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Research Note / Note de recherche

Deforestation estimation for Canada under the Kyoto Protocol: A design study

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Abstract. Deforestation is a persistently important issue locally, nationally, and internationally. It is of interest to the public, foresters, environmental organizations, and governments, yet it is difficult to obtain reliable estimates of its extent and nature. Climate change and the role of forests has given a large impetus for formalizing reporting on deforestation. Under the proposed Kyoto Protocol, industrialized nations are required to report on the carbon consequences of deforestation and include them in their greenhouse gas emissions accounting. Canada must develop measurement systems to report on the area of deforestation and the carbon stock loss. Possible data sources include the new plot-based National Forest Inventory (NFI), land use records, and satellite remote sensing. The NFI is a network of 2 × 2 km plots at a 20 km spacing for which land cover and stand attributes are interpreted from medium-scale aerial photography. In this study, medium-resolution satellite imagery, such as Landsat Thematic Mapper (TM), was explored as a potential tool for deforestation estimation and a survey of available land use records was conducted. Factors affecting the utility of each data source and various system design options were examined. An integrated system is suggested that utilizes the NFI as a base, augmented by satellite remote sensing plots and supported by local records as appropriate.

Résumé. La déforestation constitue sans contredit un enjeu important aux plans local, national et international. C'est un sujet qui intéresse le public en général, les forestiers, les organismes environnementaux et les gouvernements. Malgré cela, il est difficile d'obtenir des estimations fiables de son étendue et de sa nature. Les changements climatiques et le rôle des forêts ont suscité beaucoup d'intérêt et ont ainsi permis de formaliser les rapports sur la déforestation. En vertu de la proposition du Protocole de Kyoto, les nations industrialisées devront rapporter les incidences de la déforestation sur le carbone et les intégrer dans leur comptabilité relative aux émissions de gaz à effet de serre. Le Canada devra développer des systèmes de mesure pour réaliser des rapports sur la déforestation et la perte des stocks de carbone. Parmi les sources de données potentielles, il y a les nouveaux relevés d'utilisation du sol basés sur les placettes de l'Inventaire forestier national (IFN) et la télédétection satellitaire. L'IFN est un réseau de placettes de 2 × 2 km, ayant un espacement de 20 km, pour lesquelles les attributs du couvert et de peuplements sont interprétés à partir de photographies aériennes à échelle moyenne. Dans cette étude, des images satellitaires à résolution moyenne, comme les images thematic mapper (TM) de Landsat, ont été exploitées comme outil potentiel pour l'estimation de la déforestation. Aussi, un inventaire des relevés d'utilisation du sol disponibles a été réalisé. On a également examiné les facteurs affectant l'utilité de chacune de ces sources de données et les diverses options conceptuelles de ces systèmes. On propose un système intégré basé à la fois sur les données de l'IFN et sur les parcelles dérivées des données de télédétection satellitaire et appuyé par des relevés locaux lorsque nécessaire. [Traduit par la Rédaction]

Introduction

Deforestation has important ecological, environmental, and sociological impacts. Understanding the distribution, amount, rates, and consequences of deforestation is essential. Efforts to date have concentrated mainly on estimation of deforestation in the tropical forest, with remote sensing playing a key role (Skole and Tucker, 1993; United Nations Food and Agriculture Organization, 1996; Alves et al., 1999; Tucker and Townshend, 2000; Kalluri et al., 2001).

The international community is increasingly concerned about greenhouse gas emissions and their adverse affect on the environment and contribution to climate change. The Kyoto Protocol is a proposed international agreement in which industrialized nations commit to reducing their greenhouse gas emissions (United Nations, 1997). Forests, and the role they play in storing and regulating atmospheric carbon, are an important aspect of this issue. Under the United Nations Framework Convention on Climate Change (UNFCCC), as part of its annual greenhouse gas emissions and removals inventory, Canada is required to report on deforestation. The underlying principles of the Kyoto Protocol forest-related Article 3.3 are that countries should be accountable for the carbon consequences of conversion of forest to other uses (deforestation) and should benefit from the carbon sequestration resulting from afforestation and reforestation. Deforestation results in loss of carbon stock and release of carbon into the atmosphere. The current formal definition of

