

# **An Historical Summary of Forest Inventory Sampling Designs in British Columbia**

A Report to the B.C. Ministry of Forests  
Inventory Branch  
Timber Inventory Task Force

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## **INTRODUCTION**

Forest inventory sampling methods have changed dramatically in British Columbia since the first attempts to quantify the timber resources in the early 1900's. Initially, inventories did not involve sampling in the usual sense but were compilations of any available information including rough guesses of volumes and areas. Often surveys of many different types were summarized to a common standard. Inventory sampling methods have become broader in scope and increased in complexity with the need for more detailed information, increased requirements of statistical reliability, improved aerial photography and computer technology, and improved aerial and ground access.

The Province is now preparing to re-design and undertake another inventory of the forest resources. Undoubtedly this inventory will be more intensive and more sophisticated than former ones and include factors that were not of concern in the past. More emphasis will likely be placed on non-timber resources. The Timber Inventory Task Force has been formed to advise on the technical aspects of the new inventory. Part of the process is to review the former inventories. This report is presented as part of this review and is concerned only with the sampling designs used in the previous forest inventories.

This report was prepared from discussions with individuals who were involved in the last two major inventories starting in 1951, and from a wide variety of published and unpublished historical and technical documents. The scope of this report is limited to the sampling designs used for estimating volume and does not consider sampling for decay or growth and yield. Included are various notes and comments that relate to general factors and conditions that may have affected what actually occurred. Unfortunately, this report was prepared under severe time limitations and thus not all possible sources of information were reviewed. However, this report should contain the major components of the sampling designs of the previous inventories. Hopefully this is sufficient information for the Task Force to interpret the objectives of the previous inventories and the sampling designs used in attempts to achieve them.

The history of inventory sampling in the Province is not always entirely straightforward. Often many programs were conducted simultaneously at various stages of development. I have tried to simplify the situation by discussing the sampling designs and other events in specific time periods. Sometimes this is appropriate and other times it might result in slight confusion or misrepresentation of the events.

The body of this report contains two major sections. The first gives an overview of four major periods in the history of inventory in the Province. The second discusses the historical trends in the inventories, and possible affects of future developments on inventory sampling designs. This is followed by three appendices. Appendix I is a table showing some important characteristics of the sampling designs by time period. This

should facilitate comparison among the various inventories. Appendix II gives a more detailed point-form listing of the major items of the sampling designs that were summarized in the first section of the report and in Appendix I. Appendix III is a histogram showing the number of inventory plots established by year, inventory period, and type of sample plot.

## SUMMARY OF MAJOR INVENTORY PERIODS

Many events have occurred since the first inventory near the turn of the century and often the timing and sequence overlaps and is confusing. This section summarizes the major events in four subsections. These subsections are named by major events that occurred in the time period. The following list shows the specific events (given in Appendix II) that are covered in these subsections.

### *Compilation Inventories (1910-1950)*

- Up to 1910 The First Compilation Inventory
- 1911-1918 The Second Compilation Inventory
- 1919-1937 The Last Compilation Inventory
- 1938-1950 Maintenance Surveys

### *The First Complete Inventory (1951-1960)*

- 1951-1957 The First Complete Inventory
- 1958-1960 Maintenance Surveys

### *The Second Complete Inventory (1961-1977)*

- 1961-1977 The Second Complete Inventory

### *Inventory and History Updates (1978-Present)*

- 1978 Sub-Unit Surveys
- 1979-1981 Inventory Update Program
- 1982-1987 History Update Program
- 1988-1991 Re-Inventory Program

## **Compilation Inventories (1910-1950)**

Prior to 1951, inventories were merely compilations of existing information. Of the three inventories in this period, and especially in the first (Fulton 1910), volume was estimated by guessing for many large areas. The next two inventories (Whitford and Craig 1918,

Mulholland 1937) used an increasing amount of information from surveys, but sampling was not done specifically for either. Where surveys were available, they were often done to different standards and thus were very difficult to summarize on a common basis. Sampling was really only used in the last inventory starting in 1927 and only for some areas of the Province. The sampling used in the 1927 inventory was strip cruising at various intervals, widths, and lengths. Estimates were given of volume by drainage basin and Forest Districts (roughly equivalent to the present Forest Regions).

The objective of these early inventories was to estimate how much wood was available for harvest. This was the level of information needed by the expanding industry at the time. Utilization standards changed dramatically in this period in terms of the size and species that were considered merchantable. Estimates quickly became outdated because of rapid expansion of the industry, the ability to utilize new species and smaller trees, and increasingly intensive management. Two World Wars and the depression of the 1930's had a dramatic affect on field operations for these inventories (Sloan 1956).

### **The First Complete Inventory (1951-1960)**

The second major period in the history of inventory sampling started in 1951 with the creation of the Forest Surveys and Inventory Division of the Forest Service and the signing of a Federal-Provincial agreement for a new inventory of the Province. This first complete inventory of the Province from 1951 to 1957 took seven years from planning through to compilation. At the time, preliminary information from former inventories was not available for much of the area for designing the sampling plan. Also much of the area was not classified prior to sampling and the two functions were done simultaneously. Only sparse sampling was done for much of the northern region of the Province. Aerial photographs were available for most of the Province the first time. Initially they were 40 chain photos taken by the military for reconnaissance of major topographic features, and did not give the desired resolution for a timber inventory. These were gradually replaced by higher resolution 20 and 40 chain photos taken specifically for the inventory.

The stated objective of the inventory was to provide estimates of total volume to a precision of  $\pm 10\%$  (at 2 standard errors (SE)) for major species in each Forest Inventory Zone (FIZ), and for all species at the subzone level. FIZ zones were similar but not the same as the current zones. Estimates of average and total volumes were given by what were called Summary Types by FIZ and subzone. The Summary Types were groups of related forest types delineated from the aerial photos.

