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Towards Semi-Automatic Forest Inventories Using Individual Tree Crown (ITC) Recognition

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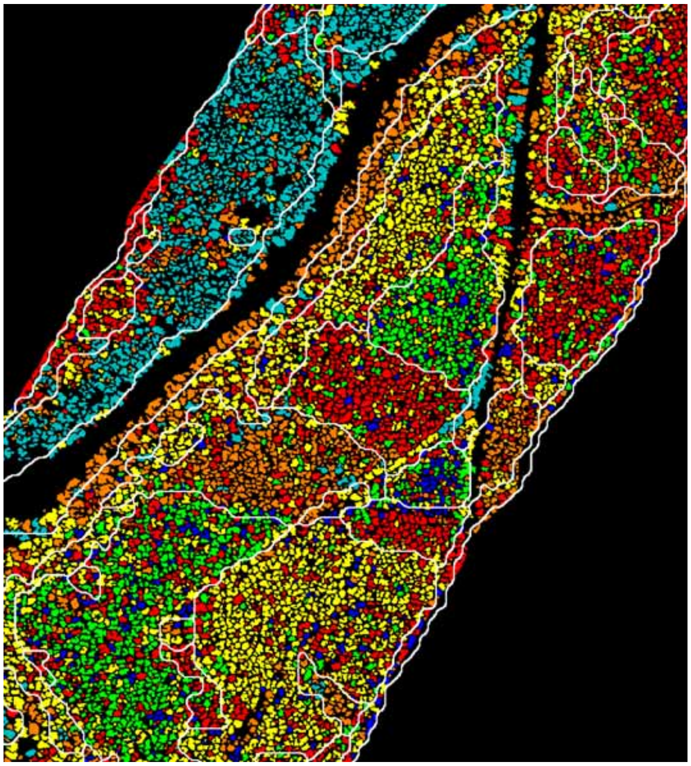

Figure 1. Individual tree crown recognition and computer-generated stand outlines. (Red = Douglas-fir; green = grand fir; blue = amabilis fir; orange = western redcedar; yellow = western hemlock; light blue = hardwood.) Forest inventories could potentially be completed much more quickly and over broader areas with this technology.

Strategic Importance

Some 24 million hectares of forest are mapped each year throughout Canada. Currently, forest management inventories are manually developed from aerial photo interpretation (at 1:10,000 or 1:20,000 scales) and field sampling. These visual processes and interpretations are labour intensive. Despite the resources expended, these inventories may be insufficient for some applications.

In comparison with conventional aerial photography, high spatial resolution multispectral images have three basic advantages:they can make better use of the colour spectrum and show information not always present on aerial photography; they are captured digitally and therefore lend themselves to better and more direct computer analysis; and images and resulting information can be more readily tied to geographic locations, leading to direct transfers to the Geographic Information Systems (GIS) where most forest inventories now reside.

A long-term objective of this work is to generate precise forest management inventories using semi-automatic techniques. Implementation of automated methods for collecting and assessing forest inventory information from high resolution digital remote sensing images will ultimately provide new types of information for multiresource management, expand the use of inventories, and increase the precision, accuracy, cost-effectiveness, and timeliness of forest information.

Achieving a semi-automated interpretation of high spatial resolution digital data for forestry requires that several components work together. A key component is the automatic isolation of visible individual tree crowns. This step has been demonstrated with remotely sensed aerial images and digitized aerial photographs of high spatial resolution (10–100 cm per pixel). This result implies a shift from the pixel-based classifications and area-based segmentations typically used at lower spatial resolutions to a novel capability of analyzing forest images by “individual tree crown” (ITC).

A New Approach: ITC Recognition

The ITC-based approach separates the crowns from one another and from the background vegetation, recognizing their species one by one. If needed, the crowns are

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regrouped into forest stands. Alternatively, existing or newly interpreted stand boundaries as well as geopolitical boundaries can be used as reporting entities. The conceptual steps toward the semi-automatic production of forest inventories, which would identify the species composition of stands or environmental strata with precision, are shown in Figure 2.

