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REVIEW

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A review of the sampling theory of comprehensive forest resources monitoring

Abstract Sampling is a key technique in comprehensive forest resources monitoring. The history of the sampling survey was briefly reviewed and sampling theories were classified and compared in detail. On the basis of that, the application of different sampling methods in comprehensive forest resources monitoring was illustrated in accordance with the sampling classification of Michael Köhl et al. Improvement of the sampling system in China was discussed to meet the new requirements of forest monitoring.

Keywords comprehensive forest resources monitoring, national forest inventory, sampling theory

1 Introduction

Comprehensive forest resources monitoring refers to: in a given time and spatial range, various kinds of technologies concerning information collection, processing and analysis and other related techniques are used to have a systematical observation, measurement, analysis and evaluation on forest ecosystems, wetland ecosystems and desert ecosystem, etc. The purpose is to completely demonstrate the evolution of forest resources and ecological conditions during monitoring periods and reveal the interrelationship of various factors, as well as their internal change patterns. In addition, this kind of monitoring serves to provide overall and accurate information for forestry and ecological construction, the nation's macro-decisions, publicly as well in a timely manner (Ding, 2006). The sampling survey is a key technique in acquiring comprehensive monitoring information on forest resources. In monitoring, it is essential to use proper sampling methods accurately on the basis of different monitoring targets and various scales. According to the sampling classification system of Michael (Michael et al., 2006), in order to offer sampling technology reference for comprehensive forest resources monitoring in China, the status of different sampling methods applied in this field are discussed in this paper.

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2 Historical background of sampling survey

The sampling survey is an early branch of application and development of statistics. It has been a long time since the thoughts that the population was estimated by the portion (Feng et al., 1994). The stages of sampling survey development can be mainly classified into four (Feng et al., 2004). In the first stage, sampling methods were only used in certain fields and they had not become popular as a method of statistical survey. The most influential method at that time was ratio estimation used by French mathematician Laplace to estimate the national population. In the second stage, the sampling survey was officially proposed as a kind of method, extended and gradually popularized. In 1895, Norway statistician Kiaer A. N. formally put forward the method of "representative survey" on the fifth conference of the International Statistical Institute. From then on, the study of theories of sampling design was initiated. In the third stage, probability sampling began to take a leading position. In 1906, British statistician Bowley A. L. pointed out the necessity of the application of probability sampling to a statistical survey. Meanwhile, he presented the theory of simple random sampling, which established the theoretical foundation for sampling survey. In 1923, British statistician Fisher R. A. founded and developed the theory and method of variance analysis, and proposed the important principles of randomization, repetition and blocks (Feng et al., 1994). British statistician Gosset W. S. used the normal error theory to set up the small sample theory, namely student's *t*-distribution. The sampling theories were gradually perfected through thirty years' development. In 1925, the scientific nature of sampling methods was fully affirmed by the Research Association of Sampling Method Application, both in theory and in practice, during the 16th International Statistical Institute held in Rome. In the fourth stage, it was the stage of development and perfection of modern sampling survey theories. In 1934, Neyman J. established the sampling theory of randomized inference, which was on the basis of classical probability theory. The most important feature of this theory was that estimation of the statistics like the variance and mean was totally based on a law of large numbers and a central limit theory and derived from randomization theory. In addition, he confidence interval theory was successfully set up and optimal allocation and ratio estimation were proposed, which laid the foundation for stratified sampling and cluster sampling. With the birth and development of multivariate statistical theory, as well as the maturity of statistical inference models, the application of a statistical model in sampling design was surely inevitable. In 1963, Brewer put forward the inference method depending on models, which initiated the new field of statistical inference concerning model dependency.

3 Classification and comparison of various sampling survey methods

The tatistical survey can be divided into the complete survey and partial survey (Fan, 1995; Feng et al., 2004). Complete survey aims at each unit of the population to collect information, which is also called the census (Du, 2005). The partial survey only collects information on partial units of the population (Du, 2005). Information from a partial survey can be used to estimate and analyze the population features and this kind of survey can be classified into a typical survey, positive survey and sampling survey.