Access was very poor for many regions of the Province compared with today and this severely limited sampling operations. The emphasis of the inventory was on mature timber

and older age classes. Attempts were not made to implement a statistically valid traditional stratified random sampling design because budgetary and logistic constraints made this infeasible. The strata subjectively chosen for sampling were based largely on mature timber and available access. Random location of sample plots was used in the initial phases of the inventory, however, this was quickly replaced with subjective location of sample plots in "*representative*" areas of stands identified from aerial photographs. The number of samples was not determined based on desired sampling precision because of budgetary limitations. Practical and logistical restrictions were major factors affecting the sampling plan.

Activities in the last three years of this period (1958-1960) involved primarily maintenance surveys. These used the same methodology as the recently completed inventory and were designed primarily to enhance classification and to supplement the inventory. New 20 chain photos were used almost exclusively and sampling and classification were undertaken as separate functions.

## **The Second Complete Inventory (1961-1977)**

The third major period in the history of inventory sampling brought the second complete inventory of the Province done between 1961 and 1977. The surveys done in this inventory are often referred to as *Unit Surveys* because the major sampling units were management units (Public Sustained Yield Units - PSYUs). Most of the volume data currently in the inventory data base ( $\approx 77\%$  of the sample plot clusters) were collected in this period. The emphasis was also on mature timber and used a similar sampling approach as the 1951-1957 inventory. Major differences were: more samples taken; more refined strata definitions; new management units; more refined classification variables of age, height, site, and stocking; sampling and classification were combined; and higher resolution, larger scale (20 chain) aerial photos.

The objective of this inventory was to estimate total volume for each Unit (PSYU) to  $\pm 10\%$  (at 2 SE). The principles of stratified sampling were used, but logistic, budgetary, and administrative difficulties prevented the random selection of strata, stands, and samples (clusters of plots). The resulting sampling design was termed "*modified stratified random sampling*". The strata were defined as age, height, and stocking classes within a given Inventory Type Group (ITG). ITGs were groups of forest types related by species composition.

Strata were subjectively chosen such that sampling was concentrated in older age classes of the larger types. Often most of the area in a PSYU was contained in a small number of the strata, thus strata with proportionately small areas were usually not sampled. Stands

within strata were chosen to avoid sampling areas where samples already existed, and with the objective of ensuring a geographic distribution of samples throughout the PSYU. Access was also a major consideration in stand selection and often was possible only by boat, float plane, helicopter, or on foot. Thus stands from several strata were often selected to be near each other to facilitate access.

Samples were sometimes randomly located in the target stands by using a grid overlay on aerial photos. However, many samples were subjectively located in areas considered to be representative of the stand. In mountainous areas, samples were often located on lower slope positions accessed by vehicle or boat, and on upper slope positions accessed by helicopter. The number of samples actually located was determined by the number that could be established by the crews in a field season. Rules of thumb were used for estimating the number of samples to be established, but budgetary constraints were usually an over-riding factor. The number of samples established by strata was monitored during the field season to check that strata were not over-sampled. However, this was not always achieved and some major types contained many samples while others contained very few. The achieved sampling precision was not monitored during the field season which resulted in varying sampling errors among strata.

Despite practical limitations, some attempts were made to implement a statistically valid sampling plan using randomly located samples. Sample size was computed from a rule of thumb indicating 150 samples per 500,000,000 cubic feet ( $\approx 14,000,000 \text{ m}^3$ ) and also from the usual sample size formulas using estimated standard deviations. This was considered impractical to implement under the current limitations, primarily because accessing the randomly chosen samples was extremely difficult and was taking double and triple the time needed to establish the subjectively located samples.

The departure from the principles of traditional stratified random sampling were necessary because of the limitations and conditions of the time. This has probably had two major results. First, the inventory was probably more efficient in that it gave more information for the limited financial resources. The subjective selection of strata with the highest per unit area volumes (the older age classes) and the highest total volumes (strata with the largest areas) ensured that these important strata were included in the sample. However, the subjective selection of strata, stands within strata, and samples within stands has probably introduced a bias in the estimates of the average and total volumes. The magnitude of the bias is not known and probably small, but samples were often subjectively located in stands to favour what was likely higher than average conditions in terms of volume. Also the non-random sampling methods makes the interpretation of the calculated sampling errors difficult and inference based on traditional probability theory cannot be made in the usual sense.

## **History and Inventory Updates (1978-Present)**

The most recent major period in the history of inventory sampling contains several significant changes. These were precipitated largely from a need for more detailed information about the forest resources. However, a major factor in the development of the inventory methods in this period was a change in philosophy in the Forest Service of what was needed from the inventory and how the information was to be used. There was a desire to provide stand specific estimates of volume and other attributes. The former inventory was designed to estimate averages of groupings of similar forest types, thus could not provide estimates at the stand level. Consequently, a new sampling methodology was required to supply the information for the more stringent demands. This motivated significant changes in classification, sampling, data storage, compilation, and the method of estimating volumes for individual stands.

The Sub-Unit survey system developed and tested in 1977 was introduced in 1978. This sampling method was designed to provide more detailed estimates on much smaller areas. The sub-units were usually individual drainages as small as 5,000 ha. The sampling method was a multi-phase system using a linear cluster of 6 variable-radius plots and low-level aerial photographs. The sub-unit survey program was replaced with management unit surveys based on Timber Supply Areas (TSAs) in 1979 to reflect the new administrative boundaries.