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deforestation under UNFCC negotiations on the Kyoto Protocol is the “direct human induced conversion of forested land to non-forested land”. Forest is defined as an area of land “with tree crown cover more than 10 to 30% with trees with the potential to reach a minimum height of 2–5 m at maturity in situ”. Areas that are temporarily unstocked as a result of human intervention (e.g., harvesting) or natural causes but are expected to revert to forest are considered forest and are not areas of deforestation. The minimum spatial assessment unit is expected to be 1 ha or less, meaning that deforested areas of 1 ha in size and perhaps less must be accounted for. Under the Kyoto Protocol, if ratified, the carbon stock changes in the years 2008–2012 on areas deforested since 1990 will need to be reported (Intergovernmental Panel on Climate Change, 2000). Therefore, to fulfill Canada’s Kyoto Protocol reporting commitments, a national system for estimating and reporting on areas of deforestation is needed so that the carbon stock changes can be estimated. Regardless of international agreements, there is expected to be a continued demand for monitoring deforestation.

This article describes a study in which potential key components of a deforestation measurement and reporting system were analyzed, design options considered, and a viable design outlined. These components included Canada’s new National Forest Inventory (NFI), existing land use records, and satellite remote sensing.

Analysis of potential components

The basics of Canada’s new NFI design consists of a national network of 2 × 2 km plots on a fixed 20 km grid (Gillis, 2001). Within each plot, forest type and parameters are interpreted from aerial photography. These will be remeasured every 5–10 years. Therefore, change of the forest within these plots, including deforestation, will be mapped and the pre-deforestation forest type and post-deforestation land cover and land use identified. This should form a good core for a deforestation estimation system. However, deforestation events are rare, small, and distributed and more reliable results would be provided with a larger sample than the 1% area sampled by the NFI.

A survey regarding the availability and usefulness of land use records was conducted by Leckie et al. (2000). A selection of provincial forest, agriculture, energy, planning, and policy agencies were interviewed and additional leads as to possible sources of information followed up. A sample of municipal- and county-level agencies was surveyed to determine potential information sources. Considerable information is available from various sources but is quite complex to access and vet. Possible information sources include municipal planning records, forest inventory, agricultural records, and some specialized land use surveys. It was found that land records are not well summarized at the provincial level and deforestation information is not being compiled per se. Sources are variable among jurisdictions and over time. For example, municipal records will show development, but rarely whether the land was previously forested. These records are distributed throughout many locations and seldom compiled centrally. Forest management inventories do not cover all regions of potential deforestation and may not ascribe a new land use to the area that was cleared. Despite the difficulties, records do exist and can be used to help confirm and characterize many deforestation events if their location is known via other methods. In some jurisdictions, records may also be sufficient on their own and it might be possible to incorporate them into an integrated system.

Medium-resolution satellite images (e.g., Landsat Thematic Mapper (TM)) provide broad-area repeat coverage and spectral and spatial detail of an order potentially useful for detecting and delineating deforestation. The issues are as follows: What procedures are best (e.g., automatic classification, change enhancement, or visual interpretation)? How well do the methods work? How applicable are these methods to the different landscapes and types of deforestation that occur across Canada? To gain an appreciation of these issues, several studies were conducted. Using two main test sites (southern Vancouver Island, British Columbia, including Victoria; and near Petawawa, Ontario), automated unsupervised classifications of broad cover types were conducted and comparisons of classifications from two dates explored as a method for determining deforestation. Various change enhancements combining multi-date imagery were also examined. These included band ratios, vegetation indices, principal components, tasselled cap transformations, and band combinations. The detectability of various types of deforestation was visually assessed by examining two dates of imagery and a change enhancement (e.g., **Figure 1**). A formal interpretation test of a similar procedure for detecting, identifying, and interpreting the type of deforestation was completed on the two test sites. Deforestation classifications and interpretations in these studies were compared with delineations of all deforested areas within the test sites as determined from interpretation of 1 : 15 000 to 1 : 20 000 scale aerial photographs from near the two dates of the Landsat imagery, supported by ground inspection. In addition, over 100 Landsat scenes or multi-date images from across Canada were visually analyzed to determine the capability for deforestation assessment and to examine the different landscapes in which deforestation takes place and the patterns in which it occurs. A 28 year time sequence of summer and winter Landsat imagery over the Petawawa, Ontario site was used to help determine the length of time it takes to confirm regeneration on a forestry clearcut. Existing satellite remote sensing based deforestation surveys worldwide were examined and key people involved were interviewed. Details of these studies are found in Leckie et al. (2000).

