TIMELY, OBJECTIVE, AND ACCURATE CROP AREA ESTIMATIONS AND MAPPING USING REMOTE SENSING AND STATISTICAL METHODS FOR THE PROVINCE OF PRINCE EDWARD ISLAND, CANADA

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ABSTRACT

The provincial government of Prince Edward Island, Canada, required timely, objective, and accurate annual crop area statistics and mapping for 2006 to 2008. Consequently, Statistics Canada conducted a survey incorporating medium-resolution satellite imagery (10 to 30 m) and statistical survey methods. The objective was to produce crop area estimates with a coefficient of variation (CV) as a measure of accuracy, and to produce maps showing the distribution and location of different crops and land cover types. Conducting a multi-year study gave Statistics Canada an opportunity to refine the methodology in order to reduce data collection and processing while maintaining high quality estimates. The optimal parameters to design the area survey and the choice of the satellite imagery depend on a number of parameters: average size of field, desired accuracy, distribution and abundance of crop types, as well as availability of historical data. Data collection, using a sample frame of the entire province, was conducted from the roadside or air, so did not require any input from farmers. Results were produced within one month after data collection. When comparing 2006 with 2008, accuracy was maintained for potato (CV of 1.6% in 2006, 1.9% in 2008) and total agriculture area (CV of 2.7% in 2006, 2.3% in 2008), while the amount of sampled land surveyed dropped from 16% to 7% of the total area (5,700 km2), substantially reducing the amount of work for preparation, collection and processing. The results of this study will help users to select optimal parameters for an inventory of their area of interest. The benefits of using this type of survey compared to the traditional crop survey methods are: relatively low cost, no response burden on farmers, timeliness, objectivity and accuracy of the estimates, and no sophisticated survey infrastructure requirement.

Keywords: agriculture, crop mapping, crop area estimation, statistical methods, remote sensing, Canada

INTRODUCTION

Timely and accurate information on the area and location of crops, and more generally land cover/land use, is an important input to agricultural, rural and environmental decision making and policy development. For example, such information can inform debates concerning crop rotation, conversion of forested land to farmland, loss of farmland to urban development, environmental issues related to rural and urban areas, and so on. Traditional techniques to generate this type of information involve direct collection of information from land owners or users, which not only involves respondent burden but requires also the existence of a complete farm register for the survey frame. Delays may also be introduced due to the combined length of the collection, processing and analysis periods. The quality of the published results is also subject to the accuracy of the data supplied by farm operators.

Area sample frames have been used for a number of years for replacing a farm register (Von Hagen et al., 2002, Faulkenberry and Garoui, 1991), especially for crop area estimation (Graham, 1993, Gallego, 1999, Adami et al., 2007). Multiple parameters to conduct this particular type of survey need to be set, and will influence the quality of the results (Leica Geosystems, 2003), although research to study their impact is very limited in agriculture, especially with operational applications. Wang et al. (2008) have studied the effect of changing the size of sampling units and the sampling method in the accuracy of crop area estimates. Local conditions have to be accounted for, for example land accessibility, the average size of fields and the number of crops found. In addition of using an area sample frame, the availability and declining cost of remote sensing imagery, in conjunction with ground data collection and the use of statistical methods, have opened up the opportunity of producing crop area estimates without any contact with respondents (Group on Earth Observations, 2008).

In the United States, this methodology has lead to the production of the Cropland Data Layer (USDA/NASS, 2009), a satellite derived distribution map of crop types for the entire country, which resulted in the production of annual area estimation by crop type by state or county, an extremely valuable tool for the agriculture community.

The Agriculture Division of Statistics Canada was engaged by the Prince Edward Island (PEI) Department of Agriculture in the spring of 2006 to conduct a study on the improvement of potato area estimation and land cover classification for a three year period. Apart from producing timely, objective, and accurate estimates and a land-cover/crop type map, secondary objectives were to monitor crop rotation, enforced by provincial regulations (Government of Prince Edward Island, 2008), and provide data for modeling nitrate contamination on surface and ground water (Savard and Somers, 2007).

This paper reviews the methodology used and presents results from the three year study period, emphasizing the difference in the sample design made between the three years, with an explanation of why modifications were implemented.