High spatial resolution multispectral images (10–100 cm per pixel)

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Preprocessing

- Remove non-forested areas (manually or semi-automatically)
- Select the best spectral image for tree delineation
- Smooth that image

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Delineating individual tree crowns

- Remove large shaded areas
- Follow valleys of shade between crowns
- Follow rule-based process to finish delineation of individual crowns

↓

Classifying individual tree crowns

- Generate species signatures
- Classify individual tree crowns
- Verify (assess accuracy)

↓

Regrouping (into stands or strata)

- Obtain stem density images
- Obtain canopy closure images
- Feed to an unsupervised classifier
- Filter small areas
- Vectorize contours
- Generate forest stands or environmental strata information with precise species composition.

Figure 2. Conceptual steps required for the semi-automatic mapping of forest stands with precise species composition.

Preprocessing

The three main steps in preprocessing are selecting the best spectral image for tree delineation, smoothing that image, and removing non-forested areas. Remove non-forested areas by:

- applying conventional pixel-based unsupervised classification, or
- using special programs such as NVEGMASK, or
- manually delineating the non-forest areas on the screen.

Delineating Individual Tree Crowns

In most mature forests, the visible individual tree crowns or tree clusters can be isolated using the areas of shade that typically separate them. Shade may be on the ground, in the understorey, or in parts of the crowns. The process uses a series of computer programs as shown in Figure 3.

A near-infrared band is typically used for general forest inventory because of its sensitivity to illumination variations and its good response to vegetative material. Using a geographical analogy, the bright individual tree crowns in an image appear like mountains (i.e., high pixel values). The darker areas surrounding them, the shaded lower branches and understorey, appear like valleys (i.e., low pixel values). Using a smoothed version of the near-infrared image, the isolation process (ITCVFOL) first thresholds the image to remove large shaded areas. It then finds local minima (the darkest pixels of shade between tree crowns) in the remaining forested areas of the image. From these points, it systematically follows the valleys of shade, which are found between the higher intensity crowns. This step leads to an initial separation of coniferous crowns, but does not always fully separate them from their neighbours.

A delineation process (ITCISOL) uses a rule-based approach to systematically follow boundaries from the inside of a specific crown (or cluster) to produce more distinct crowns. That process contains numerous, context-sensitive crown separation criteria. At this point, the ITCs are considered distinct entities or objects, but they can still be represented in image format (ITC bitmap).

Generating Species Signatures

Spectral signatures are acquired for representative tree crowns of each species and are averaged to create the species signatures (ITCSSG). For relatively uniform stands or plantations, sample areas for each species must be delineated on the screen. The ITCSSG software uses the ITC bitmap to calculate the spectral signatures of the ITCs within the sample areas and amalgamates them to produce the species signatures. The procedure for mixed stands is more demanding; specific crowns must be clicked on in the image to create the species signatures.