The multi-phase sampling design used 70 mm aerial photo plots as the first phase and ground based prism plots as the second phase. The intent was to define a relationship between estimated volumes of fixed-area plots from photo measurements and the actual volume measured from ground based variable-radius prism plots established in exactly the same place as the photo plots. This relationship could then be used to adjust a large number of other photo plots that could be taken less expensively. The multi-phase sampling methodology was the most statistically rigorous sampling design to date, but the system was difficult to implement and had many technical problems. There was also a lack of experience and expertise to operate the very sophisticated system at the Forest Region level where the cameras were based. Camera failures occurred frequently and were not detected until after the pictures were developed. Photo processing was done in Ontario which caused additional delays. Also it was very difficult to match the ground and photo plots. The multi-phase sampling system was unsuccessful because of a lack of funding and many practical problems. However, the opinion of those familiar with the process is that with modern technology and well trained specialists, the concept has great potential in certain stand and geographic conditions and the short-comings of previous attempts can be rectified.

A re-inventory program was initiated in 1988. However, this was really only a re-classification program because field sampling for volume was not undertaken.

Other major changes in this period include converting the inventory data base to continuous variables instead of the formerly used classes. This was a significant change in the data base and allowed for the storage of actual values taken from samples and other measurements. Data previously collected and recorded as classes were either re-interpreted to a higher resolution or converted to class midpoints. The change to continuous variables was also accompanied by a change in the way in which volume were assigned to forest cover polygons. The formerly used Average Volume Line (AVL) approach where all stands in a given strata were assigned the average volume was replaced by predicting volumes for individual stands from a regression function using the polygon attributes expressed as continuous variables.

## **DISCUSSION OF HISTORICAL AND FUTURE TRENDS**

Sampling designs used in forest inventories in British Columbia have changed from a mere compilation of available information or "*stock taking*" of timber to sophisticated multi-phase sampling designs. Prior to 1951, the areas of interest were those under current exploitation or planned for development in the near future. Samples were not needed for inaccessible areas and those that did not have timber that was considered merchantable with technology of the day. Surveys reflected current utilization standards in species and size of trees. As a result, these inventories quickly became outdated as standards changed. Practitioners of the time realized that technology would change and allow utilization of currently non-merchantable timber, but priorities were on providing information for current management. Inventory sampling methodology has now changed to be more rigorous and covers the entire Province, involves much lower merchantability limits, and includes species that were formerly omitted. Despite differences of former inventories and advancements in sampling techniques that have paralleled advances in technology, there are several trends that emerge over the various periods of inventory that have profound affects on sampling designs. There are factors in large-scale inventories that are the same today as the turn of the century. Many of these factors will probably be the same in the next inventory. A review of historical trends and consideration of future possibilities may help to identify some areas that warrant special consideration.

### **Information Needs**

Sampling systems are usually designed to provide only the type and resolution of information that is needed about the population being surveyed. Sampling systems used in

former inventories were designed to provide the information needed at the current time under the current limitations. This was especially true of the first inventories. Forests are dynamic systems, and thus it is often said that inventories are outdated the minute the information is published. This is true and probably cannot be avoided. However, a major factor leading to the apparent lack of longevity of these inventories to provide information for management was that they often were designed to provide information to a standard that was very quickly replaced by more stringent requirements. The inventories naturally became outdated as the forest grew and changed, but became outdated much faster because of changing requirements for information. This was certainly the case in the early years with merchantability standards of size and species of trees.

Some examples of changing standards are that in early years, surveys were done on the coast to 24 inch diameter limits and excluded hemlock and balsam. This information soon became inadequate when markets and technology changed to allow the utilization of other species and smaller trees. Also lodgepole pine was considered a non-merchantable species for most of the Province until the 1950's and 1960's. Prior to the mid 1960's, much of the central interior was classified as pine-scrub and led to thoughts that available merchantable timber volumes would soon be depleted. Deciduous species were considered non-merchantable until recently and were not intensively sampled in the last inventory between 1961 and 1977. In the previous inventories it was recognized that more of the resource would be merchantable as markets and technology changed, but sampling was usually designed to meet immediate needs only. It is likely that in many cases these anticipated changes occurred much faster than expected which resulted in outdating the inventory much faster than anticipated.

From a sampling perspective, these changes in utilization standards are simply changes in the type of information needed from the sample. Sampling systems were designed at the time to provide the needed information. Statistical reliability was not needed in the early part of the century because cut control and availability of timber was not a major consideration and survey methods were designed accordingly. Some changes in information needs are brought about by changes in the technology to utilize different types and sizes of wood and the ability to sample and process data. However, others are brought about by changes in the public need for information about the forest. Future inventories must not only consider present and future utilization of timber, but also the need for information about the many other components of the forest. This type of information has not played a large role in the design of former inventories but will surely be a major component of future information needs. This will surely affect the sampling designs of future inventories.

Presently more detailed information is needed from the forest than ever before and from a myriad of forest resources other than timber. From the timber perspective, more detailed information is needed than has been collected in the past including information at the

individual tree level. The current information needs are not only for an inventory in the traditional sense of what is out there, but also needed is information about the forest, trees, and ecosystems that will allow the detailed modelling of tree and stand growth and yield. Furthermore, the method in which growth and yield is modelled dictates the type of information that is needed. An example of the type of information that will probably be needed is spatial and temporal distributions of trees, information on crown characteristics, and information about the ecological characteristics of the forest. Information requirements will become more demanding as modelling techniques become more sophisticated.

## **Use of Information**

Another trend that is apparent from previous inventories is that the information has been used, without exception, for purposes other than which the sampling plan was designed to provide. This has led to dissatisfaction with previous inventories because the information was expected to provide answers that were not considered when the sampling system was designed or the questions had not been asked. For example, strata averages from the 1951-1957 inventory were sometimes used to estimate volumes for individual timber sales. It was not the objective of the inventory to estimate volumes of individual stands, but the inventory information was used for this purpose and it created a perception that it did not adequately represent the forest. The likelihood of using information from the next inventory for purposes other than it is designed is almost assured. The challenge is to provide a sampling design that provides information for current as well as future information needs. Of course there is a trade-off between utilizing finite resources to obtain currently needed information against uncertain future information needs. It is impossible to know exactly what information will be required of the next inventory into the future. However, trends in timber utilization, public opinion and use of the forest, and forest management can be used to help identify the type of information that might be needed in the future.