OBJECTIVES

The primary objective of this project was to develop a methodology to produce timely, accurate, and objective crop area estimates using satellite image data and statistical methods.

A secondary objective was to refine the methodology over the three years of the project to generate efficiencies while preserving the high level of accuracy of the estimates produced.

METHODOLOGY

Study site

Prince Edward Island (PEI) is Canada's smallest province. The island is located in the Gulf of St. Lawrence, on the east side of the country (figure 1). It is about 224 kilometres in length and between 6 and 64 kilometres in width, with a land area of approximately 5,662 square kilometres (566,171 ha).

Agriculture is one of the dominant industries of the province. According to the 2006 Census of Agriculture (Statistics Canada, 2006), the province had 2,509 square kilometres of land devoted to agriculture (44% of total area), with 1,712 square kilometres in annual crops (30% of total area), 228 square kilometres in pasture (4% of total area), and 560 square kilometres for other agriculture land (mostly fallow, wetlands and woodlands, 10% of total area). Agriculture is present in all areas of the province, but with an uneven distribution throughout the area (see figure 2, section on stratification).

Statistics Canada holds information about crops grown in PEI for the three years of the study. Although the data were not available at the time the remote sensing work was completed, they were used after results of this project were obtained as a basis for comparison.

Statistics Canada runs the Census of Agriculture every five years by distributing questionnaires to all Canadians that claim to generate revenues in the agriculture industry during the Census of Population data collection. Data are gathered at the beginning of the growing season, so areas provided by farmers are "to be seeded" or "to be harvested", depending if seeding already took place.

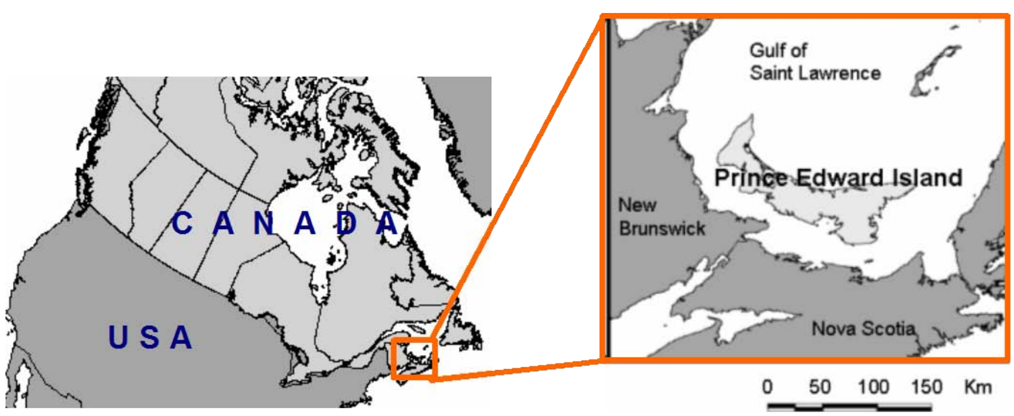


Figure 1. General location map of study site

The last Census of Agriculture was conducted in 2006, the first year of this study. Statistics Canada's Farm Register is updated using the Census data which is then used by traditional agriculture surveys as their sampling frame.

Other sources of traditional estimates (that is, collected by survey directly from farmers using the Farm Register) are the Field Crop Reporting Series (FCRS) and the Potato Area and Yield Survey (PAYS). This information is collected every year in different stages, from seeding intentions in the spring to the harvested areas in the fall.

Between 10,000 and 30,000 farmers are surveyed (Canada wide) for the FCRS program, and 550 farmers are surveyed in the PAYS in each phase of the program. This allows the release of information on seeded and harvested areas, yield, production and stocks for major crops by province, and by smaller Census agriculture regions, when the sample size is large enough for the crop type.

Table 1 enumerates areas of the main crops of the province, using 2006 Census of Agriculture data, as well as the survey estimates for the three years of the project. Potato area is of particular interest to PEI since farm cash receipts from this crop represent over 80% of the total crop receipts in the province, and especially since PEI accounts for nearly a quarter of total Canadian potato production (2008 figures).

