POSSIBLE SYSTEMS FOR MEASURING AND REPORTING ON DEFORESTATION IN CANADA UNDER THE KYOTO PROTOCOL

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Abstract. A national system for determining and reporting on areas of deforestation is needed to fulfill Canada's Kyoto Protocol reporting commitments. An enhanced National Forest Inventory (NFI) forms a reasonable national framework on which to build a deforestation reporting system. The NFI consists, at its core, of a grid system of 2x2 km plots on a 20 km spacing. The base design calls for forest parameters to be determined from aerial photo interpretation. A subset of plots are sampled on the ground. This core can be enhanced with data from other sources. One possible enhancement is the integration of the NFI plot system, medium resolution satellite remotely sensed data (e.g., Landsat TM), and existing land use records to improve measurements of deforestation in the context of the Kyoto Protocol. Important in such a system are what data are available and how to integrate the data.

Key issues related to the appropriateness of public land use records are: what records are available; from who; their content, coverage and reliability; are they spatially explicit; are they yearly; are they legislated, regulated or voluntary; and are there access restrictions. Questions related to the potential use of satellite remote sensing include: what types of deforestation can be detected, how accurately and at what minimum mapping unit; for what types of deforestation can you infer deforestation using only one image; how long a time interval do you need to prove deforestation or alternately disprove deforestation; what information can one infer regarding remaining carbon stocks. Issues related to integration into a system within the National Forest Inventory structure are: sampling system design (random, systematic, focused); scaling; sampling interval; what to do when different sources give different answers; and how area and location of deforestation can be related to forest type, biomass, and remaining carbon on site so the impact on the carbon budget can be determined. In this paper these factors were considered and viable integrated systems outlined.

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1. Introduction

Recently, a need for data in response to Canada's commitment to reduce greenhouse gases has emerged. Under the Kyoto Protocol, Canada has agreed to reduce greenhouse gas emissions to six percent below the 1990 level by 2008. A significant effort will be required to meet this goal; carbon (C) emissions must be reduced and C sequestration must be increased. Canada's forests play a major role in this effort. Through increased afforestation, additional C can be sequestered in the new forests, and through decreased deforestation, C emissions can be reduced.

To document the 1990 baseline data and subsequent C changes, a national reporting and monitoring system is required. The Canadian Forest Service (CFS) has been cooperating with the provinces and territories in the development of a new plot-based National Forest Inventory (NFI). A new approach is needed because the current design cannot meet the new needs for data and information (e.g., Criteria and Indicators of Sustainable Forest Management). The NFI provides a suitable framework on which to build a forest carbon monitoring and reporting system but the capability of identifying changes in the area of land cover classes and land use classes must be improved, in particular deforestation and afforestation. This study focuses on deforestation but most of the procedures also apply to afforestation.

The basic NFI design includes complete interpretation (stratification and classification) of approximately 20,000 primary sample units, or one percent of Canada's land mass using mid-scale aerial photography. Primary sample units (photo plots) are 2 x 2 km in size and are located on a 20 x 20 km network. Estimates of land cover and other forest stand attributes are acquired. A ground-based sub-sample of approximately one in ten photo plots will be established for the estimation of species diversity, biomass, and other detailed data not available from aerial photography. Twenty-five core attributes will be derived from the photo interpreted and ground-based estimates. The initial measurement of photo and ground plots will provide an estimate of the current state of the resource. An estimate of change will be derived from repeated measurements of both photo and ground plots (all plots are permanent). Estimates will be reported for Canada as a whole and by ecozone. They will also be available for each province/territory.

This design provides a good framework for achieving the Kyoto deforestation objectives: it includes a network (grid) of photo plots from which area estimates are obtained, a sub-sample of ground plots for estimating other attributes, and re-measurements to estimate changes over time. However, the accuracy or reliability of the change estimates depends very much on the attribute in question.