## **Statistical Requirements**

Despite attempts of former inventories to adhere to the statistical principles of sampling, it was not possible. Practical, logistical, administrative, and budgetary limitations were always over-riding factors. There were not enough resources to sample all strata and access was limited. Random location of samples in stands was achieved in some cases, but subjective location was favoured because of simplicity. The result is the inventories may have been more efficient in providing more information with the finite financial

resources than a strict random sampling procedure, but this deviation from statistical principles has probably introduced a bias (probably small but of unknown magnitude). Furthermore, interpretation of the sampling error and confidence intervals cannot be made from probability theory in the usual sense.

Implementation of forest inventory sampling based on strict random requirements is very difficult. The amount of additional confidence in the estimate in terms of unbiasedness may not be worth the large additional expense required to achieve the randomness. This was the finding of the practitioners who attempted to establish completely random samples in the 1961-1977 inventory. However, it is highly desirable to have unbiased estimates unless the amount of the bias is known to be small. Other sampling systems can be combined with random sampling to increase efficiency. Multi-phase and multi-stage designs combined with selecting units with probability proportional to size (PPS) and systematic sampling can greatly increase sampling efficiency and reduce the amount of randomness needed at the ground level.

## **Technological Advancement**

Technology has also been a major factor in the design of forest inventory sampling systems. Initially the ability to sample the forest was very limited by ground and air access. The advancement of aerial photography has probably been the most significant technological development aiding forest inventory. The sampling system used in all the inventories after 1950 have been made possible by the ability to identify and map homogenous portions of the forest from aerial photos. Now high, medium, and low-level photography are all used to some extent in forest inventory sampling.

Another major technological advancement that has affected forest inventory sampling designs is the ability to store and manipulate virtually unlimited amounts of data with computers. The class-based inventories prior to 1977 were the result of the inability to manually deal with large amounts of data expressed as continuous variables. Now the difference in the amount of computer memory needed to store a class variable as opposed to a continuous variable is not important. The cost of mass storage of data is now so inexpensive that it is of little concern.

Technological advances of the future will undoubtedly have an equally or even more profound affect on the forest inventory sampling designs. The ability to manipulate and store data has far exceeded our ability to collect the data. The next major development in technology affecting forest inventory will probably be made in use of digital image analysis of aerially captured data. This will affect sampling designs in that large amounts of data will be captured quickly and easily at relatively low cost. These data can then be

combined with relatively few very intensive sample points in a multi-phase sampling design similar in concept to that developed using 70 mm photography. This type of data capture and analysis could also be used to sample for other types of attributes that have not traditionally been measured in forest inventories such as the spatial distribution of trees.

Also measurement techniques for ground sampling have changed little since the first inventory in the Province. The enhanced ability to collect large amounts of precise data from ground measurement of trees will surely affect sampling designs. For example, upper stem diameters are almost never collected except under research conditions. The number of trees measured at a given plot is a function of the amount of time taken and the amount of information obtained. As with aerial technology, the next major advancement in ground sampling will probably be in digital image analysis of data captured at the plot level. Also the use of lasers or other technology for distance measurements will dramatically alter the way in which information is collected at the plot and higher levels. These technological advancements will surely require changes in the sampling designs used to obtain the information.

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## APPENDIX I - Some Important Characteristics of Major Inventory Periods in British Columbia.