Table 1. Area for major crops in Prince Edward Island

	Survey estimates – seeded area[1]			*Census of Agriculture*[2]
Crop type	***2006***	***2007***	***2008***	***2006***
		--------	ha	--------
Tame hay	58,300	63,100	58,700	63,699
Potatoes	39,499	38,851	37,435	39,512
Barley	36,400	34,400	31,200	32,071
Spring wheat	12,100	7,700	15,000	9,267
Soybeans	4,900	4,500	7,300	4,580
Oats	4,500	4,900	4,900	5,079
Mixed grains	5,700	4,000	3,200	4,096
Blueberries	3,845	NA	4,047	3,967
Total rye	NA	NA	NA	2,205
Winter wheat	2,800	3,000	2,000	2,012
Corn	NA	2,400	2,800	2,627

Data sources

[1]Survey estimates: Field Crop Reporting Series, Canadian Potato Production, and Fruit and Vegetable Production, Statistics Canada, catalogue number 22-002-XIE, 22-008-XWE, 22-003-XWE

[2]Census of Agriculture: Statistics Canada 2006 Census of Agriculture

Sample design

Historical census and survey data gives a good indication on what to expect for the preparation of the remote sensing work.

Since it would be too expensive in cost, human resources and time to acquire information on the entire land area, the sampling approach was used. The objective was to draw an efficient and representative sample of these area units, measure the variables of interest, and produce a weighted estimate that would apply to the entire population of units. The area estimates include an estimate of the coefficient of variation (CV), which basically provides a statistical measure of the precision of the sample estimate.

The statistical parameters used for designing the sample survey include:

- Definition of sampling unit;
- Stratification;
- Distribution of sample between strata;
- Sample size.

Sampling unit

A key decision in the design of a sample survey based on area is the definition of the sampling unit. For traditional agriculture surveys, a sampling unit is logically defined as a single farm operation. In terms of size, farm operations all have different sizes. The information of the location of each land parcel of every farmer is not available, so using farm operations as a sampling unit is not an option.

A second option would be to use individual fields as units. This method would require holding a register of fields that are in operation at the time of the survey. A land cover and crop type classification of year 2000 was available (Dobbins et al., 2000), however it was already 6 years old at the beginning of this project, while changes occur: every year, some fields are merged, others are split, new fields are created and some are abandoned. It was felt that the 2000 land cover data was not a reliable source of information because of the potential under- or over-coverage on the register.

The method mostly used for area estimation using an area sample frame is to divide the total land area into parcels of equal size that cover the entire area. This method would allow accounting for expansion or desertion of agricultural land because the entire land area is part of the population, and is the chosen option for this project. The grid definition follows the Universal Transverse Mercator projection system, zone 20 (using the North American Datum 1983 earth model).

The size of the sampling unit is a parameter of sampling design. Several factors were considered in the choice of the size.

The benefit of using large sample cells is that since sampled units will need to be visited during sample data collection, the use of large units will minimize time and traveled distance between units. However, large cells would generally hold the same general contents (proportion of cropland, pasture, forest, etc.) compared to smaller cells, so this reduces the benefit of stratifying the population (see next section).

On the other hand, there are several benefits in using small area units. Smaller cells will likely have more homogeneous contents, resulting in less variability in the parameter to measure, a benefit that stratification will take advantage of. Also, data collection by air is not efficient when too many fields need to be collected in a small area, and causes the team to fly in a light aircraft and circle over the area many times. Another reason for using smaller cells is that a greater number of units will be required for sampling, and will give better geographic representation, in case the distribution of the variable of interest is asymmetric throughout the area.

The drawbacks of using small area units need also to be considered. It is imperative to take into account the average size of the unit to sample, in this case a field. The average field size in PEI varies from 4 to 9 hectares, depending on the region. It is necessary that each sampled unit contain a minimum number of fields to reduce variability in the parameter to quantify, especially for single crop type area estimation. Also, the smaller the unit, the larger the sample size will be, which means the total traveling time and total distance between cells during data collection will be greater.