Area of deforestation is, at the national level, a small quantity. For example, for the period 1986-91 Lemprière and Booth (1998) estimated that the annual area of deforestation in Canada was about 110,000 ha, which is only about 0.01% of the total forest area. The Lemprière and Booth estimate was based on data from the Canadian Council of Forest Ministers (1997) which indicated that 88,000-103,000 ha of forests was permanently converted each year to non-forest uses in Canada. An extensive sample such as the NFI, which does include deforestation as an attribute, covers only a small proportion of the population area (1%). Although the NFI will provide useful deforestation data, it cannot be expected to pick up and sample reliably such small and likely scattered areas. A useful way to get deforestation is to use NFI as a framework, but it must be enhanced.

Enhancements to the NFI are required to increase the reliability of the estimates of small and scattered areas of deforestation. Enhancements include:

- improving the capability of determining changes in land cover
- improving the capability of identifying land use classes and their changes, in particular deforestation
- including carbon stock and carbon change in the estimation of attributes

This paper describes a design for a measurement and reporting system based on an enhanced NFI structure using remote sensing information to report on deforestation for the Kyoto Protocol. Details of the design options and the remote sensing studies are contained in Leckie et al. (2000). The following presents various design options based around a core design. Issues related to the designs are discussed. The paper concludes with a description of the next steps in the development of a national system for determining and reporting on areas of deforestation under the Kyoto Protocol.

2. The Core Design

The core design should be simple and cost-effective. It should make use of the information available from the NFI, specifically the deforestation data available from the 2 x 2-km plots. This would avoid having two different estimates and should make the design more cost-effective.

A core design must consider the sources of information, the attributes of interest and any design constraints. The core design illustrated in Figure 1 is an integrated design with the following characteristics:

- Initial stratification of the population into areas of high and low deforestation activity
- The use of NFI and remotely sensed data to obtain an estimate of deforestation in high activity areas. The two estimates of deforestation are integrated using a ratio estimator.
- The use of NFI photo plots to obtain an estimate of deforestation in low activity areas.

The population is that area of Canada that can be expected to grow trees. Deforestation is expected to occur mostly on the forest fringe (i.e., on the borders with agriculture, industrial and urban areas). The population will be stratified into areas of high deforestation (Stratum H) and areas of low deforestation (Stratum L). Different sampling approaches and intensities will be used in the two strata – Stratum H will be sampled intensively, while Stratum L will be sampled extensively.

The specifics of the shape and size of Stratum H remains to be determined, but it is anticipated that there will be a number of areas in Stratum H, and that the area of Stratum H will be much smaller than Stratum L. NFI stratification (by Ecozone and by province/territory) will be retained.

2.1. STRATUM H - EXPECTED HIGH DEFORESTATION

Estimate deforestation area as follows:

1. Obtain suitable multi-date satellite imagery covering the area of Stratum H.

2. Establish NFI size plots on a 10 x 10-km grid and extract from the satellite imagery areas of any change that could possibly be deforestation. Using a sequential approach[1], label the change areas as deforestation. One quarter of these plots will overlap the NFI plots.
3. Obtain the NFI derived deforestation data for the NFI plots.
4. Use a double sampling estimator to obtain an integrated estimate of the deforestation area.

The 10 x 10-km spacing of the satellite based plots means that there are four times as many of these as of the NFI plots. This is therefore the larger sample. One-quarter of the satellite plots reside at the same location as the NFI plots. This comprises the smaller double sample, having deforestation estimates from both the satellite and NFI sources.

The derivation of an integrated estimate is accomplished through the double sampling estimation formulae. Several versions are available. An appropriate one is double sampling for ratio estimation, in which the average deforestation area is estimated by:

$$y_R = (y/x)\, x'$$

where: y_R = average deforestation area;
y = average deforestation area from the NFI plots (small sample)
x = average deforestation area from the satellite plots (small sample)
x' = average deforestation area from the satellite plots (large sample).