Comparison of forest and non-forest classes of the two dates of automated classifications detected forest clearing reasonably well. However, the next step of determining whether a clearing is permanent (deforestation) or an intermittent disturbance, such as a forestry clearcut, is problematic. Using two dates of imagery, one before and one after the deforestation event, a

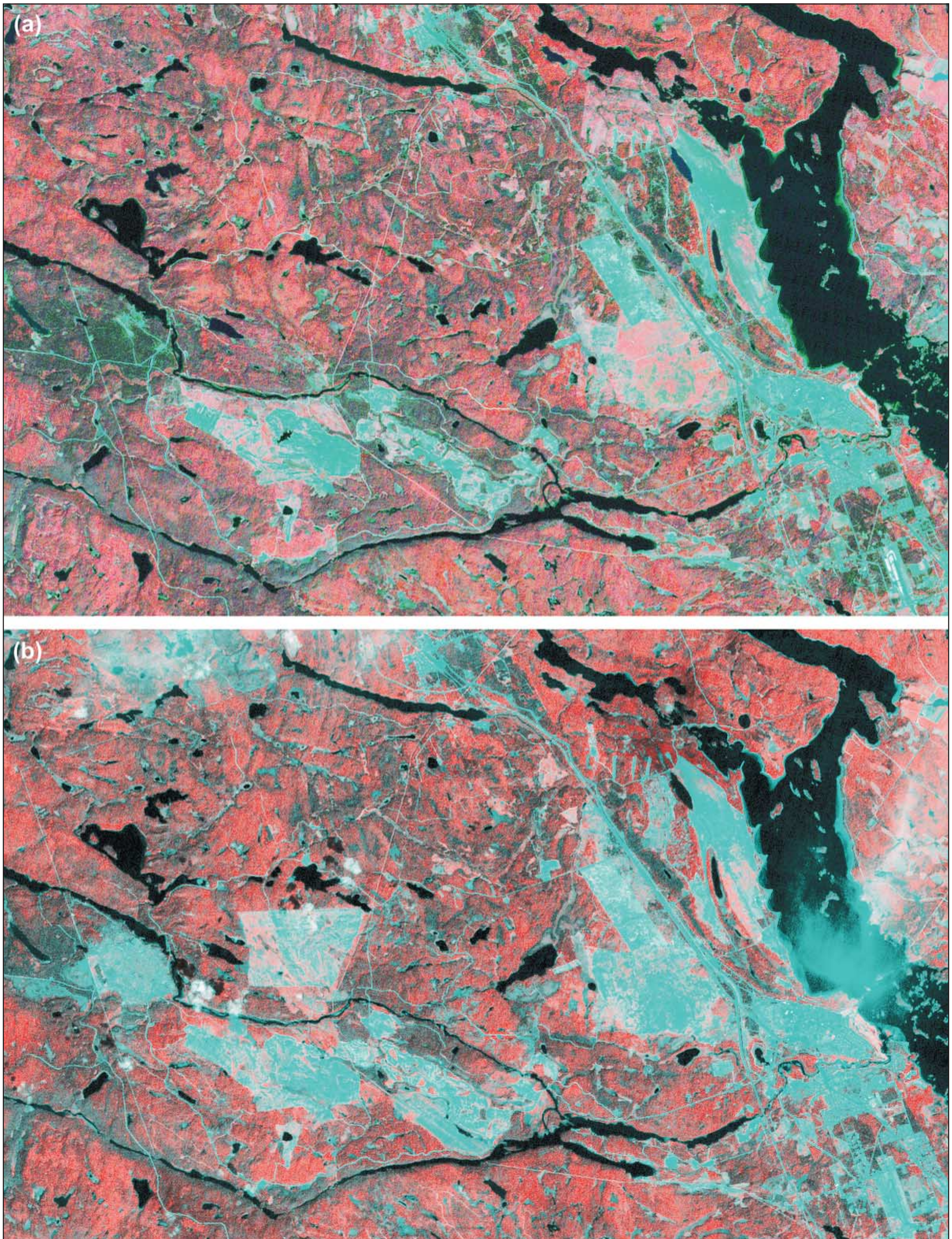

Figure 1. Example of satellite imagery, change enhancement, and sample plot design for the deforestation measuring and reporting system. The image is a 30 × 19 km area near Petawawa, Ontario (45°56′N, 77°27′W). (a) Landsat TM colour infrared composite from 25 August 1984. Red, band 4 (near-infrared); green, band 3 (red spectral band); blue, band 2 (green spectral band). (b) Landsat TM colour infrared composite from 16 August 1998. Red, band 4; green, band 3; blue, band 2.