3.1 Summary of sampling survey

The sampling survey is regarded as the most perfect statistical survey method, with a scientific foundation to estimate and represent the population, among the three partial survey methods. Compared with the complete survey, it has the advantages of low cost, rapid speed, high precision, guaranteed probability, good flexibility and wide use. In addition, the sampling survey can solve the problems that complete surveys cannot, like infinite populations, including the population of future time series, and huge populations.

On the basis of probability and mathematical statistics, sampling survey technology is a subject that specializes in sampling theories, methods and application (Song et al., 2007). Its basic idea is to estimate the population based on the materials obtained through partial surveys. That is to say, according to the given ways and procedures, partial units are extracted from the population, and these extracted samples are surveyed, tested and measured. As a result, the acquired data is used to estimate the features of the population, including quantity, quality and spatial distribution, which helps to have a recognition and judgment of the population (Sun, 2007). The sampling survey is widely used in various fields, such as social survey, economic survey, population survey, as well as the national resources and environmental survey.

3.2 Classification and comparison of sampling survey methods

One of the basic problems of the sampling survey is the sampling methods of samples (Feng et al., 1994). From the view of sampling patterns, the sampling survey can be divided into probability sampling (random sampling) and non-probability sampling (Fan, 1995). Non-probability sampling is that wherein samples are not extracted to a certain probability, instead, they are extracted with subjectivity and voluntary participation (Du, 2005). Non-probability sampling mainly contains judgment sampling (experience sampling), convenience sampling, voluntary sampling, snowball sampling and quota sampling. Due to the subjectivity of non-probability sampling, some estimations and predictions even do not have their corresponding errors. Therefore, non-probability sampling only offers reference significance, which is rarely used in practical monitoring (Sun, 2007).

Probability sampling is a sampling method on the basis of probability theory, whose samples are totally extracted at random, without the influences of the subjectivity. This method can guarantee representativity of samples, avoid human disturbance and deviation, and estimate the sampling errors; it is the most scientific and widely used sampling method, including equal probability sampling and unequal probability sampling. There are five basic sampling methods (Feng et al., 1994): simple random sampling, systematic sampling, stratified sampling, cluster sampling and multi-stage sampling (Table 1).

Different sampling methods are applied to different projects. In practice, a specific sampling plan is usually the combination of five basic sampling methods. The key of the plan is the reasonable matching of sampling methods and estimation methods (Sun, 2005).

In sampling theories, there are two main schools (Annika et al., 2006): design-based inference and model-based inference. Thompson classified sampling designs into conventional designs, adaptive designs and nonstandard designs. Michael et al. (2006) divided sampling designs into two groups: one-phase sampling and combined sampling, according to the decision on whether or not to use auxiliary information (Fig. 1).

Table 1 Comparison of different basic sampling methods

sampling methods	features	applicable conditions
simple random sampling	basic sampling method–sampling in random and with equal probability	spatial sample points are in even distribution and balanced change
systematic sampling	put the population in certain order, randomly extract the initial sampling in the given range and extract others on a suit of rules	easy and representative, difficult to estimate the variances, applied in monitoring net and grid sampling
stratified sampling	stratify the population into several independent sub-population and calculate the value of the population by the weighted sub-population (proportion stratification, optimization stratification and index stratification)	small variances inside layers and large variances among layers, applied in larger-area sampling
cluster sampling	put the population into several primary units, extract the secondary units by certain way and survey all the secondary units	small variances inside clusters and large variances among clusters, convenient and costless
multi-stage sampling	put the population into several primary units, extract the secondary units from it until last units can be surveyed directly	complex population structure and large-area survey with obvious stratification