Having identified the areas of deforestation, the amount of carbon sequestered on these areas before and after the deforestation (the carbon change) must be determined. Carbon is usually measured indirectly, from biomass (in general, one tonne of oven-dried biomass is equal to one-half tonne of carbon). Biomass is estimated from biomass equations, which tend to use the same independent variables as wood volume equations. Biomass may be derived from the volume equations; therefore carbon can be derived from the volume data available from forest inventories.

The average deforestation area (y_R) must be multiplied by the average carbon stock change for that area. Average carbon change is derived from the stand characteristics of the deforested areas on the NFI plots. These in turn are based on forest inventory data. For each plot, on each measurement occasion, stand characteristics of the deforested areas are determined and applied to yield models to derive volume estimates. Biomass estimates are derived from the volume estimates and, from the biomass estimates, the carbon estimates are derived.

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[1] The sequential approach to labeling of change areas involves:

1. Use the imagery/maps and other readily available sources of information to determine
   - which change areas are definitely deforestation
   - which change areas are definitely not deforestation
   - which change areas are doubtful
2. Use other sources of information (land use data, air photos, local agencies) to determine which of the doubtful ones are deforestation.
3. If some change areas remain doubtful or uncertain, set up a procedure to handle them.

Next, calculate the carbon change for each plot and the average for all plots. This average is expanded to represent the total carbon change due to deforestation for the strata represented by the plots.

2.2 STRATUM L - EXPECTED LOW DEFORESTATION

Only the NFI plots are used in this stratum so the procedure for estimating deforestation area is simple, obtain the deforestation data from the NFI plots in the stratum and calculate the average.

Unlike Stratum H, carbon change can here be derived for each NFI plot and averaged. The procedures is as follows:

1. Obtain the stand characteristics for deforested areas of each plot, on each measurement occasion
2. Apply stand characteristics to yield models, determine biomass from the resulting volume estimates and, from the biomass estimates, the carbon estimates
3. Calculate the difference for each plot and the average for all plots. This is the average multiplied by the area of the strata.

This approach is standard simple random sampling so formulae for the derivation of precision estimates are commonly available.

2.3 POPULATION STATISTICS

Population statistics are arrived at by combining the estimates from the two strata. Population means and totals are weighted (by area) averages of the two stratum values. Precision estimators, if not available, can be derived.

3. Discussion

This approach utilizes the satellite imagery to sample intensively where deforestation activity is high (Stratum H), and integrates these estimates with the NFI based values using a double sampling estimator. In Stratum L, where deforestation activity is low, only the NFI plots are used. Due to the large area of Stratum L, the sample size will be large and the anticipated precision good. This is a simple base design on which to build and discuss options.

Many modifications may be made to the core design including eliminating the stratification and changing sample size and plot size. The exact nature of the stratification strongly influences cost and the number of satellite images needed. This needs to be explored in more depth. The total area of satellite imagery interpreted impacts the time and cost of interpretation. How this area is best distributed in terms of number and size of samples is a design consideration. Indeed, it may be viable to delineate deforested areas for the entire coverage (Stratum H). It must be noted that the vetting of possible deforestation to confirm them as deforestation by closer scrutiny or use of other sources of information, as in the sequential approach, is one of the most time consuming elements. As well, determination of the carbon change for sites requires that the forest cover be known so volume to biomass to carbon relationships can be applied. This implies that the location of the deforestation be related to the forest inventory or at a minimum a broad forest type interpretation from the imagery. The work load involved in relating sites to forest inventory data depends on the information access and extraction tools and protocols available. The trade-off between careful vetting and leaving some areas unconfirmed is an important issue. Options range from: a) applying the double sampling to all sites identified as possible deforestation without any vetting, to b) assuming all unconfirmed sites are deforestation (if the area is small it may be more cost effective to accept the negative carbon consequence than expend effort in determining the carbon change more precisely), to c) a case where time and money is spent to confirm all cases and the double sampling is not needed. The most appropriate options will depend on, among other factors, the number of possible sites that remain doubtful after simple image interpretation of the satellite imagery along with the use of easily available ancillary information (local records). The most likely operational scenario will lie somewhere between these extremes; the following gives an example of such an integrated system.