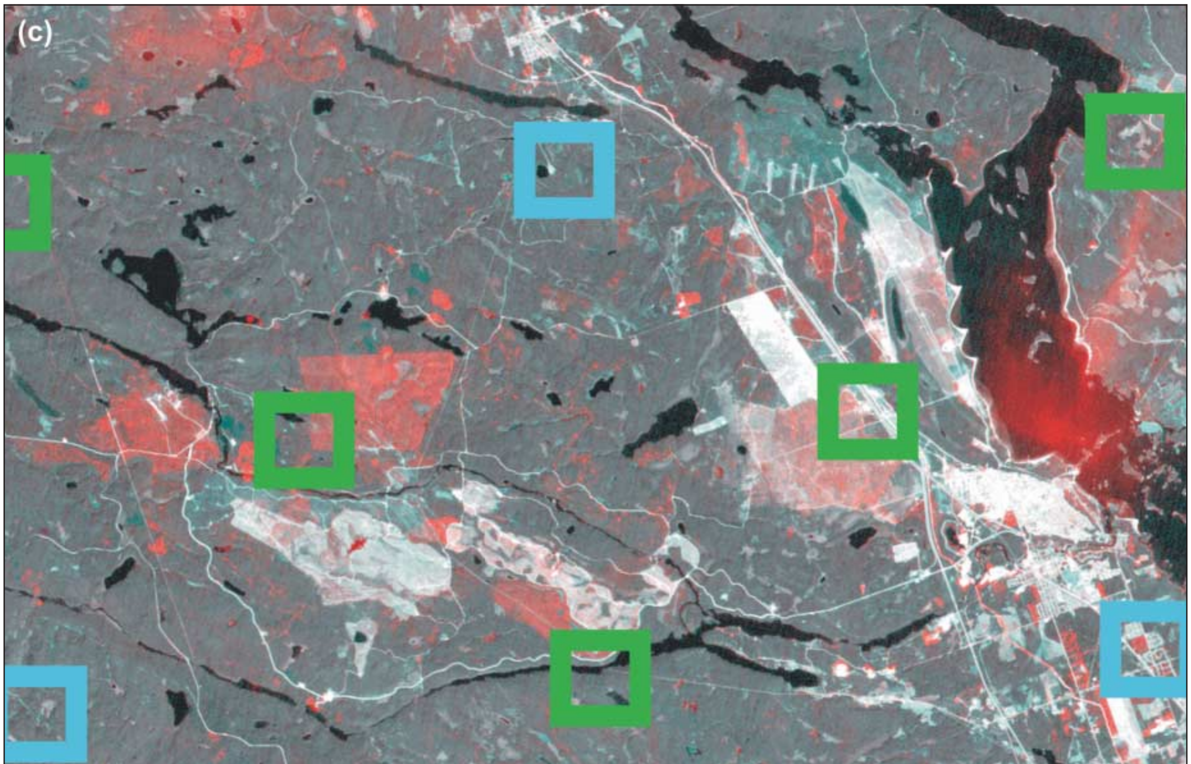

Figure 1 (*concluded*). (c) Landsat change enhancement, 1984 and 1998. Red, 1998 band 3; green and blue, 1984 band 3. Areas with lower vegetation density in 1998 (e.g., cleared areas) show as red. Thin cloud zones in the 1998 imagery show as wispy red areas in the top left-hand side and middle right-hand side of the image. Boxes are the 2 × 2 km sample plots on a 10 km grid. The blue boxes are the samples that correspond to a National Forest Inventory plot (i.e., a 20 × 20 km grid).

considerable amount of auxiliary information or clues will often be needed to make a decision as to whether a site is deforestation or not. This evidence is best incorporated by a human interpreter. Therefore, visual interpretation with the aid of a change enhancement is recommended as the primary method of determining deforestation. The decision would be easier if one can afford the luxury of examining a series of images for many years after the forest clearing event. Regrowth of forest and evidence of any new land use such as agriculture, industrial, or urban would be much clearer. This study assumes this will not be the case. For example, under the Kyoto Protocol there is a need to have current deforestation information during the commitment period and to report shortly after the period.

