



Forest disturbances impose challenges to the monitoring of forest resources

Dynamic sampling and inference for a smart forest monitoring with applications to the French National Forest Inventory.

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Thematic action concerned: WP2

Context —

The effects of global change and the loss of biodiversity are issues that entered the public and political spheres, and the awareness of the imprint of human actions increases expectations towards forests. These new expectations highlight the need to quantify and monitor not only the condition of forests but also their ability to support the provision of these ecosystem services. However, large-scale inventory methods have been developed for resource monitoring and at a multi-annual timescale. New expectations, as well as more intense and frequent disruptions, require a review of these methods, to make them evolve towards greater responsiveness.

The sampling and estimation methods of the French national forest inventory were redesigned in 2004 with the aim of allowing annual coverage of the territory and adaptability of the sampling effort. The data collected over the past 15 years constitute an unequaled empirical basis, which should make it possible to assess the effectiveness and limits of current methods.

Moreover, the skills needed to analyze survey and estimation methods are extremely rare, particularly in the forestry sector. The premature disappearance of the pairs (Jean-Christophe Hervé, Adrian Lanz) leaves a deep lack in a very small community. The role of the project is to contribute to the renewal of these skills and to develop new sampling and inference strategies, by bringing together within the framework of the project people who can each contribute a specific and complementary experience.

Objectives —

The goal of the project is to develop survey methods, ranging from sampling to estimation, to respond to rapid modulation constraints of the sampling intensity, while maintaining high levels of precision. Although developed in the context of the national forest inventory, the general nature of these methods will be maintained and strengthened to allow them to be used in ecosystem surveys.

A first objective is to describe and evaluate current post-stratified statistical estimators, and to compare them with existing estimators in critical contexts. A second objective is to evaluate and optimize forest stratification/post-stratification schemes with perspectives on variance-bias trade-off and small strata issues. A third objective is to redesign the sampling strategy of this inventory and increase its flexibility and independence.

Approaches —

The approach has two very complementary aspects: axiomatization and quantitative analysis. The axiomatization constitutes a formalization of the sampling and estimation methods of the national forest inventory. This formalization represents an effort to anchor inventory methods in the survey theory, and therefore represents an essentially theoretical activity. This activity aims to provide the work with statistical foundations specific to the discipline as well as a base of bibliographical references. The formalization also ensures the development of the limit properties and the validity hypotheses of the statistical estimators.

The quantitative analysis is based on the development of the exceptional database of the national forest inventory, and first, to carry out a critical quantitative analysis. The hypotheses and theoretical limit values will be compared with the ranges and variance of the empirical values collected during the fifteen years of operation of the inventory method.

Key results — (presented as separated bullet points)

- The statistical estimation methods of the French National Forest Inventory (NFI) have been described in accordance with the sampling theory for the first time since the creation of the “new inventory method” (2004). They confirm the total estimators used by the NFI.
- The theoretical analysis of statistical estimators (i.e. axiomatization) makes an original contribution by proposing a new generation of statistical estimators capable of operating with variable sampling rates in time and space. There is currently no estimator of this type in the literature, which favorably positions the thesis work in a perspective of specialized scientific publications.
- The theoretical analysis allowed the creation of statistical estimators linking tree-level data to target estimates at the territory scale. This is a first: the tree level had until now been completely absent because it was simply absorbed by the calculation of average plot level values. This progress has theoretical implications because it solves old forestry sampling problems.
- The theoretical analysis of the estimators revealed a set of conditions and assumptions necessary for the absence of bias in the estimates. These hypotheses will play a very important role in future reflections on the optimization of sampling methods in the IFN. These results will therefore have scientific repercussions but also very important practical repercussions for the NFI.
- A sampling and estimation simulator has been developed. This is a suite of functions in R for simulating complex samplings and implementing various estimation methods. This simulator will be coupled with a large forestry digital twin: for the first time, all the steps from sampling to estimation will be grouped in a single simulator capable of implementing very complex methods representative of NFIs.

Main conclusions including key points of discussion —

- Firstly, it should be underlined that the PhD project is proceeding in very favorable conditions, the PhD student being a highly motivated and hardworking student, and the progress rates are totally conform to the program established at the start of the Labex project.
- The theoretical analysis of the French NFI estimators, and more generally of the complex estimators used in other modern NFIs, represented a first milestone in the project. This milestone was achieved and successful. This first hard step was the most difficult because it supposed that the PhD student made a very intense personal investment. It has opened many perspectives.
- The results obtained during this first year are already quite considerable and are currently synthesized with the objective of writing scientific publications out of it. This work dedicated to publication just started.
- The heavy investment in theoretical aspects will be completed by other works consisting in doing simulations and in analysis true data. Here again, the outcomes are potentially very substantial and relevant to both the survey sampling research field and to that of the environmental sciences.

Perspectives —

- This first marathonic year of the PhD has allowed us to open up a large number of avenues. This PhD is the first in France since 1986 to deal with forest inventory methods, after that of F. Houllier. The deficit is therefore substantial, and this PhD will offer a support to regain these competences. From there also comes the large variety of perspectives, and expressed needs.
- The PhD has allowed the accretion of skills around thesis work. This critical mass of knowledge should be enhanced, for example by further related work.

Valorization —

1. Presentation at a conférence

PhD / Postdocs Labex day 2022, Location: INRAE Champenoux, Date: October 11th, 2022

Type: Oral Presentation

Titre : Dynamic sampling and inference for a smart forest monitoring with application to the French NFI

2. Presentation at a conférence

Journée scientifique du LIF; Location: IGN, LIF, Nancy ; Date: November 28th, 2022

Type: Oral Presentation

Titre : Sampling and estimation methods of the French NFI

3. Presentation at a conférence (forthcoming, accepted)

12th International Conference on Surveys ; Location : Aubervilliers Campus Condorcet, Date: 22nd to 24th March 2023

Type: Oral Presentation

Titre : Formalization of the sampling design and of the estimators used in the French NFI

Leveraging effect of the project—

In a context where survey specialists are increasingly rare (in France and globally in the world), while the demands and expectations of environmental monitoring are growing, the thesis makes it possible to strengthen the community in these key skills with usage opportunities well identified.

The international influence is a very important element of the leverage effect of the project. This outreach involves two complementary “levers”:

- the lever of collaboration: it is planned that the doctoral student will do a research stay in the Neuchâtel survey laboratory to work with Alina Matei. This laboratory is the one in which Yves Tillé, a world reference in terms of soundings, also works.
- the lever of publications: many aspects are new and make it possible to reposition ourselves among the leading laboratories working on aspects of monitoring and inventory of natural resources.