Applying the double sample to all plots and deforestation sites seems unnecessary, as the satellite and NFI interpretation will be correct in most cases. Using the double sampling for only the uncertain areas/areas of doubtful deforestation may be a good option. Figure 2 outlines this approach. The derivation of an integrated estimate is accomplished through the double sampling estimator in which the average uncertain deforestation is estimated by:

$$y_R = (y/x)\, x'$$

where: y_R = average uncertain deforestation area;
y = average uncertain deforestation area from the NFI plots (small sample)
x = average uncertain deforestation area from the satellite plots (small sample)
x' = average uncertain deforestation area from the satellite plots (large sample).

Having identified the areas of uncertain deforestation, the amount of carbon sequestered on these areas before and after would be determined from the forest inventories as above. The average deforestation area (y_R) must be multiplied by the average carbon change for that area. Average carbon change per hectare of deforested land is derived from the stand characteristics of all the deforested stands identified on the NFI plots. These are based on forest inventory data. Stand characteristics of the deforested sites of each NFI plot are determined on each measurement occasion. Volume estimates for each site are then determined by applying the stand characteristics to yield models. An average over all the plots is determined and applied to the average uncertain deforestation area of the remote sensing plots (y_R). Within this example there are design variants related to, for example, whether the carbon change should be derived using an average of all deforested areas of the NFI plots or just an average for the uncertain, or whether it is determined by calculating the carbon stock an all uncertain areas identified on the satellite plot and then using the double sampling parameter (y/x) to estimate what proportion of this is related to actual deforestation. This procedure or variants of it gives an estimate of the carbon change on the uncertain areas of the satellite plots.