Stratification

Stratification is commonly used to reduce sampling costs. Stratification is done in order to divide a population frame into consistently homogeneous strata, from which samples within homogeneous strata are selected. Stratification therefore lends itself to producing sample estimates with less variance or with greater precision than from a non stratified population. It is desirable to identify as few strata as possible while retaining a high degree of uniformity in each stratum. Stratified units do not have to be spatially connected.

Stratification implies that preliminary information is known for the area of interest, which may not always be the case. A common practice to overcome this requirement is to acquire earth observation satellite data and to classify the area using image interpretation (Group on Earth Observations, 2008). Archived mid-resolution (spatial resolution between 10 to 100 m) satellite data are usually available at no cost.

Knowledge of the surveyed area helps in selecting the variable used for stratification. Since a 3- to 5-year crop rotation pattern is a common practice in PEI, using a single crop with a single year of data is not recommended. With a single year of data, a better decision would be to use to the entire agriculture land for stratification (figure 2). In the case of our study, one of the objectives was to produce the most accurate estimate for a single crop, namely potatoes. Since potatoes are not necessarily evenly distributed in the province, the best variable to use for estimating potato area would be historical potato areas, but multiple years of data are required because of crop rotation.

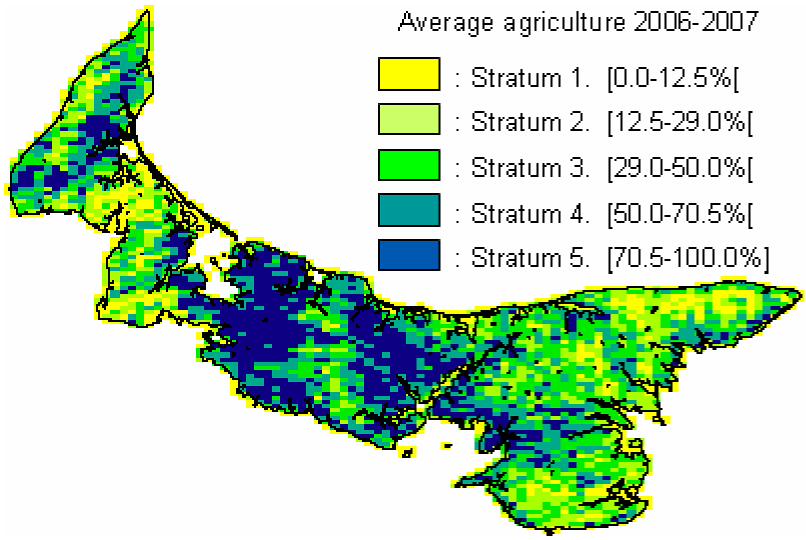


Figure 2. Stratified area sample frame for year 2008

Distribution of sample between strata

Weights will be established based on the number of units per stratum and the number of sampled units. The stratification process established homogeneous clusters of units, with their own variability. A smaller number of units are required to be selected for the strata with less variability: in our case, the stratum with the lowest amount of agriculture (<12.5% of total land for the 2008 design). A small amount of sampled units will create larger weights, which can produce unpredictable results and cause the accuracy to decline, especially for single crop area estimate, where crop rotation is observed. The objective for this step is then to maximize the amounts of sampled cells in strata of higher variability (proportional to variance), but with retaining a minimum amount of units per stratum, to avoid weights that are too large.

Sample size

The last parameter to set for sample design is the sample size, which is usually driven by resource availability. A large sample size has a greater probability of producing estimates of greater accuracy, but would require a large effort in data collection and processing, which would delay the production of results. This would also more likely generate a larger proportion of collection and processing errors. The desired accuracy must also be taken into account when making the decision as to the number of sampled units required.

Holding auxiliary information will help in optimizing the decision on sample size. In the case of this study, the work achieved in 2000 was used to run simulations to anticipate accuracy obtained for different sample sizes. After completion of year 1, results were used in year 2 to simulate accuracies expected using different sample design models. The decision on sample size and other parameters for the sample redesign were more optimal for year 3, because of the availability of data from the previous two years of the study, and the experience and results obtained from the first two years.