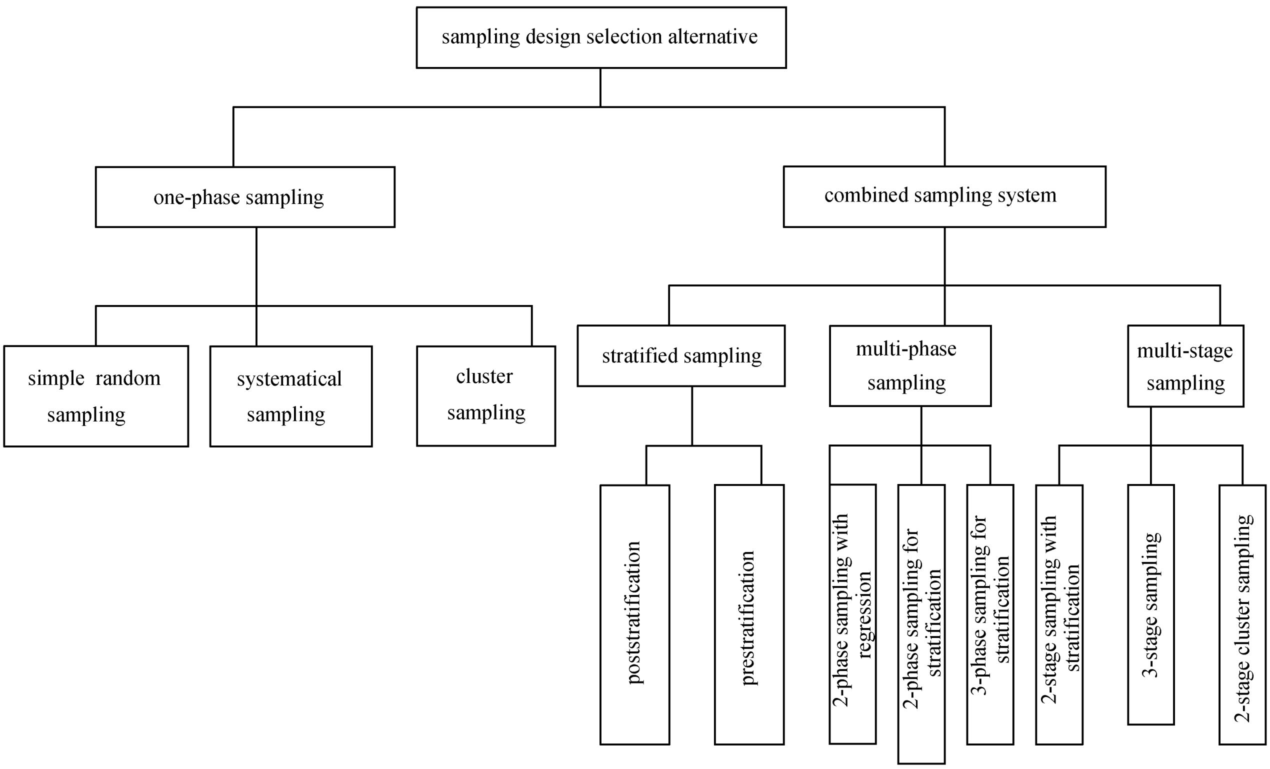

Fig. 1 Sampling design alternative

3.3 Optimal sampling design

The process of a sampling survey can be summarized in three basic parts: sampling, survey and estimation. There always exist deviations between the estimation value and population true value concerning each part like sampling methods and processes, survey observation, measurement, and records and statistical processes, as well as the estimation methods, which is the error problem of sampling surveys (Sun, 2007). Errors generated in each step may be cancelled by each other or accumulated, which leads to the total error. According to the source and properties of the errors, the total error can be classified into a sampling error, bias and non-sampling error (Song et al., 2007). Different controllable degrees and methods are adopted based on different sources of the three kinds of errors. The non-sampling error belongs to random error or accidental error; bias belongs to systematical error, which is a constant error, and sampling error is the differential value of sample values and true values of the population. In practice, the standard error is often used to take the place of the actual error. Sample size, unit and shape both have some direct impact on the estimation of the population. The sampling error usually decreases as sample size increases, but it becomes stable after a certain stage. The non-sampling error increases with the increase in sample size (Xie et al., 1998). When designing sampling plans, sampling methods and sample organization patterns should be on the basis of the population features and calculating the extracted numbers of sample units under certain error limitations.