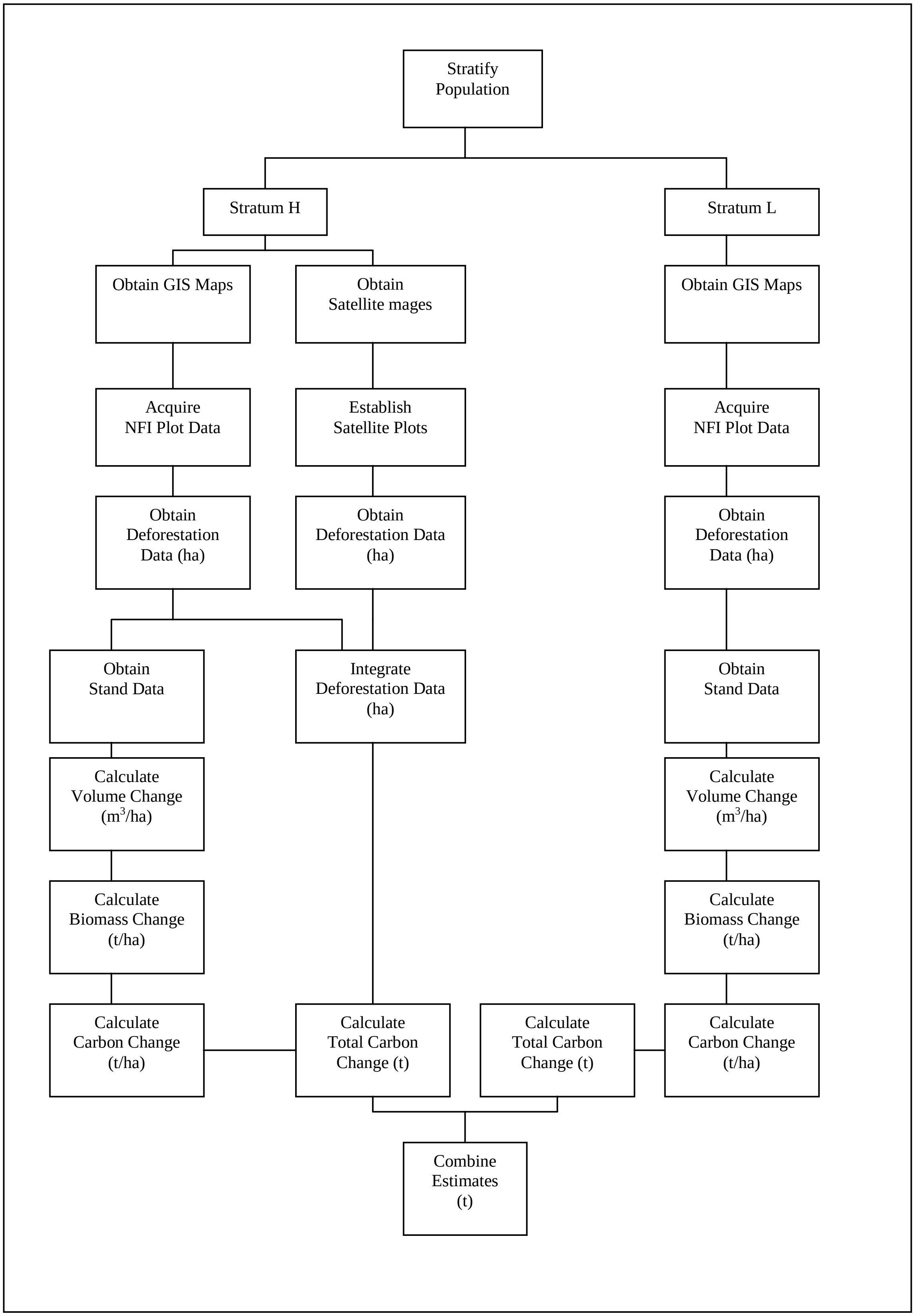

Figure 1. A schematic of the integrated, stratified core design.