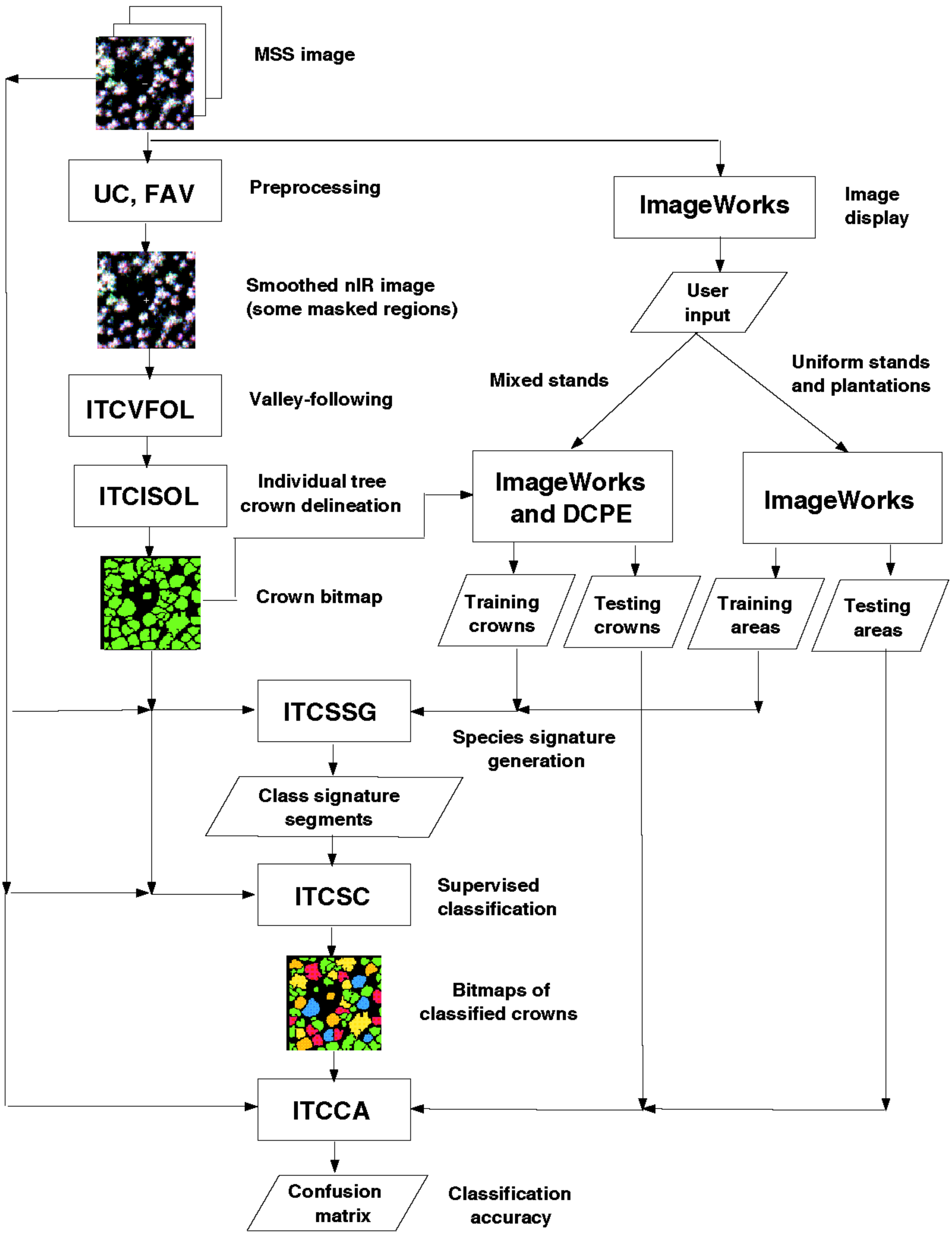

Figure 3. Methodology for individual tree crown delineation and supervised classification.

Classifing Individual Tree Crowns

After all of the ITC-based species signatures have been acquired, an ITC-based classification is run (ITCSC). For each ITC encountered in the image, its spectral signature is computed and compared with the various species signatures. A maximum likelihood decision rule is used to assign a species (class) to the unknown ITC. A confidence interval threshold is also used so that ITCs with signatures that are significantly different from any species signatures are left unclassified. Bitmaps showing all of the ITCs assigned to a given species (class) are produced and can easily be displayed.

Delineating Forest Stands

Forest stands are still the preferred units of Canadian forest management inventories. With the existing interfaces between image analysis systems and GIS, the ITC-based information for existing stand boundaries is easy to summarize. Consequently, detailed stand information can be produced for species composition, average crown areas by species, stand density, crown closure, average gap size, and gap distribution.

Alternatively, if existing stand boundaries are inappropriate, the ITCs can be regrouped using the semi-automatic methodology shown in Figure 4. This method incorporates stem density and crown closure using the ITC bitmaps produced by ITCISOL and by ITCSC.

