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# COMPARISON OF THE COST AND ACCURACY OF A FOREST INVENTORY USING ALS AUXILIAR DATA WITH A TRADITIONAL FIELD DATA INVENTORY

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**Abstract.** This paper synthesizes the conclusions of the research group on the applicability and improvement of forest inventory results, using auxiliary data from ALS technology, compared to a traditional inventory with field data obtained by sampling with plots.

ALS data are a great advance for the improvement of knowledge about forests and forest variables, this improvement of knowledge does not mean that the field work and therefore the costs of a forest inventory are decreased. When the smaller units are considered, ALS methods appear as more advantageous alternatives than those based on classical inventory.

True progress in forest management involves maintaining sampling efforts, in some cases reaching the intensity of a traditional inventory, to obtain acceptable estimates of the aggregate variables (V, B, G, Dg, Ho, N) in the AOI (Areas Of Interest), into which the forest can be divided for management.

On the other hand, this also allows improving the estimates of the diameter distribution in the total forest and subpopulations (forest or management units) of the area where the sampling was designed.

**Keywords:** Forest inventory, ALS, sampling inventory, comparative costs.

# СРАВНЕНИЕ СТОИМОСТИ И ТОЧНОСТИ ИНВЕНТАРИЗАЦИИ ЛЕСОВ С ИСПОЛЬЗОВАНИЕМ ВСПОМОГАТЕЛЬНЫХ ДАННЫХ ALS С ТРАДИЦИОННОЙ ИНВЕНТАРИЗАЦИЕЙ С ИСПОЛЬЗОВАНИЕМ ПОЛЕВЫХ ДАННЫХ

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**Аннотация.** В данной статье обобщены выводы исследовательской группы о применимости и улучшении результатов лесоустройства с использованием вспомогательных данных, полученных с помощью технологии ALS, по сравнению с традиционной инвентаризацией с использованием полевых данных, полученных путем отбора проб на делянках.

Данные ALS являются большим прогрессом для улучшения знаний о лесах и лесных переменных, но это улучшение знаний не означает, что полевые работы и, следовательно, затраты на лесоустройство уменьшаются. Когда рассматриваются более мелкие единицы, методы ALS оказываются более выгодными альтернативами, чем методы, основанные на классической инвентаризации

Истинный прогресс в управлении лесами предполагает сохранение усилий по отбору проб, в некоторых случаях достигающих интенсивности традиционной инвентаризации, для получения приемлемых оценок переменных агрегированных лесов (V, B, G, Dg, Ho, N) в зонах интересов (AOI), на которые можно разделить лес для его управления. С другой стороны, это также позволяет улучшить оценки распределения диаметров в общем лесу и субпопуляциях (лесных или хозяйственных единицах) на территории, где проводился отбор проб.

**Ключевые слова.** Инвентаризация лесов, ALS, выборочная инвентаризация, сравнительные затраты.

Light Detection And Ranging (LIDAR) sensors implemented in Airborne Laser Scanning (ALS) have been used for a variety of forestry applications. The high correlation shown by different LIDAR metrics with different stand variables makes them a primary source of auxiliary information for the estimation of forest variables.

Estimates obtained for aggregated variables such as volume (V), basal area (G), biomass (N), dominant height (Ho), Quadratic Mean Diameter (Dg) and stem density (N), can be better than those obtained from classic inventories based on random plots and basic stratification.

In Pascual et al. (2019) are summarized different analyses and conclusions on estimation of forest variables assisted with discrete pulse ALS data, in pine forests in the mountain systems of central Spain. The methodology was the area-based approach (ABA).

Table 1 refers to a Central Spain Forests zone, Cercedilla, occupied by *Pinus sylvestris* with average G greater than 30 $m^2$ $ha^{-1}$. The study area covered 147.5 ha, with 140 plots, the LIDAR density was 11.6 pulses $m^{-2}$. The inventory with ALS allows to reduce number of plots for the same relative error for the variables g, Ho, B, V, and N. For Dg there is no improvement with ALS except for 5% error. Several groups of variables with the same behavior can be distinguished. Tree height requires low sampling intensities with both classical and ALS sampling. Variables with significant improvements when including ALS data and with average or low sampling intensity requirements are G, B and V. Variables without significant improvement with ALS are Dg and N.

**Table 1.** Number of plots needed to reach 5%, 10%, and 15% relative errors in study area Cercedilla (Madrid). Decrease in percentage of sampling intensity when including ALS data. Sampling intensity is calculated as the number of hectares corresponding to a plot, ISc: Sampling intensity for field only inventory. ISals: sampling intensity for ALS inventory (Pascual et al. 2019).