Sampling theories study the method of how to extract units to constitute samples and estimate the population values using observed sample values, as well as the comparison of efficiency of different methods according to their costs and errors (Xie et al., 1998). The ideal sampling design should hold the features of no deviation, low-cost survey and easy use. The optimal sampling design should try its best to achieve the highest precision under the condition of fixed financial funds, or make the total cost lowest under the condition of reaching precision (Feng et al., 1994).

4 Application status of sampling theory in comprehensive forest resources monitoring

The development of forest survey technology around the world has gone through three phases (Ma et al., 1995): visual measurement survey, actual measurement survey and forest sampling survey.

4.1 Status of sampling system concerning national forest inventory in developed forestry countries

Forest resources inventory mainly undergoes three development stages all over the world (Xiao, 2004), namely wood resources survey, forest comprehensive resources survey and forest environment monitoring. In the developed forestry countries, forest resources monitoring has developed to the integration of resources and the environment (Sun, 2007). Not only wood resources are investigated, but data concerning tourism, recreation, water, fish, wildlife, mine, grassland, pleasant environment and nitrogen are also investigated and revealed periodically. Monitoring of forest environment changes mainly includes formation mechanisms, environmental function, and influence on many resources like recreation of diseases and insects, wind damage, snow damage, forest vigor, forest health and acid rain. There are two large systems of forest resource monitoring methods (Zhao, 1997): one is the complete survey in the Western Europe system, the other is the sampling survey system of Northern Europe and Northern America. Since 2002, Canada has embarked on the new forest resources inventory design based on plots (Mark et al., 2003), namely stratified sampling design. Since 2003, America has wholly adopted the new design in its forest resources inventory (Ye, 2003), namely three stage sampling design. Table 2 shows the forest resources inventory systems in the world's developed forestry countries.

As can be seen in Table 2, Germany and Switzerland both adopt double sampling for stratification. In Germany, forest resources and environment monitoring is carried out under the same sampling framework, while in Switzerland, sampling with partial replacement is used to estimate growth amount. A double sampling for stratification was once regarded as the best survey method of forest resources by the IUFRO (Song et al., 2007).

Table 2 Comparison of national forest inventory system in some developed countries

countries	sampling method	survey cycles	sampling intensity	inventory features
U.S.A	three stage sampling	5 years	first stage: forest and non-forest land	nationwide unified design of systematic sampling
			second stage: a plot with area of 2428.23 hm^2	unified system of forest resources inventory and monitoring
			third stage: extract 1 plot from 16 plots	improving and perfecting organization perfect investment mechanism of funds
Canada	stratified sampling	10 years, slow change 20 years	4 km×4 km basic sampling distance; 20 km×20 km grid sampling adopted by nation	nationwide unified sampling grid; different sampling intensity of each layer stratified on ecological zones; use of remote sensing images, forest management files and other auxiliary information sources; improving and perfecting organization but with dispersion and independence; no unified investment mechanism of funds; mature and unified system framework of multi-stage sampling survey technology based on aerial photograph and satellite remote sensing
Germany	double sampling for stratification	10 years	4 km×4 km	unified sampling framework
Switzerland	double sampling for stratification	3 years	1 km×1 km	double sampling for stratification by aerial photograph; partial replacement sampling to estimate growth
China	systematic sampling	5 years	from 2 km×2 km to 8 km×8 km	monitoring system of double sampling for stratification, combining remote sensing and ground survey, supported by 3S integrated technologies