Regression Estimate

This method involves the use of auxiliary information to adjust a weighted estimate (Pantel, 2007). Collecting field data is a costly procedure, and to do so across the entire area is prohibitively expensive. As such, field data is collected on a sample basis. Satellite image-derived crop classification data, on the other hand, is relatively inexpensive to acquire, as it can be generated across the province covering all units of the statistical population. Since we expect these two sources of information to be highly correlated, a regression estimator is an appropriate statistical estimation approach to increase the accuracy of the area estimates.

To produce the regression estimate, the sampled observations are split in halves: the first half is used to produce a gross weighted estimate; the second half is used to train the satellite classification. The classification produces a distribution of the land cover variables for the entire area. For this study, only the potato area estimate, the main crop type for the province, was refined using this method, because of the importance of this crop.

A preliminary indicator of total potato area is produced by counting the number of potato pixels (and converted to an area) of the satellite classification. However, this direct conversion approach does not take into account any inconsistencies in classification performance within and between satellite images, resulting in a bias.

The regression equation is used to correct a preliminary estimate and produce an area estimate with higher accuracy (lower CV). The conditions for this method to produce accurate results are to acquire field data information of high quality (high response rate, fields digitized using accurate imagery) and to produce a satellite classification with complete coverage and high precision. This will produce a high correlation between both data sources, resulting in good performance of the regression estimate. Figure 3 shows the regression fitted for the potato area in 2008.

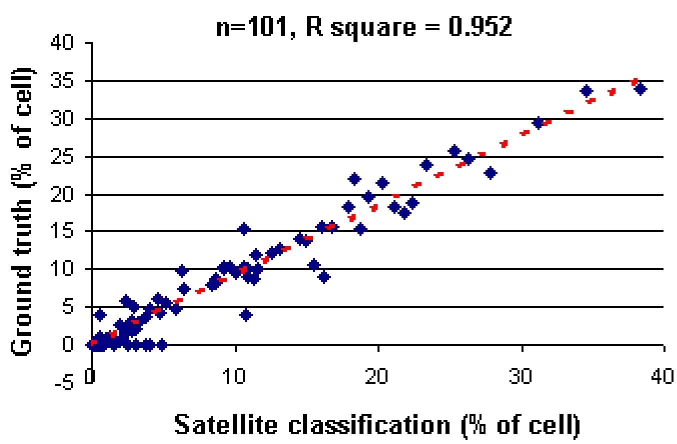


Figure 3. Illustration of correlation between ground truth and satellite classification for 2008 potato area regression estimate

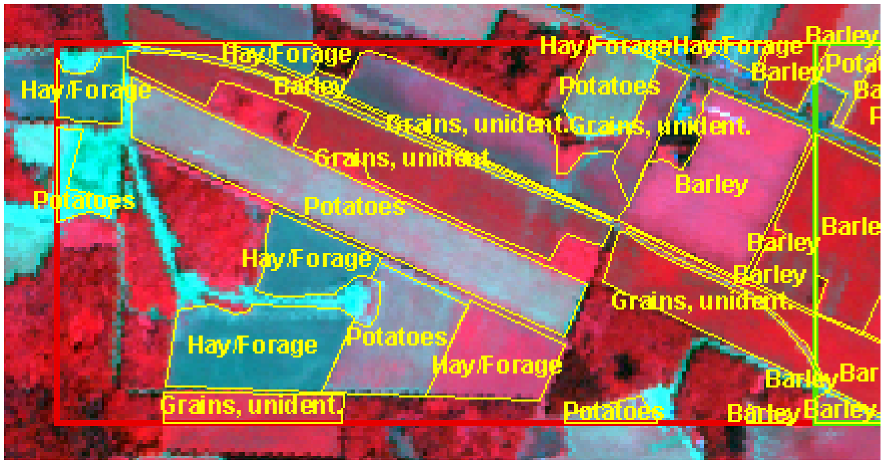


Figure 4. Digitized fields for one sampled area unit for 2008

Data collection and information extraction

Input data in two forms are required to produce the estimates using the regression technique: 1- Ground data collection 2- Satellite data imagery

Ground data collection

All agricultural fields and land cover must be identified and located correctly within each of the sampled cells. This field data is collected using a combination of aerial and ground surveillance and is conducted during the last week of July through early August, when identification of most crop types by airplane or from the roadside is easiest.