STEMDENS creates an image of stem density by reducing every crown to its centre of gravity and summing the stems found in a fixed-size roving window. CCLOSURE creates an image where each pixel corresponds to the quantity of crown material found in a fixed-size roving window around that pixel. STEMDENS and CCLOSURE are also used on the species-based bitmaps produced by the ITC classification. Then, all of the images produced are input to a pixel-based unsupervised classifier. The classification is repeated a few times, asking for a different number of classes, until a regrouping judged reasonable is achieved. Stands smaller than a given minimum area are removed (SIEVE $^{+}$) and a mode-based filter (FMO $^{+}$) smooths out the stand boundaries. Finally, the classes are fed to a raster-to-vector conversion program to obtain polygons that can be transferred to a GIS. The ITC-based information within the newly generated boundaries can be extracted (ITCPCD) and also moved to the GIS as polygon attributes.

Species Classification Results

The degree to which the programs will confuse one species with another is a major consideration in determining accuracy. The ITC-based delineation, classification and regrouping system was tested with a geometrically corrected Compact Airborne Spectrographic Imager (CASI) image of the Nahmint species demonstration area, Vancouver Island, B.C. For this study, eight spectral bands (~25 nm) with a nominal spatial resolution of 60 cm per pixel were acquired from the CASI. The ITC-based approach was then used to recognize five western Canadian coniferous species and a generic hardwood class. Table 1 shows the confusion between the coastal species of the Nahmint area as produced by ITCCA (Figure 3). Table 1 lists the classification accuracy assuming that all stands are pure, which is not the case.

The overall classification accuracy was 60%. Western hemlock was easily separated (83%) from other species, with minor confusion (11%) with Douglas-fir. The hardwoods were also well recognized (68%), with some confusion with western hemlock (13%) and western redcedar (18%). Douglas-fir was also relatively well recognized (64%). Amabilis and grand fir were confused mostly with each other. The lowest classification accuracy was with western redcedar (27%), which was significantly confused with Douglas-fir (34%) and amabilis fir (27%). This confusion is attributed to broad intra-species variations and the assumption imbedded in ITCCA that the western redcedar stand was relatively pure.

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Table 1. Confusion by species between classification results and test areas (in the Nahmint area of B.C.)

	Actual species					
	Douglas-fir	**Grand fir**	**Amabilis fir**	**Western redcedar**	**Western hemlock**	**Hardwood**
Number of crowns in test area	108	100	40	102	106	72
Species detected (%)						
Douglas-fir	63.9	16.0	7.5	34.3	11.3	0.0
Grand fir	9.3	59.0	25.0	8.8	2.8	0.0
Amabilis fir	11.1	21.0	57.5	26.5	1.9	0.0
Western redcedar	1.9	3.0	5.0	27.4	0.9	18.1
Western hemlock	13.9	1.0	5.0	2.9	83.0	12.5
Hardwood	0.0	0.0	0.0	0.0	0.0	68.1