| Period    | Objective   | Sampling Design  | Strata Definition  | Precision Objectives  | No. and Type of Plots   | Location of Plots   | Comments   |
|-----------|---|--|--|---|---|---|--|
| 1910      | Quantify forest resources in B.C.   | No sampling. Compilation of existing information. Much guessing.                                 | NA   | NA  | None  | NA  | First attempt at any inventory in B.C. (Fulton 1910).  |
| 1911-1918 | Estimate available merchantable timber supply in the Province.  | No sampling. Compilation of available information. Took three years to compile information.      | Province divided into 66 drainage basins.  | NA  | None  | NA  | Second attempt at an inventory (Whitford & Craig 1918). Much of the Province was unexplored. WWI interrupted sampling.                   |
| 1919-1937 | New inventory in 1927 to more accurately reflect the current state of the forests and new merchantability standards.                  | Some areas surveyed, but was a compilation of surveys, cruises, and other available information. | Estimates given for the new 5 Forest Districts (somewhat similar to current Forest Regions) by drainage basin. | NA  | 27,000 km of strips and 4,800 km of aerial photo strips. Reconnaissance surveys done where others were not available.             | Systematically located strips.  | Third attempt at an inventory (Mulholland 1937). Depression of 1930's affected sampling. No new estimates for northern part of Province. |
| 1938-1950 | Maintenance surveys only. Update function. No new inventory.  | Strip cruises.   | NA   | ± 10% of merchantable volume/acre   | Strip cruises.  | Systematic strips at intervals of 1/2-one mile, and 1/2-one chain in width.   | Sampling suspended in 1942 because of WWII.  |
| 1951-1957 | The first complete inventory of the Province. Objective to estimate average volumes for strata.                                       | Intent was modified stratified random sampling at the FIZ subzone level (not current FIZ).       | Summary Types (groups of related forest types) by age, height, and stocking class.                             | ± 10% of total volume for: species by Province; major species by zone; and all species by subzones. | 7,057 clusters of 4 fixed-radius sample plots.  | Subjective location in representative areas of stands. Random location of plots attempted but considered infeasible.                    | First complete inventory in Province took 7 years.   |
| 1958-1960 | Maintenance surveys for the enhancement of classification.  | As above.  | As above.  | NA  | 2,824 clusters of 4 fixed-radius sample plots.  | Subjective location in representative areas of stands.  | New aerial photos available at 1:15,840.   |
| 1961-1977 | Unit Surveys. Second complete inventory of B.C. Objective to estimate total volume by strata for aggregate forest types in each PSYU. | Intent was modified stratified random sampling at the PSYU level.                                | The 42 inventory type groups by age, height, and stocking class.   | ± 10% of total volume for each PSYU.  | 37,963 clusters of 2 fixed-radius sample plots.   | Subjective location in representative areas of stands. Random location of plots attempted but considered infeasible.                    | Class-based inventory. About 77% of current data base from this period.  |
| 1978      | Sub-unit surveys. Objective to estimate detailed stand characteristics for smaller land units (usually individual drainages).         | Multi-phase stratified random sampling using 70mm low level photography and ground samples.      | Individual stands for sampling. Aggregated forest types for compilation and precision control.                 | ± 10% of total volume for aggregated forest types.  | 612 6-prism plot sample clusters.<br>Phase 1: 4-8 fixed area photo plots along a strip.<br>Phase 2: 6-prism plot sample clusters. | Phase 1: random strip in stand. Phase 2: plots selected randomly or in a restricted random manner to represent full range of variation. | Concept developed and tested in 1977.  |
| 1979-1981 | Re-inventory and update functions decentralized to Regions.   | As above.  | As above.  | As above.   | 1502 6-prism plots sample clusters.   | As Above.   | Program initiated but unsuccessful because of practical problems. Photo plots were used for classification.                              |
| 1982-1987 | History update program for major depletions from harvesting, fire, and insects.   | NA   | NA   | NA  | 278 6-prism plot sample clusters.   | None.   | Field sampling ended in 1984. Monitoring from satellite imagery and silvicultural records.   |
| 1988-1991 | Re-inventory Program. Objective to re-classify TSAs on a 10 year cycle.   | NA   | NA   | NA  | None  | NA  | No field sampling (except for classification).   |

## **APPENDIX II - Point-Form Summary of Significant Inventory Periods**

### **1910: The First Compilation Inventory**

- Fulton (1910) reported on his Royal Commission on Forestry on the general state of the forest industry.
- This was the first attempt to quantify the forest resources in British Columbia.
- No sampling was done and very little information was available.
- Had information on some tenures but broad based estimates were from guessed averages per unit area multiplied by estimated total areas.
- A major difficulty in estimating timber volumes was in defining merchantability limits because "the standard of timber that can be profitably cut is being lowered every year" (Fulton 1910).
- No effort was made to estimate the volume of immature, non-commercial, not restocked forest land, or rate of growth.

### **1911-1918: The Second Compilation Inventory**

- Increased awareness of natural resources resulting from activities of WWI.
- Recognized the need for an inventory of forest resources.
- Whitford and Craig (1918) reported on the Forests of British Columbia.
- This was the second attempt at an inventory in British Columbia but was only a compilation of other surveys.
- The objective was to secure an estimate of the available supply of merchantable timber in the Province.
- No sampling was done.
- No air photos were available.
- Took three years to compile report.
- Estimates of merchantable timber volume by species given for the 66 drainage basins covering the Province.
- Estimates based on available information from reports provided by the newly created B.C. Forest Branch (in 1912), timber owners, surveyors, and others.
- Compilations were for minimum stump diameter of 10 inches (which was considerably below utilization standards of the time (Sloan 1945. p. 199)).
- At the time much of the area of the Province remained unexplored.
- At best only reconnaissance surveys had been done in undeveloped areas.
- Had problems defining what was merchantable timber and land, e.g., older cruises were designed to estimate only amount of timber that was economical to cut, and Balsam and Hemlock were omitted from cruises as well as timber less than 24 inches in diameter.

## 1919-1937: The Last Compilation Inventory

- The previous inventory was still a good source of information for many resources, but became increasingly inadequate for timber.
- Required a new inventory to meet current demands of industry and for administration of the forest resources.
- Forest Service began a new inventory in 1927.
- Mulholland (1937) reported on the Forest Resources of British Columbia.
- This was the third attempt at an inventory in British Columbia, but as with the 1918 inventory, was only a compilation of many other smaller surveys.
- The objective of new inventory was to provide more detailed estimates and to give as accurate a description of forest conditions as possible from available information.
- Province divided into 5 administrative Forest Districts (what now fairly well resemble our Forest Regions).
- Preliminary estimates were completed and published in Forest Service annual reports for individual Districts between 1928 and 1935.
- The Mulholland report presented a complete inventory for the Province including updates for the Vancouver and Prince Rupert Forest Districts.
- Emphasis of inventory was on volumes of mature timber and some description of the growing stock for future estimates of growth.
- Estimates were to current utilization standards of 11 inches dbh, and sometimes down to 8 inches in the interior.
- No volume estimated for immature stands or trees that were considered to be wasted in the logging of mature stands.
- Intent was to continuously update the inventory as required to reflect change.
- The inventory was made mostly during the depression years of the 1930's and the poor market conditions and low profits were reflected in its assessment of merchantability (Sloan 1956, p. 203).
- Surveys done for some areas and overall inventory was a compilation of all known cruises from private owners and the Forest Service.
- Field reconnaissance was done for areas not covered by surveys.
- Attempts were made to adjust different cruises to a common standard.
- Forest surveys covered 4,000,000 ha of productive forest, about 13% of the estimated total area in the Province capable of timber production.
- 27,000 km of survey strips were done recording age, height, dbh, and volume.
- 4,800 km of aerial photography was stereoscopically plotted.
- Estimates of volume for the 27,000,000 ha "*unorganized northern territory*" were based on estimates from Whitford and Craig (1918) because at the time Mulholland (1937 p. 151) stated that "the forest resources of that bleak country are not of commercial importance and are entirely inaccessible at present".