The easiest and most reliable method of identifying land cover or crop type is from roadside. To reduce response burden to producers, land cover and crop type identification is made only from public roads. Fields or other portions of land that are not visible from the roads are collected from the air, in order to ensure a 100% response rate to maximize the accuracy of the results.

Once data is collected, polygons are digitized using historical background medium-resolution satellite imagery (figure 4) and area by cell for each class is calculated with a geographic information system.

Satellite data imagery

In order to identify land-cover and crop type using satellite data, multi-spectral imagery of the visible and infrared areas of the spectrum are acquired preferably from 2 periods: end of spring (late May to early June) and from the middle of summer (end of July to mid-August). The early season imagery is used to separate perennial forage (hay/alfalfa), pasture and grasslands fields from later season cultivated annual crops (i.e., potatoes, cereals, soybeans, vegetables etc.). Ideally, the image data is also cloud- and haze-free.

The average size of a field for the area of interest will dictate the required spatial resolution. A resolution too coarse will produce a large proportion of mixed pixels (pixels that include more than one cover class), producing a classification of poor quality. A resolution that is too high will not bring additional accuracy but will be more expensive to acquire (cost) and to process (time and disk space). In the context of PEI, a spatial resolution of 10 meters is ideal (offered by SPOT 5), while SPOT-4 (20 meters) and Landsat-5 (30 meters) served as a secondary solution in case of extensive cloud-coverage on the SPOT-5 imagery.

The classification method used is described in Fisette et al. (2006), and is a rule-based multi-date and multi-spectral classification, using a land segment model to filter the classification result to remove isolated pixels.

The results of the satellite data classification can be used in two ways. First, for the production of a map, that aside from being an attractive visual product can be used to estimate crop areas or other land cover types by any available geography layer, such as watersheds or municipalities. The second use of the classification is to generate the regression estimate and improve weighted area estimates. Figure 5 shows a portion of the 2008 classification map.

RESULTS AND DISCUSSION

This section describes results obtained for potato and total agriculture area estimates and changes brought to the methodology for the sample design between the three years.

Table 2 summarizes the different parameters described in the methodology section used for the three years of the project, and the accuracy of the results obtained. The following section discusses the main reasons for refining the methodology. It was not possible to isolate the effect of changing one parameter on the accuracy obtained for this project because of operational constraints. Each year, a combination of parameters were changed simultaneously to expect the desired result.