4.2 Research status of sampling theory in comprehensive monitoring of forest resources in China

The first use of sampling technology in forestry in China was the introduction of enumeration of the angle gauge in 1957 (Song et al., 2007). In 1964, China introduced several survey methods like stratified sampling, two-stage and multi-stage sampling, regression estimation and double sampling with regression. The bulk of studies has been carried out and tested, which established the foundation for China to set up the nationwide unified forest resources inventory system. At present, the forest resources inventory system is established on the mathematical statistical sampling survey, serving as a theoretical basis. In addition, provinces and cities act as the sampling population and fixed sample plots have been laid systematically and reexamined periodically. The sixth national forest inventory has comprehensively introduced the remote sensing technology, supported by 3S integrated technologies, and a remote sensing monitoring system with double sampling for stratification, combining remote sensing monitoring and ground survey, has been adopted (Zhang et al., 2007). The methods of forest management survey mainly include regression estimation, sample controlling population and visual measurement (Ma et al., 1995). Forest management surveys in China usually adopt the method using a combination of the sampling survey and comprehensive survey of sublots, namely, a sample controlling population. Survey of sublots can be specific to the degree of plots, while sampling survey can control the precision of the population. Sampling survey methods adopted mainly include cluster sampling, angle gauge line sampling, systematical sampling, stratified sampling and cluster-stratified point sampling. Forest operational survey all use actual measurement and systematical sampling.

In Taiwan Province, according to the regional scope and survey purpose, the forest resources survey can be classified into three kinds (Chen, 2007): forest resources survey for large region, inspection survey to compile the management plans and project survey for forest operations. These three methods can have mutual complementation, which forms the forest resources inventory system. In addition, they have the basic job of reasonable and sustainable management, realization of multi-function use of forest resources, as well as establishment and perfection of forest resources management system. At present, forest resources surveys for large regions, have been carried out three times in Taiwan Province, whose survey cycle was 15 years. The specific periods were from 1954 to 1956, from 1972 to 1977 and from 1990 to 1993. As for the sampling methods adopted, the former two surveys both used double sampling for stratification, while the third survey adopted the stratified sampling method. As for the survey methods adopted, concentric plot methods was used for the first survey, horizontal line transect method was adopted for the second survey, and rectangles-shaped plot method was applied for the third survey. As for the selection of plots, for the first survey, the Neyman formula was used to calculate ground plots and decide by optimal allcation; for the second survey, systematical sampling method and then random sampling method were adopted; and systematical sampling method was used for the third survey.

4.2.1 One-phase sampling method

According to the classification system of Michael, the one-phase sampling method includes simple random sampling, systematical sampling and cluster sampling.

On the early stage of the inventory system in China, many provinces divided into several sub-populations and adopted different sampling systems and survey methods based on different kinds of sub-populations. Here are some examples. In 1984, Hubei Province used a cluster concentric sampling method in plain areas; in 1993, Henan Province adopted a cluster sampling method in the forests of plain areas. Via 30-year exploration and experience, most places in China apply the systematical sampling method as a main method for forest inventory system, with proportion sampling method for area estimation as well. In Guangxi, the angle gauge sampling method is adopted, while systematical sampling method is still used in point display modes.

The strip sampling method, including equal-length strip sampling and non-equal-length strip sampling, can be used in random sampling, which is fit for small-area surveys. On the basis of fixed sublots, Jiang (2003) adopted the non-equal-length strip sampling method for resource surveys. The conclusion he obtained was that the non-equal-length strip sampling method is a kind of forest survey method with the features of equal probability, randomization, independence and unbiased estimation sampling, which displays strip plots based on sublots and estimate sampling precision on the basis of compartments, with the actual precision over 90% (Jiang, 2003).

The sampling method applied in the forest management survey of Zhejiang Province is systematical sampling. Combining practice with the current theories and methods of forest survey, Liu et al. (2005) and his partners have carried out a study on population volume control method of forest management survey in Chun'an County of Zhejiang Province. The result shows that efficiency of regression estimation is usually higher than that of systematical sampling.

Yu et al. (2003) and his partners analyzed the application of systematical sampling method in forest operational inventory and pointed out that the precision of the systematical sampling method is higher that that of the simple random sampling method. Tokola et al. (1999) summarizes the different sampling designs used in forest resources survey and proposed that the systematical sampling method cannot meet the demand of independence selection concerning samples. In addition, the true error of systematical sampling method still can not be calculated by reasonable formulas. Instead, it is only approximately estimated by simple random sampling or other methods (Song et al., 2007). However, systematical sampling is easy to operate and as a result, it is widely used in actual surveys all over the world.