- Maps showed volume per acre and percent species composition for mature stands, and composition, comparative density, and height of immature stands.
- Statistics were compiled from the summation of volume estimates from minor watersheds, blocks of timber, and individual surveyed lots and timber licences.
- Published figures were by drainage basins and Forest District.

### **1938-1950: Maintenance Surveys**

- Subsequent dissatisfaction of the maps created in the previous inventory for the unsurveyed areas were encountered because they were being used for purposes other than for which they were designed (BCFS 1947).
- Maps were continually updated as new surveys of areas were completed.
- Sampling methods involved strip cruising at various widths and intervals, depending on the purpose of the specific survey.
- Strip intervals usually varied from one-half to one mile, and samples were from one-half to one chain wide and up to 20 chains in length.
- Precision of specific surveys was intended to be within  $\pm 10\%$  of total volume.
- Standard forest surveys continued until 1942 when operations were suspended because of WWII (Sloan 1956, p. 203).
- The first Sloan (1945) report used the 1937 inventory with some amendments made from the surveys conducted in the intervening years.

### **1951-1957: The First Complete Provincial Inventory**

- The first complete inventory began in 1951 after the creation of a new Forest Surveys and Inventory Division of the Forest Service.
- The inventory was funded through a Federal-Provincial agreement to collect information to a standard for inclusion in national statistics.
- Planning began in 1951 and sampling started in 1952.
- The inventory took seven years and was complete in 1957 (B.C. Dept. Lds. For. 1957).
- The second Sloan (1956) Commission report used the inventory published in the 1954 Annual Report. This was an interim report as field sampling was not yet complete.
- Malcolm (1957) described the sampling procedures for this inventory.

#### ***Classification***

- Province divided into 7 inventory zones ranging from 1.6 to 16 million ha (not the current Forest Inventory Zones) and subzones of about 400,000 to 800,000 ha.
- Initially only old air force photos available, but new 20 and 40 chain photos were flown for the entire Province.
- Forest types delineated on photos from stereoscopic interpretation aided by ground and

air observations.

- Forest types delineated by:
  - 1) stand structure (e.g., mature, immature, etc)
  - 2) species composition
  - 3) age class (3 to 5 classes depending on structure)
  - 4) height class (4 for mature timber)
  - 5) stocking class (3 classes based on no./acre)
- Minimum forest type size was 16 ha and at the outset of the inventory was much larger.
- Classification and sampling procedures occurred simultaneously because did not have previously delineated photos.

### **Sampling Overview**

- Intent was to use stratified random sampling at the FIZ subzone level, but was not achieved because of practical and logistical limitations.
- The resulting sampling design was termed "*modified stratified random sampling*".
- Strata were called Summary Types and were groups of one or more of the 11 related forest types (groupings of related species) recognized in classification falling within a wide range of species composition, age, height, and stocking.
- 264 possible Summary Type combinations.
- Stated precision objectives were to estimate total volume to within  $\pm 10\%$  (at 2 SE):
  - 1) by species in the Province as a whole.
  - 2) for major species in FIZ zones.
  - 3) collectively for all species in FIZ subzones.
- Number of samples required to meet stated precision requirements not calculated or controlled until late in the inventory.
- Sample plots were fixed-radius circular plots, with size ranging from 0.004 to 0.2 ha depending on species composition, stocking, and age class.
- Samples were clusters of 4 plots for mature stands and 2 plots for immature stands.
- Attempts in the initial phases of the inventory to randomly locate samples (plot clusters) within stands using grid overlays on photos, however, this was soon replaced with subjective location of samples in "*representative*" areas of stands identified on photos.
- Average volume per acre was computed by species and forest type from the various sampling strata.
- Total volume was computed as the product of these averages multiplied by the areas computed for each areas from the forest cover maps.

### **1958-1960: Maintenance Surveys**

- Maintenance surveys conducted for the enhancement of classification.
- Had some crews supplementing the sampling from the 1951-1957 inventory.

- Larger scale 1:15,840 photos allowed more refined classification.
- Sampling and classification were separate field functions.

### **1961-1977: The Second Complete Provincial Inventory**

- Initiated the second complete inventory (Unit Survey) of the Province.
- Objective was to estimate average volume by strata for groupings of related forest types for each sampling Unit (Public Sustained Yield Units - PSYUs).
- Volumes for individual stands were assigned the average of the stratum, known as the Average Volume Line (AVL) approach (as with the previous inventory).
- Most of the current volume data base ( $\approx 77\%$  of sample plot clusters) was collected in this period.
- Sampling and classification functions were combined.

#### **Classification:**

- Air photos delineated by species, age, height, stocking, and site for productive forest land.
- Forest types (stands) classified into 42 Inventory Types Groups (ITG) by species for mature and the 17 Growth Types Groups for immature, and by 9 age classes, 8 height class, 4 stocking class, and 4 site classes.
- Samples were summarized during the field season to ensure that target types were actually sampled.

#### **Sampling Overview:**

- Survey projects were undertaken separately for each Unit (PSYU) which ranged in size from 140,000 to 5,500,000 ha.
- Each PSYU was sampled in a single season and was not revisited until a re-inventory was scheduled, thus additional samples were not located in strata determined to be sparsely sampled after compilation of the data.
- Sampling design based on principles of stratified random sampling but were not achieved because of practical and logistical limitations.
- Resulting sampling design was termed "*modified stratified random sampling*".
- Strata were ITGs by age, height, stocking, and sometimes site class or disturbance class.
- Precision requirements were to estimate total volume of the PSYU to  $\pm 10\%$  (at 2 SE).
- Ground sample information was collected as continuous variables but was recorded in the data base only as classes.
- The resulting inventory was class-based.
- Data base only included: species to the nearest 10%; age in 20 year classes up to 140, then 141-250, and 250 and older; height in 30 foot (9 m) classes; and stocking into 5 broad classes.
- Original data for the exact measurements were kept only on the field sheets.