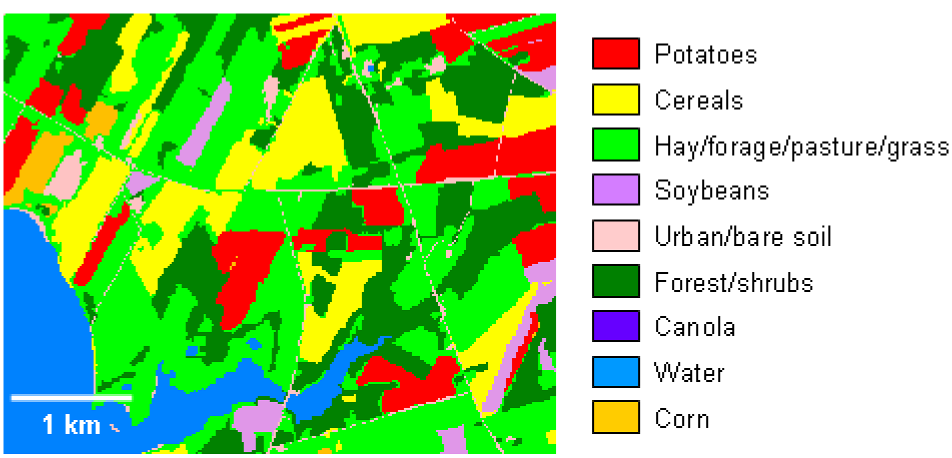


Figure 5. Portion of the 2008 Land-Cover/Crop Classification

Table 2. Parameters for sample design and results for the 3 years of the study

	Year		
Design Aspect	***2006***	***2007***	***2008***
Sample unit (cell) size	2 km x 3 km	1 km x 1 km	1 km x 2 km
Population size	1,217	6,546	3,387
Sample size	147	360	202
Sampled area, km^2	882	360	404
Portion of province in sample, %	15.6	6.4	7.1
Number of strata	6	5	5
Stratification variable(s)	Total agriculture in 2000	Average % of area in potatoes in 2000 and 2006	Average % of area in agriculture in 2006 and 2007
Allocation of sample to strata	equal	proportional to variance	proportional to variance
Largest sampling weight	29.4	206.5	29.95
Travel distance between cells, km	Air : 1,045 Ground: 1,472	Air: 1,390 Ground: 1,943	Air: 1,158 Ground: 1,628
Time required for data collection, hours	Air: 30 Ground: 15	Air: 20 Ground: 45	Air: 15 Ground: 50
Area and CV for total agriculture (weighted estimate), ha (CV %)	182,462 (2.7)	187,371 (5.4)	193,986 (2.3)
Area and CV for potato area (regression estimate), ha (CV %)	38,700 (1.6)	40,200 (3.4)	37,460 (1.9)

Year 1 – 2006

For the first year of the project, only the 2000 land cover and crop satellite map project was available as a reference. As well, traditional survey (conducted every year) and the Census of Agriculture numbers (2001) served as general information of the agriculture activity in the province, but without information on spatial distribution.

The size of the area unit was set at 6 square kilometres, the same size used in the 2000 project (Dobbins et al, 2000). Because only a single year of historical data was available in 2006, it was preferable to use total agriculture in 2000 for stratification, because single crop distribution changes year to year with crop rotation. Almost equal weights between strata were used to avoid large sampling weights of individual sampling units.

To make sure accurate results would be obtained and given the lack of recent data to produce simulations, a large sample size was used. Because of the large amount of ground truth data collected required, it was decided to acquire most of the land cover data by air, where large distances can be covered rapidly. Ground information was collected only for fields that were missed or could not be identified from the air.

Very accurate results were produced for year 1. A simple weighted estimate was enough to produce a total agriculture area estimate (CV of 2.7%), while the regression estimator for potato area produced a very low CV of 1.6%. Estimates with a CV under 5% are considered of excellent quality.

Year 2 - 2007

The amount of field data required to produce the high quality results for year 1 required an enormous amount of time during the process of data collection (planning and execution), data processing and quality control. This resulted also in a delay in delivering the estimates. It was decided for year 2 to try to reduce the amount of sampled area by changing parameters to optimize the sampling design.

Even if data collection from the air is productive, operational constraints limit flying time to 3 to 4 hours per day. Also, the high speed of the plane imposes expeditious data collection, which results in omissions and identification errors that have to be corrected from ground identification or image interpretation (6.9% of all fields for 2007, Bédard (2007)). Also, bad weather conditions can delay data collection by air, which is rarely the case from the ground.

As a result, it was decided that for year 2, most of the data acquisition would be made from roadside. Although more time-consuming, this collection method produces fewer identification errors and omissions than from the air (2.4% of all fields, Bédard (2007)). Also, data could be acquired for longer periods of 8 to 10 hours per day. It was found that around 70% of the fields could be identified from public roads.

Simulations using year 1 of the study concluded that smaller cells (1 square kilometre) using potato area for 2 years (2000 and 2006) would produce higher quality estimates using a much smaller sample size. The total area sampled was reduced from 15.6% to 6.4%.

Finally, one last design aspect that was changed from year 1 was to have a distribution of sampled units proportional to the variance between strata. But since only two years of potato area data was available, this produced unexpected results: one sampled unit with a large weight without potatoes in 2000 and 2006 found a relatively large area of potato cropped for 2007, resulting in a lower accuracy of the final potato estimate. Accuracy of the regression estimate for potato area was dropped with a CV that increased from 1.6% to 3.4% (still an estimate with high accuracy).

The accuracy of the total agriculture area estimate also declined with a CV going from 2.7% in 2007 to 5.4% in 2008.

Year 3 - 2008

Specification from the client for year 3 required that Statistics Canada produces area estimates with accuracies comparable to year 1. This necessitated another redesign to increase accuracy without returning to a sample size comparable to year 1.