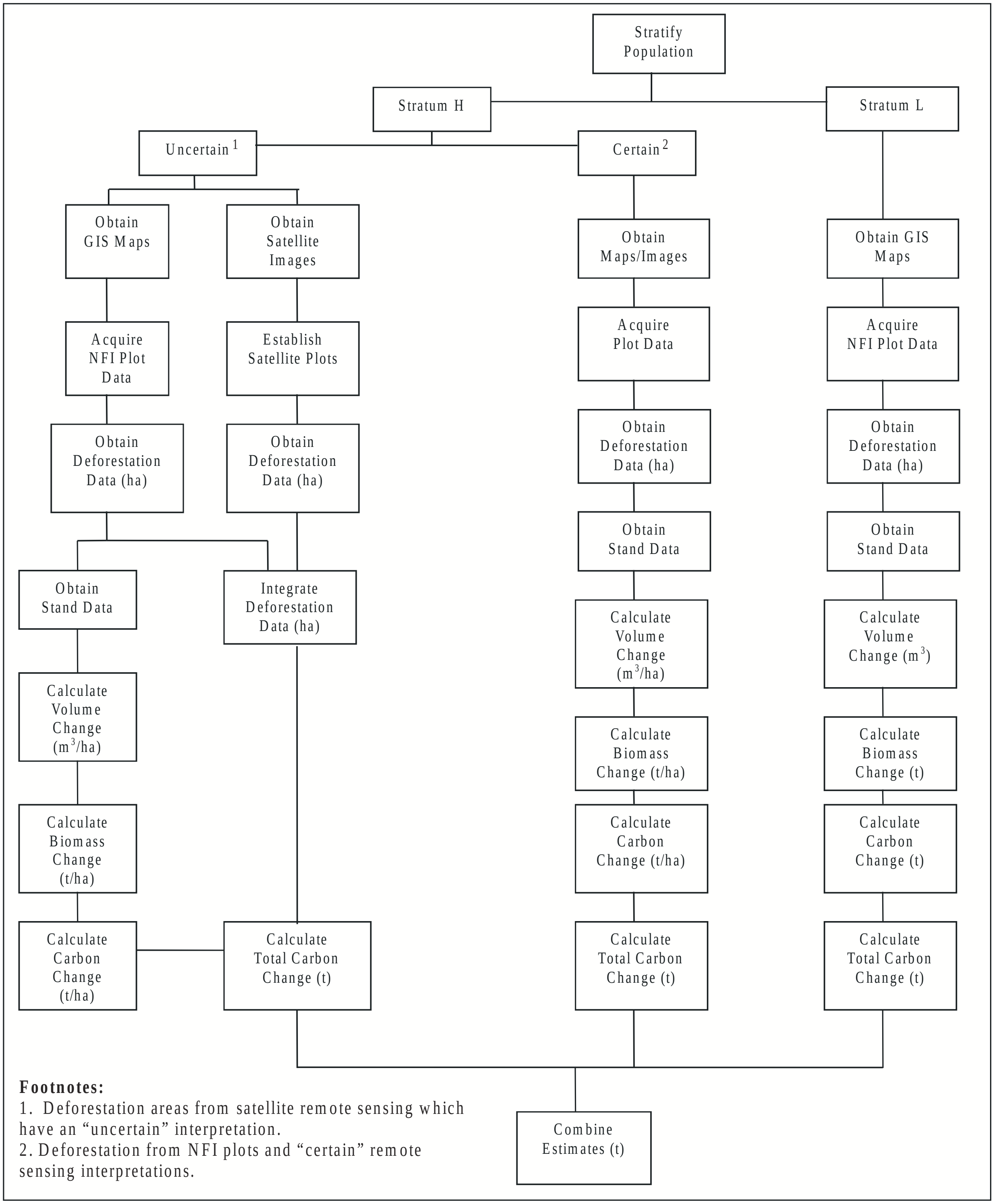

Figure 2. A schematic of the integrated, stratified core design with double sampling for uncertain satellite interpretations.

The estimate of total carbon change due to deforestation for all the plots would be the sum of the carbon change for the “certain” deforestation areas calculated for the NFI plots and for confirmed areas of the satellite plots plus the estimated carbon change (through the double sampling method) for the uncertain areas of the satellite plots. This would then be prorated/expanded to estimate the total carbon change for the strata represented by the plots.

4. Next Steps

The next steps in developing a deforestation measuring and reporting system are to test the design and to arrive at a refined, tested and ready-to-implement system design using NFI, remote sensing, and other data sources to address deforestation.

Testing with three components is proposed.

1. Testing the core design methodology on two study areas. This involves establishing 100 - 200 NFI photo plots (linked with NFI pilot projects) and two Landsat TM scenes per study area. This process exercises the mechanisms and procedures, providing an opportunity to refine the system and reporting the test results. The steps include:
    - Establishing NFI plots (drill existing provincial inventory databases or interpret from aerial photography)
    - Expanding the coverage using satellite TM imagery. Define areas of change; label the type of change
    - For the deforestation areas, extracting information about forest cover and using this to derive wood volumes, from which biomass and carbon estimates can be derived
    - Combining satellite data sources with NFI data sources
    - Generating statistics
    - Assessing accuracy and efficiency of system design
    - Identifying areas of refinement
    - Adjusting and reporting
2. Conducting a pilot project (operational trial) on a region of high deforestation activity. This would involve a complete remote sensing/NFI photo plot incorporated trial.
3. The testing and the operational trial are undertaken over a limited range of conditions. To address this and to demonstrate some national capabilities, a national survey using approximately 40 satellite images would be conducted. This would provide additional experience on the remote sensing analysis under a wide variety of conditions. This would also help identify the types, locations, patterns and rates of deforestation. A national survey could also help define where to focus the sampling and identify the sample design. This could also provide a first approximation of the amount and rate of change associated with deforestation in Canada. A minimum number of NFI plots would also be established as part of the survey.

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