| | **Basal Area (G)** | | | | | **Dominant Heigh (Ho)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **relative Error %** | **Classic Inventory** | **ABA** | **% decrease** | **IScl** | **ISals** | **Classic Inventory** | **ABA** | **% decrease** | **IScl** | **ISals** |
| 15 | 15.57 | 9.03 | 42.00 | 9.48 | 16.33 | 3< | … | … | … | …. |
| 10 | 32.02 | 16.66 | 47.97 | 4.61 | 8.85 | 6.13 | 4.74 | 22.68 | 24.06 | 31.12 |
| 5 | 106.92 | 46.67 | 56.35 | 1.38 | 3.16 | 35.87 | 14.67 | 59.09 | 4.11 | 10.05 |
| | **Biomass (B)** | | | | | **Volume (V)** | | | | |
| **relative Error %** | **Classic Inventory** | **ABA** | **% decrease** | **IScl** | **ISals** | **Classic Inventory** | **ABA** | **% decrease** | **IScl** | **ISals** |
| 15 | 16.59 | 3< | … | 8.89 | … | 17.60 | 12.39 | 29.58 | 8.38 | 11.90 |
| 10 | 34.14 | 7.00 | 79.50 | 4.32 | 53.90 | 36.42 | 17.60 | 51.69 | 4.05 | 8.38 |
| 5 | 114.81 | 53.06 | 53.79 | 1.29 | 36.46 | >140 | 55.19 | … | … | 2.67 |
| | **Quadratic Mean Diameter (Dg)** | | | | | **Stem Density (N)** | | | | |
| **relative Error %** | **Classic Inventory** | **ABA** | **% decrease** | **IScl** | **ISals** | **Classic Inventory** | **ABA** | **% decrease** | **IScl** | **ISals** |
| 15 | 11.53 | 15.21 | -32.00 | 12.80 | 9.69 | 42.60 | 34.43 | 19.17 | 3.46 | 4.28 |
| 10 | 22.52 | 24.10 | -7.04 | 6.55 | 6.12 | 90.41 | 71.28 | 21.16 | 1.63 | 2.07 |
| 5 | 78.54 | 72.84 | 7.25 | 1.88 | 2.03 | >140 | >140 | … | … | … |

Forest managers typically need estimates for areas of interest (AOIs) such as stands, management units (MUs) or groups of MUs that are spatial sub-divisions of an entire forest or study area.

Small-area estimation (SAE), techniques can be applied under the ABA framework and allow obtaining unbiased estimates for AOIs that imply a high level of spatial disaggregation.

Mauro et al. (2016) results showed that estimates for subpopulations using ALS are better than those obtained using only field plots using the same number of plots. The improvement was errors 2 to 6 times smaller depending on the variable. In addition, in this case the estimation of diameter distributions using the same number plots as a classic inventory was also more advantageous with ALS data. The average area of these AOIs was 25.4 hectares and the average number of plots per AOI was 3.74 plots. Between 3.5 and 4 plots may be sufficient for small areas.

The cost-benefit ratio of incorporating ALS data to the inventory must always be studied and depends on the accuracy level that is required for the estimates.

A cost study was carried out comparing a traditional inventory and another with ALS auxiliary information. The costs included the installation of plots, the LIDAR flight and the processing costs (Ortuño et al. 2013).

Table 2 refers to study area (Valsaín, Segovia), a 300 ha natural *Pinus sylvestris* forest with average G above 40 $m^2\ ha^{-1}$, treated by shelterwood system. Simple random sampling was performed in this area using 37 plots of 20 m radius. LIDAR density was 2 pulses $m^{-2}$ (Ortuño et al. 2013).

**Table 2.** Cost comparison of classic sampling inventory with freely accessible LIDAR inventory (Ortuño et al. 2013).

| | **Relative error 5%** | | **Relative error 5%** | | **Relative error 15%** | |
|---|---|---|---|---|---|---|
| Variables | Classic Inventory | ABA | Classic Inventory | ABA | Classic Inventory | ABA |
| **V** | 136.29 | 26.01 | 37.72 | 21.77 | 19.68 | 19.65 |
| **G** | 62.71 | 24.59 | 19.68 | 20.36 | 11.35 | 19.65 |
| **N** | 269.89 | | 71.26 | | 34.47 | 27.37 |
| **Ho** | 26.03 | 29.69 | 19.35 | 23.68 | 11.68 | 22.48 |
| **Dg** | 64.56 | 27.42 | 20.14 | 22.48 | 11.81 | 20.36 |
| **B** | 73.36 | 26.01 | 21.99 | 21.77 | 12.73 | 19.65 |

The cost of obtaining ALS data has been greatly reduced and freely ALS data are available in many places.

The inventory costs with free access to LIDAR auxiliary variables for 15% sampling error are still higher than those of the traditional inventory for most variables except for N, and are equal for V. For 10% error, the cost difference between both types of inventories is reduced, the costs free LIDAR data are lower for V and similar for B and Dg. The costs is significantly lower for the inventory with free LIDAR data for all variables when the maximum allowable error is 5%. In addition, it must be borne in mind that diameter distribution can be estimated better with traditional inventory because it uses a greater number of plots.

The previous results show that many inventories carried out with ALS are economically inappropriate to estimates forest means and totals, since a simpler classic inventory would have sufficed in forest with good accessibility. This reasoning changes when we start to consider AOIs.

For the case of a 300 ha forest with 9 subunits (33.3 ha on average), we can calculate the number of plots needed using the data in Table 2, to obtain consistent estimates for the 9 subunits and the total forest. In the case of volume, for a relative error of 15%, 35.8 plots would be necessary for a classical inventory by sampling and 25.2 in the case of using ALS, for the total forest.

If we take as a reference the existence of at least 4 plots per subunit to apply the SAE techniques, we would need 36 plots for the inventory, 10 more than those calculated for the total forest using ALS and the same as with the classic inventory. Using the 36 plots would bring us closer to the relative volume error of 10% for the forest as a whole, a value that would be reached if the 36 plots of the classical inventory were maintained.

**Conclusions:** Cost-benefit studies should not only evaluate the decrease in the number of plots to obtain estimates at the forest level but also the sampling efforts required to estimate at a stand scale (or similar AOI). When this smaller units are considered ALS data appear as more advantageous alternatives than those based only in a classical inventory. Therefore, it is necessary to increase the sampling intensity with ALS, in some cases reaching the intensity of a traditional inventory, but this also allows to improve the estimates of the diameter distribution in the total forest and subpopulations (forest or management units) of the area where the sampling was designed.

The real advantage of this technology to describe and characterize the forest structure derives from the supplement of precision and information that it can provide to classical methodologies, maintaining its sampling effort and not decreasing the field data collection.

This added knowledge represents an advance for the improvement of forests and land management.

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