4.2.2 Combined sampling system

According to the classification system of Michael, the combined sampling system includes stratified sampling, multi-phase sampling and multi-stage sampling.

1) Stratified sampling method

Stratified sampling can fully use the existing auxiliary information to extract sampling, which really improves the efficiency of forest surveys. According to the classification system of Michael, stratified sampling method includes prestratificaion and poststratificaion.

In forest surveys, recent results by forest management survey and remote sensing images are often used to reach the purpose of classification.

2) Multi-phase sampling method

The multi-phase sampling method is also called multiple sampling, which does not only do one-time sampling to the population. Usually, the sample taken from the first-time survey extraction is not the required target parameter. Instead, it is the survey that acquires the auxiliary information quickly with not much work. Then, with the auxiliary information, a survey with small sample numbers is carried out to investigate the needed target parameter. Usually, the latter small sample is extracted from the former larger sample (Sun, 2005). In the current provincial or large-range inventory system in China, two-phase sampling method is often used. Especially in forestry surveys, there are some methods that are usually applied, including double sampling for stratification, double sampling with ratio estimation, double sampling with regression estimation and double sampling with point sampling. Actually, methods adopted in national forest inventories in China are double sampling with regression estimations in essence. That is to say, the first examined sample is a first-phase sample, whose observed values of each sample unit are the auxiliary factors (x); the reexamination sample is the second-phase sample, whose observed values of each sample unit are the main factors (y). Then, x and y are combined as (x_i, y_i) for the same fixed plot as the observed values, in order to form the regression formula to estimated the population.

Using the relationship between the remote sensing data and ground plot survey data at different periods of time, Ge et al. (2007) took the remote sensing interpreted plots as the first-phase sample, all the prophase data of ground plot as the second-phase sample, and ground samples by annual monitoring as the third-phase sample, which formed the method of a three-phase sampling framework. In addition, the three-phase sampling formula concerning area proportion of annual monitoring was given, as well as its corresponding variance estimation limit distribution formula, which improved the area estimation precision of annual monitoring.

3) Multi-stage sampling method

The multi-stage sampling method is suitable for populations with little difference among the one-stage units (Song et al., 2007). In 1991, when the second reexamination of national forest inventory was carried out in Xinjiang, the two-stage sampling method was adopted in the second sub-population. A multi-stage sampling method is fit for some sampling events with a large quantity and large area, like the national forest inventory and quantity survey of forest insects. Since 1970s, the multi-stage sampling method has received attention in the inventory and planning of forest resources survey in China. In recent years, especially in the work supported by remote sensing technology and materials of resources satellites, multi-stage sampling method has become an indispensable basic sampling survey method.

4.2.3 Unequal probability sampling method (PPS sampling)

In 1943, Hamsen and Hurwitz presented the theory and method of unequal probability sampling method (Song et al., 2007). Its definition is that the extracted probability of each unit in the population is not the same, that is to say, the extracted probability of each unit is proportional to unit size, namely PPS sampling (sampling with probability proportional to size). PPS sampling includes point sampling, 3P sampling (sampling with probability proportional to prediction), PPES sampling (sampling with probability proportional to an estimate of size), unequal probability cluster sampling, unequal probability double-stage sampling, and unequal probability three-stage sampling. In addition, equal probability sampling can be regarded as a special case of unequal probability sampling. The method of unequal probability sampling is widely used in forest surveys, and studies by Song (2007) show that the variance of unequal probability sampling method is less than that of probability sampling method. Therefore, it is suggested that the unequal probability sampling method be adopted in making sampling plans.