The cell size was increased from 1 to 2 square kilometres to reduce variability within each unit and increase the average number of fields per unit. Larger cells would also reduce total travel time between cells during data collection.

Also, total agriculture area, much more stable in time than individual crops, was used for stratification, and year 2000 was dropped and replaced with the most recent data available (average of year 2006 and 2007).

Although sample selection was based on variance between strata, a limitation of weight per cell comparable to year 1 was imposed to avoid the unexpected results of year 2. The total sample size was slightly increased from 6.4 to 7.1% of the total area, but the results of the area estimates improved greatly with a CV of 2.3% for total agriculture and 1.9% for potato area.

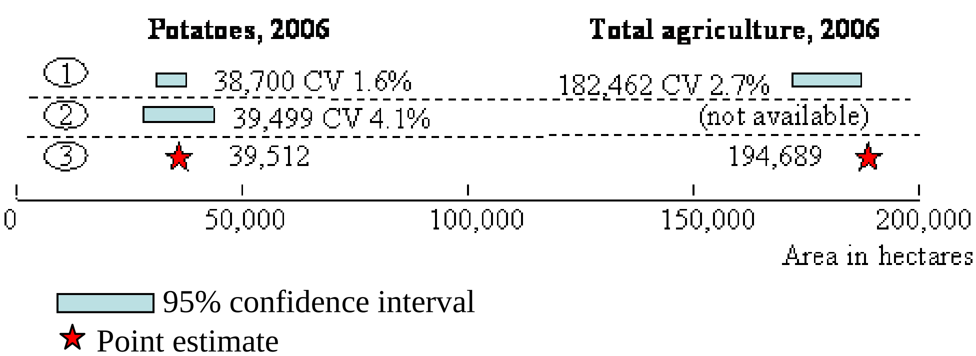
Comparing study results with traditional survey methods

Results from this project were compared with 2006 census data and traditional survey data for the three years. Figure 6 shows that estimates produced in this project were comparable using any of the three methods, but area estimates using the methodology described in this report are more accurate than the survey estimate and are released earlier.

This method does not recommend eliminating traditional surveys or the Census. Much more information can be collected by direct contact with farmers: in the case of crops surveys, information on stocks, yield, area seeded and harvested and production are also collected.

But the use of remote sensing and an area sample frame will have the following proven or potential benefits:

- Increase the accuracy of area estimates for certain crops (for PEI, potatoes, soybeans, total grains)
- Add crop area estimates that were not published by traditional surveys due to lack of accuracy (in the case of PEI, total corn and canola)
- Reduce response burden by reducing the sample size of traditional surveys.
- Solve land balance issues for a census of agriculture



1: Remote sensing and statistical methods, released September 2006
2: Canadian Potato Production, Statistics Canada, released November 2006
3: 2006 Census of Agriculture, Statistics Canada, released May 2007

Figure 6. Comparing results with traditional methods for 2006

CONCLUSION

For countries without the existence of a complete and accurate farm register that is up to date, which is expensive to build and maintain, the use of remote sensing and an area sample frame might be the only efficient method available to produce crop area estimates. Traditional survey methods also are dealing with the design, distribution and gathering of questionnaires and dealing with non-response. In addition to eliminating response burden on farmers, the remote sensing method also brings the benefit of showing the spatial distribution of crops, giving the possibility of showing regional differences and producing small area estimates using any standard or custom geographic boundaries.

Optimal parameters in the sample design using an area sample frame will not be the same for all crops and will vary from region to region. Parameters like general knowledge of crops grown, average size of fields, availability of historical data, available human and financial resources, available hardware and software, accessibility on the land to verify crop type, and the desired accuracy for results will all influence the design. This 3-year project, with the goal of producing accurate area estimates, summarizes the logic behind decisions that were taken to achieve the objectives given the resource limitations. Optimal parameters for such a project are rarely available ahead of time and have to be set with the available information at the beginning of the project.

Parameters set for the third year of this project proved to be the most efficient design, given the accuracy of the results obtained and the relatively small sample size, compared to the first year.

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