With a change enhancement and interpretation of two dates of imagery (**Figure 1**), Landsat-type data provide good detection of cleared areas representing possible deforestation. Even small areas of 0.1 ha, such as those for single dwellings plus yards, were detected on the Landsat images used. Context, shape, adjacency, expansion of existing features, texture, and spectral evidence are important for identifying a detected forest clearing as deforestation as opposed to a forestry cut or other temporary clearing. Regardless, there will still be errors and uncertainty in the interpretations of deforestation. Identification of detected forest clearings as deforestation is more difficult and confusing if they are small and when they occur in landscapes where there is a mixture of forest, agriculture, urban–suburban, and industrial development. This is particularly true when there is a distinct land ownership pattern and the boundaries of the forestry operations, agriculture fields, and industrial or residential developments follow this pattern.

Detection and identification of deforestation are proposed, at this time, to be by visual interpretation. Automated techniques could add useful supplemental detection and delineation information. For example, it should be possible to automate the delineation of the boundary of some deforested areas once they are identified through manual interpretation as deforestation. Sophisticated automated techniques incorporating such information as context, shape, and adjacency could be added to a visual interpretation based system as they are developed and proved.

System definition

Considering the requirements for reporting deforestation and its carbon consequences and available records and tools, a baseline design was determined (Leckie et al., 2002). **Figure 2** outlines the steps of the design. Canada would be divided into strata of different expectations of deforestation level (e.g., “low” and “higher”). The strata would generally be large

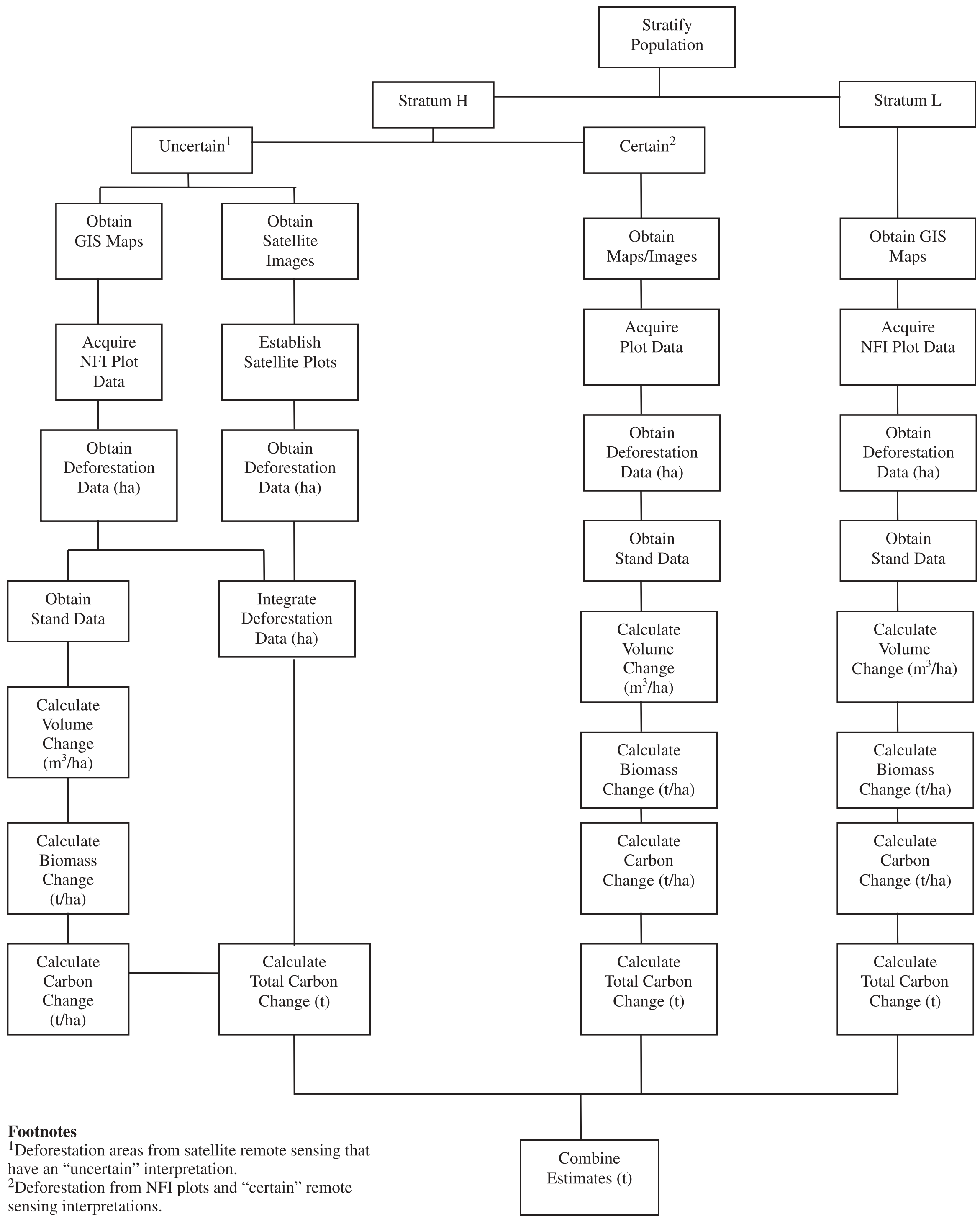

Figure 2. Schematic of the deforestation estimation system design. Strata H and L refer to the strata with "higher" and "low" expectations of deforestation, respectively.