1) Point sampling and 3P sampling

The concept of point sampling was proposed by Walter Bitterlich in 1948, belonging to the unequal probability sampling method. It can be used in large-area forest management survey and small-area sublot survey. On the basis of point sampling, Grosenbaugh proposed 3P sampling in 1963, namely sampling with the sampling probability proportional to estimated size. 3P sampling is a kind of survey method that developed from ratio-probability sampling. The combination of point sampling and 3P sampling is often applied in forest survey. According to the existing problems in especially forest resources management survey in South China, She et al. (2007) put forward the specific plans of unequal probability sampling based on counties as population and sublots as basic units, as well as the dynamic monitoring system of fixed angle gauge points concerning forest resources.

2) Unequal probability two-stage sampling method

The unequal probability two-stage sampling method includes both two stages with unequal probability and first-stage with unequal probability, yet second-stage with equal probability. In the population, first-stage units are extracted to unequal probability sampling, while second-stage units are extracted to equal probability sampling. Then, the samples extracted by two sampling methods are combined to estimate the population, which is the PR sampling method. Wang (2003) discussed the application of two-stage sampling method with different-size one-stage units in forest resources monitoring. She mentioned a double-stage sampling method with different-size one-stage units, which featured provinces acting as the population, marking values concerning counties as one-stage units and marking values concerning towns as double-stage units, and she pointed out that if a systematic sampling method was adopted to extract one-stage sample units, organized symmetric systematic sampling be recommended in order to avoid the systematic error caused by random extraction. When extracting second-stage sample units, cycling systematic sampling or organized systematic sampling could be selected, depending on the number of second-stage sample units. Zhu et al. (1999) did research into forest resources inventory of the continuous-distribution forests in Wuhu District of Anhui Province by using PR sampling method. The specific was like this: one-stage samples were used to extract map patches; second-stage samples were also used to extract patches with the same forest factors. This method solved the problem of registration concerning remote sensing material and ground plots effectively and sampling precision of the volume was 88.6%.

3) Unequal probability three-stage sampling method

PPR sampling is a kind of three-stage sampling method, and the specifics about this method are as follows: unequal probability sampling method is used in the first and second stages, and random probability sampling method is used in the third stage (Song, 2007). In 1973, Jiwen Forestry Bureau carried out the PPR sampling trial research. Qin et al. (1984) did the research into measurement of forest volume in the Liangshui teaching forest farm of Northeast Forestry College by using unequal probability three-stage sampling method and with the help of large-scale aerial photographs. The theoretical precision reached 86%. Li et al. (1985) carried out a study on unequal probability three-stage sampling method in Xishuanbanna Autonomous Prefecture of Yunnan Province and found that this method was suitable for forest resources survey in large areas.

4.2.4 Other sampling methods

1) Partial replacement sampling method (SPR)

Sampling with partial replacement is wherein part of sample units are replaced atevery period. This method was first proposed by Jessen in 1942. In 1962, this method was used in two periods of forest resources inventory by Ware and Cunia. In 1969, it was used again by Cunia in more than three periods of forest resources inventory. Jiang (2001) adopted the mathematical method of conditional extreme values to determine the rotation rate of the optimal samples or aging coefficient, on the basis of weighted estimated values constructed by sampling theories. In national forest inventory, the influence of cyclical variation on systematical sampling is the one of the main sources of systematical errors caused by the systematical sampling method. Since 1994, Zhejiang Province has been doing research on the movement of fixed plots, which can be regarded as a SPR method with an aging coefficient equaling 1/3.

2) Simulating plots sampling survey method

In 1968, Pordan introduced the six-trees sampling method to estimate breast-height basal area, volume, wood number per hectare (Anthonie et al., 2007). Ma et al. (1995) put forward simulating plots forest sampling survey method on the basis of biological features of forests and the model constructed to real plots, as well as the population estimated by simulation features. This method includes whole-distance simulating plots sampling survey and middle-distance simulating plots sampling, and it is often used in forest management surveys and forest operational inventory, adopting large-sample survey. In 1982, Ma proposed strip plot simulating forest sampling method on the basis of simulating plots. This method is a combination of conventional strip plot sampling and simulating plot sampling, which is fit for application in the old-growth forest, secondary forest and plantation forest. Especially, it is suitable for sublot survey and felling area survey concerning forest management.