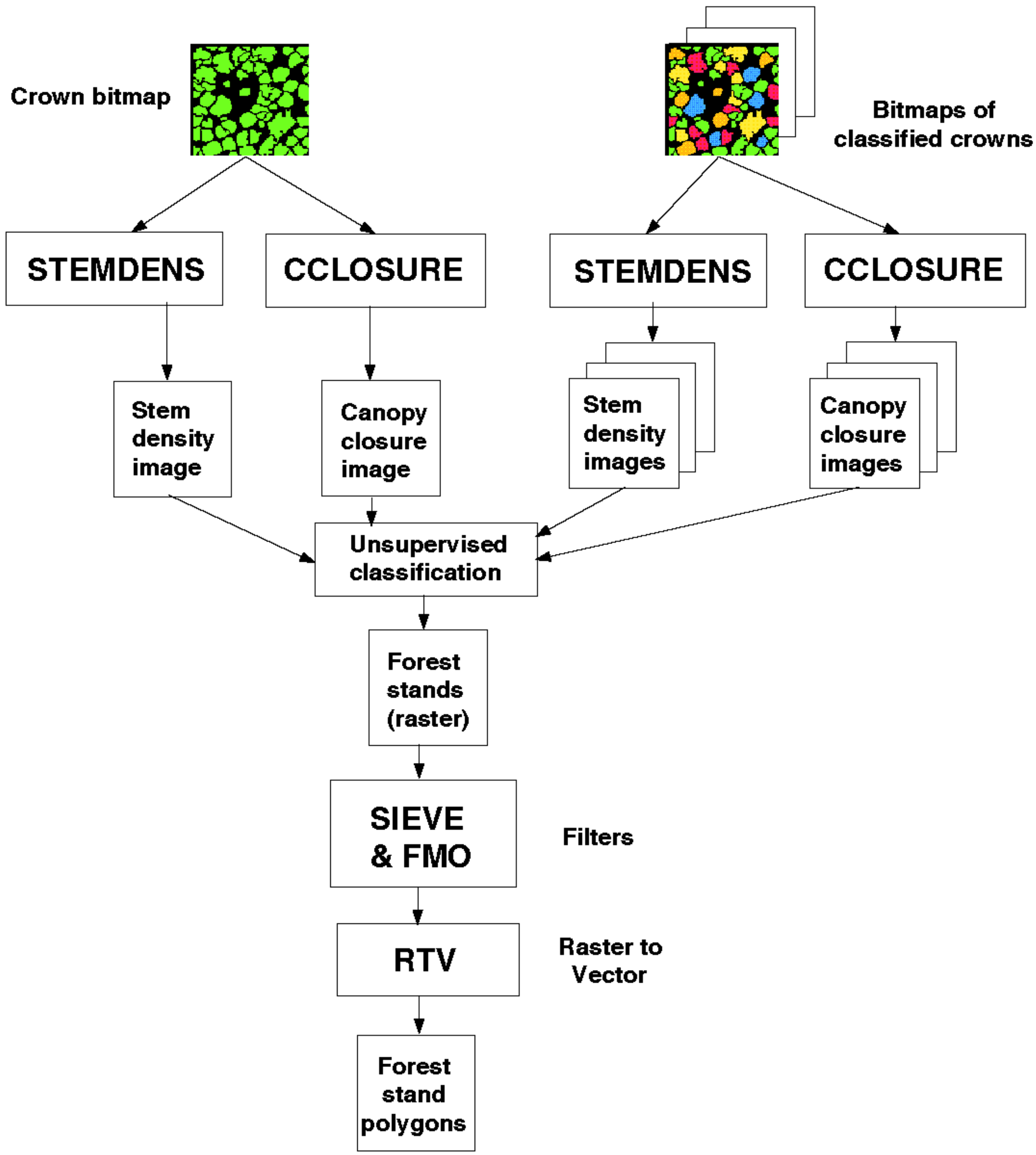

Figure 4. Methodology for generating forest stands or environmental strata outlines from ITC bitmaps.

Field Transects

A more realistic evaluation of the ITC-based classification results compared the species composition of larger test areas with field transects through these stands. The transects followed compass bearings. Information such as species, dominance, potential aerial visibility, approximate crown size, distance along the transect line was recorded for each tree within 2 m on each side of the transect lines. When suppressed trees are disregarded, the dominant species is off by 20% on average and the error when all species are considered equal is 12%.

Conclusions

Obtaining from digital remote sensing the kind of information that foresters need to manage the forest resource may be within reach. This semi-automatic ITC approach could bring increased precision, accuracy, and timeliness to forest management inventories. The results from the Nahmint demonstration area are encouraging.

An ITC-based approach also facilitates the assessment of newer inventory parameters such as non-forested gap distributions, snag locations, and other biodiversity and wildlife criteria and indicators needed for the multipurpose management of our forests. It also permits forest managers to use information at the tree and stand levels.

Additional research is quantifying the capabilities of this approach for various environments (such as old growth, regeneration, damaged areas), conditions (such as change in illumination, tree size, and topography), and media (satellite images, digitized photos).

Additional Reading

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