**Sample Size Calculation and Allocation**

- All stands in PSYUs were summarized by strata (ITG by age, height, and stocking class) from the previous inventory noting area, number of existing samples, and an estimate of the desired number of additional required samples.
- Strata were subjectively selected from each ITG to favour older age classes with proportionately large areas.
- Strata were selected such that their area would comprise about 80% for the ITG.
- Initial sampling plan developed from estimated total number of samples needed in the Unit (PSYU).
- Initially estimated as a rule of thumb that about 16 samples per major stratum were needed to achieve the desired precision of  $\pm 10\%$  at 2 SE.
- After 1963, the estimated number of samples needed for a given grouping of types of a major species was determined from experience in similar PSYUs.
- The actual number of samples was limited by the annual budget.
- Sample compilation occurred at the end of season, thus desired control over sampling size and precision was not closely controlled.
- A tally of the number of samples established in each stratum was made during the field season to help guard against over-sampling. However, some projects contained from 2 up to 100 samples in the major types (Hegyí 1990).

**Sample Location:**

- Stands were chosen for sampling to ensure geographic distribution throughout the PSYU, and to avoid areas where previous sampling had occurred.
- Access and terrain were also major considerations and most stands were selected to facilitate access.
- Samples were changed to a cluster of 2 fixed-area plots of varying size that roughly equalled the total area of the 4-plot clusters used in the previous inventory.
- Some samples were randomly located in the subjectively chosen strata and stands by selection of random coordinates from a transparent grid overlay on photos.
- However, many other samples were subjectively located directly from aerial photos to be representative of the stand.
- Subjectively located plots were often established close to roads, rivers, lakes, and on lower slope positions.
- Attempts were made at using truly randomly located plots and a rigorous stratified random sampling design adhering to statistical principles, however, this doubled and tripled the time required to establish samples and was abandoned for the subjective location of samples.

**Theoretical Comments on the Sampling Design**

- Sampling design based on statistical principles, but deviations from theoretical statistical assumptions were necessary because of administrative, practical, logistical, and budgetary limitations.

- The intended stratified random sampling design deviated from theoretical statistical principles in that:
  - 1) Not all strata were sampled and those chosen were not always chosen at random.
  - 2) Selection of stands within strata was not always random.
  - 3) Selection of sample plot locations within stands was not always random.
  - 4) Plot sizes were changed depending on stand conditions.
  - 5) Samples were not allocated proportionately among strata and estimates were not weighted appropriately for the unequal sample size and unequal area.
- Deviations from the theoretical statistical sampling assumptions probably had several affects:
  - 1) Generally, this may have resulted in a more efficient survey for estimating total volume of the PSYUs in that sampling was concentrated in the large and higher volume types.
  - 2) Estimates of average volumes were probably biased because:
    - Some strata were not considered for sampling in the subjective selection.
    - Some stands were not considered for sampling in the subjective selection.
    - Samples (plot clusters) were not always randomly located in stands and in some cases may have been located in such a manner as to favour higher productivity areas such as lower slopes and areas of better than average stocking.
    - Samples were not weighted by the area from which they were taken.
    - Plots of varying sizes were weighted equally in the estimates.
- Sampling concentrated on the older stands thus only poor representation from younger age classes (some units had very little immature, especially on the coast), however, more emphasis was put on immature after 1973.
- Deciduous forest types and much lodgepole pine was considered to be non-commercial at the beginning of the survey and was poorly sampled (Forest Resources Commission 1990).

### **1978: Sub-Unit Surveys**

- Sub-unit Survey methodology replaced the class-based Unit surveys and was used only in 1978.
- This was in response to the need for more detailed estimates including stand level parameters at the sub-unit level (individual drainages as small as 5,000 ha).
- This change to Sub-unit Surveys was also accompanied by major changes in classification, sampling, volume calculation, and the way that inventory data were collected and stored in the data base.
- The class-based system was replaced with a system that recorded the classification attributes as continuous variables in the data base.
- Volume calculation was changed from the AVL method to a regression approach where

the predictor variables were the classification parameters expressed in continuous units.

- Sampling methodology changed to a multi-phase design.
- The first phase was low-level 70 mm air photo fixed-area plots and the second phase was variable-radius ground plots for double sampling (Hegyi 1985, 1990).
- The intent was to define relationships between photo plots and ground plots to adjust other photo measurements where ground plots were not established.
- Sample plots were changed from the previously used cluster of 2 fixed-area plots to a linear cluster of 6 variable-radius (prism) plots to facilitate the new sampling methodology.
- Only cursory testing of the new sampling method.
- The multi-phase sampling design was not successful because of poor funding and many practical problems.

### **1979-1981: Inventory Update**

- In 1979 the Forest Service reorganized, decentralized many function to the regions, and created the new management units called Timber Supply Areas (TSAs).
- Sub-unit Survey system replaced by a Management Unit (TSA) type of inventory implemented using the sub-unit classification and survey methodology.
- 70 mm photo booms developed earlier were sent to each Region.
- Intent was to provide capability for re-inventory and updating in each Region.
- Program was not successful because the practical aspects of the sampling methodology were not perfected, and operation of the camera booms required a high level of expertise and training that was not available in the Regions.
- First and second phase samples were established using the multi-phase sampling system but relationships between photo volume and plot volumes were never successfully established for assigning stand volumes on an operational basis.
- The 70 mm photographs were used mainly for classification purposes.