3) Sampling method for sparse population and wildlife

As for sparse populations, the generally adopted methods (Annika et al., 2006) are band-shaped sampling, line intersect sampling, adaptive cluster sampling, transect relascope sampling, point relascope sampling and guided transect sampling. As for wildlife, there are methods like line intersect sampling, capture-recapture sampling and the wildlife triangle scheme.

In 1941, Canfield firstly proposed the line intersect sampling method. In 1960s, Warren and Olsen applied this method to the survey of logging slash (Warren and Olsen, 1964; Brown, 1971; Vries, 1974). Liu (1998) put forward the line intersect probability of circular objects and successfully introduced it into stand survey. The line intersect sampling method is a very effective method for scattered vegetation distribution types, suitable for the surveys of trees outside forest in China. Lei et al. (2007)

introduced a new technology of unequal probability sampling, adaptive cluster sampling. In addition, examples were illustrated for comparison of survey precision and efficiency between adaptive cluster sampling and the random sampling method.

Tan et al. (2002) carried out a disease-insect survey by sequence sampling method and initially presented the concept of basic sampling number. Further, he determined the application scope of curve equation concerning sequence sampling using a maximum sampling number.

The large sample method is an often used forest sampling method, and the population is estimated by normal distribution. Liu et al. (1999, 2003) used the bootstrap method in the study of forest resources sampling survey. The results showed that the bootstrap method was the estimation method for small samples, which could reduce the field surveying workload. This method is regarded as a sampling method that is worthy of extension.

5 Questions and discussion

Conventional forest resources monitoring is established on the basis of sampling technologies and periodical observation into fixed plots, which wastes a lot of human power, materials, and financial resources, and time-advantage and automation of forest resources information is not that good. This conventional method cannot satisfy the requirements of modern forestry in monitoring systems. As a result, it promotes the combination of a remote sensing system, global positioning system and geographical information system.

Tokola et al. (1999) summarized the various sampling designs in forest resources survey and stand survey. He proposed that the systematical sampling method could not meet the independence requirement of sample selection. In addition, the real sampling error of a systematical sampling method still cannot be presented in a reasonable formula. Therefore, only methods like simple random sampling are used for estimation (Song, 2007). The cost of systematical sampling methods used in forest resources survey is high, which has gradually become unsuitable for the needs of production, saving of financial funds of users and improving work efficiency of units. At present, the ongoing 7th national forest inventory has embodied contents reflecting ecological conditions like ecological functions of forest, forest health, and biodiversity in the monitoring range. Forest resources inventory is developing in the direction of comprehensive monitoring system, including both forest resources and ecological conditions (Xiao, 2004). On the basis of social monitoring requirements, how to integrate current monitoring projects, and improve and perfect current monitoring contents has become an urgent problem for comprehensive system to solve.

In the 21st century, forestry in China has entered into a historical transformation period in which forestry is evolving from the wood production-oriented type to an ecological construction guided one. The ecological requirement has become the first need of the society in forestry. In comprehensive monitoring system of forest resources, problems wait for us to solve. For example, acquisition and estimation of various monitoring indexes from various monitoring objects realized by technology. What is more, from different scales, like the provincial level and management unit level, sampling design is the key in the plan of ground plots established in accordance with monitoring objects. Therefore, it is necessary to find the optimal sampling design to meet the new needs theoretically. In addition, problems still exist like whether or not to take the encryption mode as Germany to establish the relationship between forest resources survey and forest management survey in China theoretically. Another problem is whether or not to adopt the new sampling method at present to improve and perfect current sampling survey system, such as unequal probability three-stage sampling, three-stage cluster sampling, multi-target stratified sampling or any methods under the framework of systematical sampling, which can meet the new needs at present. Finally, how to put the above thoughts into practice and thus extend and apply the practice still needs further research both in theory and experiments.

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