation keys and ready access to ancillary data can only improve interpretation quality. The development of tools for the interpreter to review the appearance and image characteristics of stands he/she has interpreted as having similar attributes may prove the most beneficial of all computer-assisted interpretation tools. Automated single tree analysis should prove useful for identifying trees, tree sizes, crown closure, snags and gap distribution. For black and white and even colour photography the spectral information regarding species composition will be weak, but digitization at very high densities will permit structural and textural parameters to be used effectively in automated species estimation. For pixel and area based analysis methods, the approach should be less quantitative and more towards providing "clues" or "patterns" potentially useful to the interpreter, for example, highlighting areas with similar spectral content or texture. The interpreter can then determine if the areas are meaningful and add insight into the interpretation. Alternately, the system could tell the interpreter "this area or stand matches the texture pattern expected of, say, dense, mature lodgepole pine or open ponderosa pine, etc.". As well, one could match the texture, wavelet transform or variogram of a stand to that of a stand of a known density to estimate stand density. These techniques are best used if stands are already delineated but can be applied without this requisite. Development of useful area based techniques may prove problematic as stands of similar stand attributes can have quite different spectral and textural characteristics. However, the intent of the computer-assisted approaches outlined is not to provide stand alone methods but simple tools to assist the interpreter. Therefore, it is anticipated that effective area based parameters will be developed. A key immediate benefit of change detection techniques would be an efficient mechanism to identify stands with no unexpected change or boundary alteration, and thus permit the adoption of the old stand boundary, eliminating the necessity of full digitizing of all stand boundaries (an extremely costly component of an inventory). Change detection techniques will likely be the last to be developed and implemented but perhaps offer the greatest potential impact on inventory procedures.

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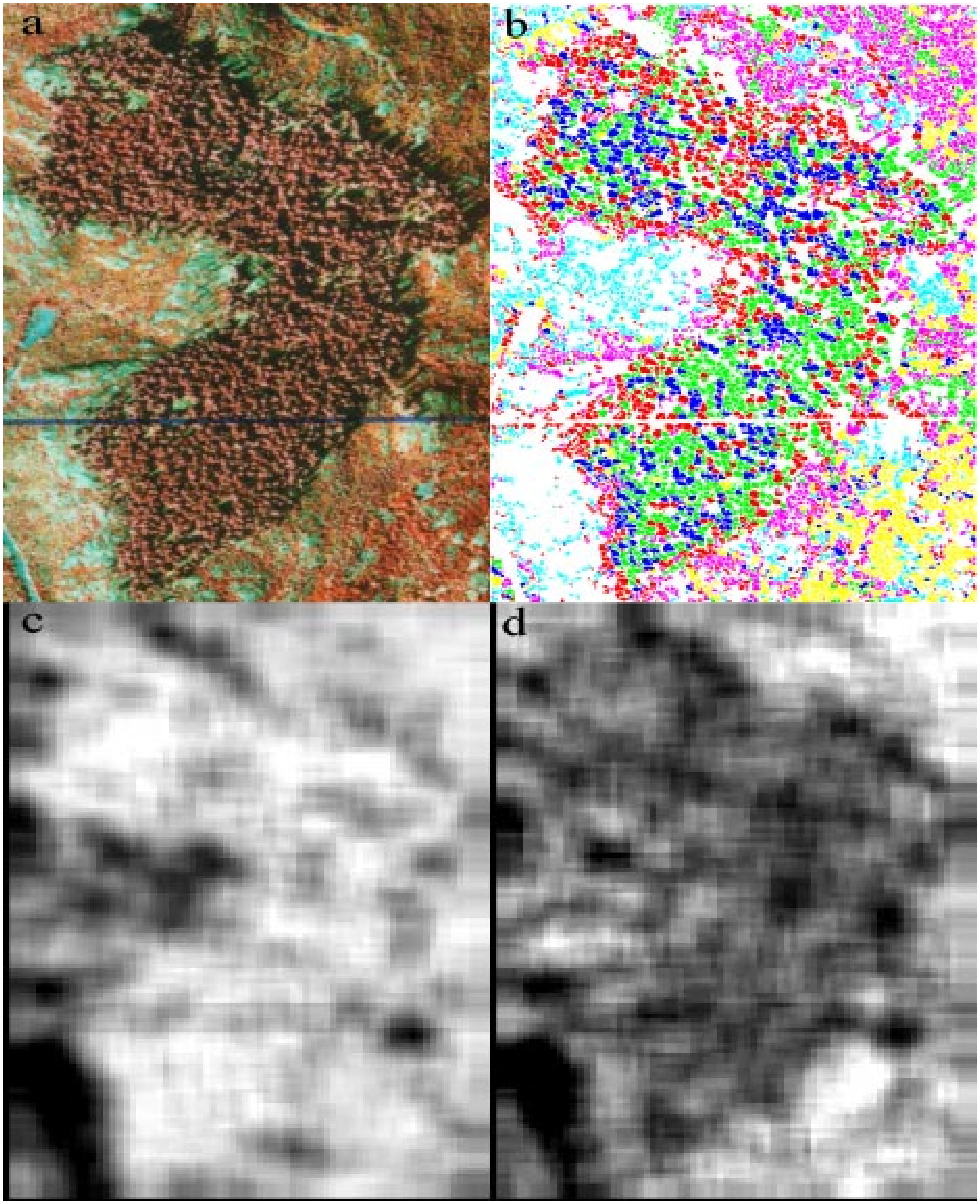

Figure 1. Digitized 1:19 000 scale colour infrared aerial photograph (60 cm resolution) and derived parameters. The area consists of a mature Douglas fir, Hemlock, Cedar stand surrounded by regeneration. a) Digitized photography, b) isolated trees with ITCISOL (Gougeon, 1998) classified into 6 species, c) crown closure image (high intensity equals high crown closure), d) stems/ha image (high intensity equals high stems/ha). (data provided by MacMillan Bloedel Ltd.).