### **1982-1987: History Update**

- Funding constraints reduced the inventory program to a maintenance mode but facilitated conversion and placement of data base to digital format and re-compilation of existing data to the new Timber Supply Area (TSA) management units.
- No major operational field sampling was undertaken.
- A program was introduced to monitor major depletions such as harvesting, insects damage, and fires. This was done through silvicultural records and high level satellite imagery.

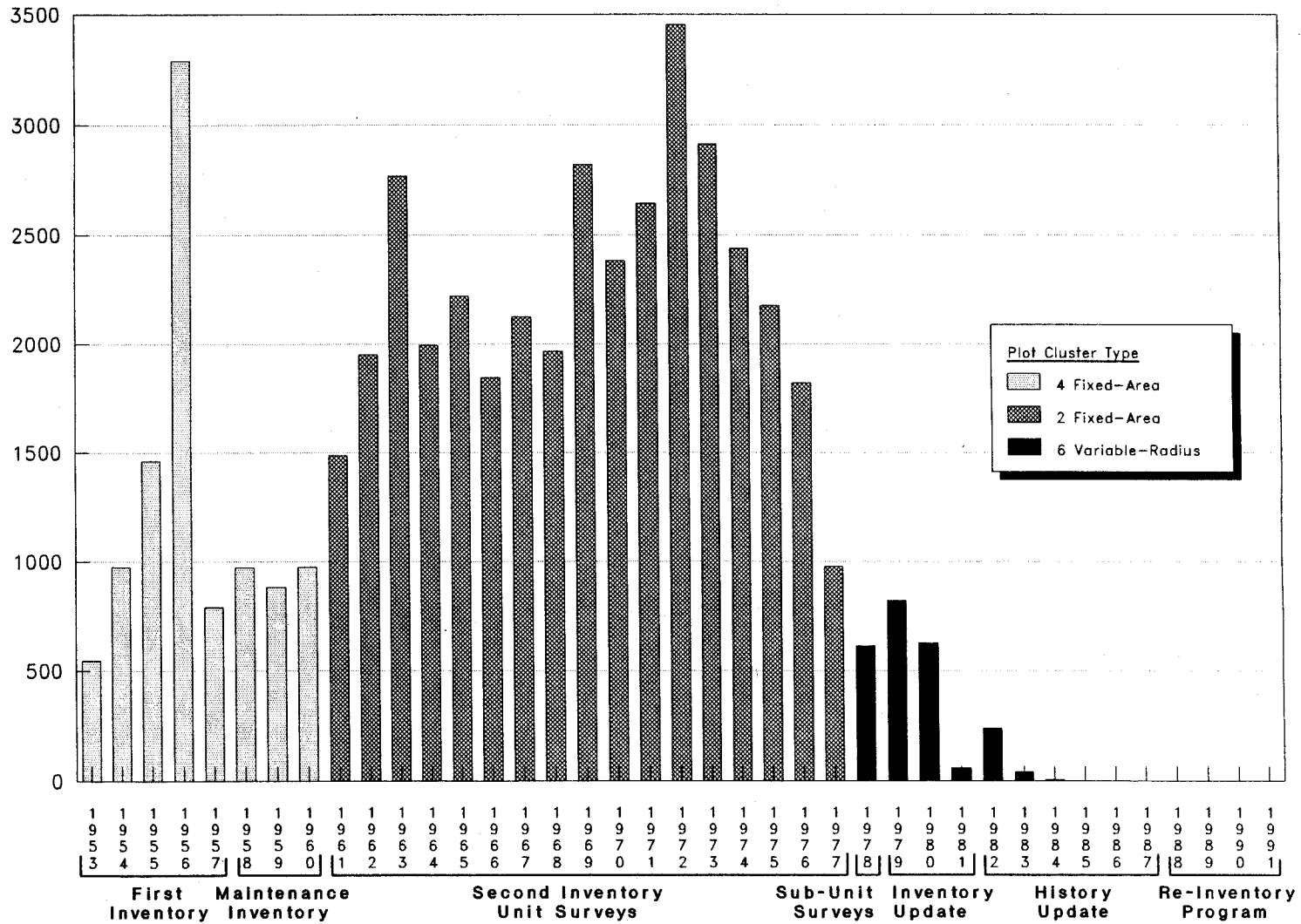
### **1988-1991: Re-inventory Program (Re-classification only)**

- In 1988, a program introduced to re-inventory TSAs on a 10 year cycle.
- Funding increased to complete conversion of forest cover maps to digital format, to begin inventory of management units (TSAs), and to improve the image analysis system used in the inventory update program (Ministry of Forests 1991).
- This initiative was not a re-inventory in the usual sense in that only re-classification of new photos was undertaken with supporting air and ground calls.
- No field sampling undertaken.
- Volumes assigned to polygons from prediction equations (VDYP) developed primarily from samples collected between 1961 and 1977.

### **1991-Present** (from Ministry of Forests 1991)

- A major increase in funding through the Forest Renewal Program (FRP) covering a five year period provided for Timber resource inventory, inventory update, forest resource geographic information systems, statistical analysis and summaries, growth and yield, and remote sensing.
- FRP funding is tied to specific inventory program goals, with little being allocated to improving current inventory systems.
- FRP funding enabling hiring of additional staff, completion of the second growth inventory; improvement of accuracy of the inventory through the installation of additional ground samples for growth and yield; possibility of integrating cruising data into the inventory; and update of all active forest cover maps on a 2 year cycle, and inactive maps on a 5 year cycle.

**APPENDIX III - Number of Sample Plots by Year of Establishment**



Source: Personal communication from Jack McLellan, January 1992.