contiguous regions as opposed to small localized units. For example, southwestern Ontario, the prairie fringe, and lower mainland British Columbia where ongoing development activity is expected might be considered as parts of the higher strata. The details of this stratification remain to be determined. NFI 2 × 2 km photo plots would form a foundation of the system. For the higher deforestation strata, the NFI plots would be augmented by medium-resolution satellite remote sensing (e.g., Landsat TM) to increase the area sampled beyond that of the NFI plots. It is anticipated that NFI plots alone would be used for the low strata. This would produce less reliable results than those for the higher strata, since sample density is lower and the deforestation events are more rare. However, the option to use satellite data for the low strata is always available. For the higher strata, full satellite coverage will be acquired for two dates, one each at the start and end of the period over which deforestation is to be reported. Leaf-on imagery is preferred, as the information content is higher for the combined tasks of detecting forest clearing, using available clues to identify if the clearing is deforestation, and interpreting the post-deforestation land type. A grid of 2 × 2 km plots at a 10 km spacing would be assessed on the imagery. Every fourth plot would coincide with an NFI plot (**Figure 1c**). The sample size and spacing of the satellite plots can be incrementally increased, if appropriate, all the way to complete coverage. Areas of possible deforestation will be identified by visual interpretation of change enhancements supported by automated techniques. Although detection of forest clearing is expected to be reliable, identification of these areas as deforestation is more difficult and a considerable number of interpretations will be considered "uncertain". Two methods will be used to resolve these uncertainties: (1) use local records or knowledge where practical, and (2) implement a double sampling system using the NFI plots. The double sampling system utilizes the fact that the true nature of the uncertain satellite interpretations coinciding with NFI plots is known through the airphoto interpretation of the plots. A regression estimator would then be developed to prorate all the uncertain satellite interpretations in a region based on the portion of uncertain within the NFI plots determined to be true deforestation. In this way an adjusted area of deforestation is estimated.

Now that the areas of deforestation have been identified, the next step is to estimate the carbon stock removed. The stock of carbon on each identified deforestation site prior to deforestation will be estimated directly by reference to existing forest inventory information for that site or from average carbon stocks for similar stand types in the region. Averages will be applied to the uncertain cases. Any carbon storage in wood removed, if required, and emissions from decay of biomass left will be estimated through knowledge of local and regional clearing and harvest practices (e.g., wood used for forest products and wood and slash burned, piled, or left scattered on site) and the product mixes common for different forest types. Total carbon will be considered, including roots, soil, and litter. Carbon accumulation from the new land cover type will be accounted for in general terms by estimation and modelling based on typical values for the new surface cover. The Canadian carbon budget model (CBM-CFS2; Kurz and Apps, 1999) will be used as the basis for the various carbon estimations. The result of these procedures will provide an estimate of the carbon consequences of the deforestation for the sampled area, and this would then be prorated proportionately to estimate the area of deforestation and carbon consequences for the whole area.

Conclusions

Deforestation is an issue of global impact and will remain so for the foreseeable future. Solid estimates and documentation are important for the public, governments, non-governmental agencies, and international community. Reporting of the carbon consequences of deforestation will be a requirement of Canada under the Kyoto Protocol if ratified. The Framework Convention on Climate Change does require reporting on deforestation as part of its national greenhouse gas emissions and removals inventory. Therefore, a national system for determining the area of deforestation over time and the change in carbon stock in that area is needed. The new plot-based National Forest Inventory (NFI) makes a strong core for a system. Deforestation, however, is an uncommon event totalling only a small fraction of Canada's forest area and the NFI plot system should be augmented to improve its reliability for determining deforestation. Medium-resolution satellite remote sensing offers a good source of data. Existing land records are difficult to use as a sole source of deforestation information but can be effective in some cases to confirm deforestation. An integrated system based on these data sources forms a sound basis for a national measuring and reporting system.

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