A New Flexible Forest Inventory in France

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Abstract.—The French National Forest Inventory was created in 1958 to assess metropolitan forest resources. To stick to new national and international requirements as well as to enhance reactivity, a new inventory method was implemented in 2004. This new method is based on a systematic sampling grid covering the whole territory every year. The size of the mesh is variable, locally adapted to the diversity and the fragmentation of French forests. The sample is defined for 5 years. It is divided into 5 annual systematic subsamples, each of which covers the whole country. The estimation method uses poststratification to enhance statistical accuracy.

Introduction

The mission of the French National Forest Inventory (NFI) is to collect information about forest and natural lands all over the European part of France. It describes forest, other wooded land, heathland, and hedges. It draws a precise map of forest types and heathland. It estimates areas per land cover and land use, and assesses forest resources including growing stock and carbon stock with their increment as well as biodiversity.

Data are produced at national, regional, or "département" (administrative unit covering each nearly 1/90th of the country) levels to help policymakers in their decisions. It also proposes results at the scale of "forest regions," which are small, continuous ecological areas. Aggregated results are available for free on the NFI Web site and particular requests can be asked. The NFI staff also conducts specific studies based on NFI results for many institutions. For example, it evaluated wood fuel resources in France (French NFI 2005) or updated indicators for forest sustainable development (French NFI 2001), as well as international level delivery to the United Nations Food and Agriculture Organization and the United Nations Economic Commission for Europe.

The Previous Method

The forest inventory was conducted since 1958 per "département" (French NFI 1985). Results were very precise at the scale of the "département," but data were updated on these areas every 12 years only. No intermediate results were available. To produce results at the regional level (22 units) and more over at the national level, the aggregation of diachronic results was used. For field observations, a stratified sampling plan was used. The stratification variables were ownership, forest regions, forest types, land use and cover. It enhanced the quality of the forest area evaluation and tree measurement results, but the impact on ecological variables remained difficult to estimate.

National and International Context

In France, administrative regions become more and more a level of policy decisionmaking, and data are needed at this level to prepare political decision. At a different level, nonadministrative management units (e.g., regional and national natural parks) need forest mensuration and ecological results from the NFI to guide their action. As a consequence, a higher geographical flexibility is required.

Reactivity is also expected. The NFI must be able to evaluate quickly consequences from important disturbances (storm, drought, forest fires, or parasite attacks) that have an impact at the regional or at the national level. The envisaged solution is to come back on the surveyed plots but the sample must be recent.

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At the international level, the French government has to provide data about forest resources every 5 years to the Food and Agriculture Organization (FAO) and to report on sustainable forest management indicators for the Ministerial Conference for the Protection of Forests in Europe. It needs data about forest carbon stock and sinks to compute the greenhouse gases balance according to the convention on climate change of the United Nations and its Kyoto Protocol. To meet these requirements, regularly updated information at the national level is necessary.

Flexible Sampling Design

Principle: A Countrywide Systematic Sampling Each Year
To respond to these requirements, the NFI changed its sampling design. At first, the sample was prepared for 10 years and was divided into two 5-year systematic subsamples, each of which covers the whole of France. It finally started with a 5-year slice. The new sampling is based on a systematic square grid covering the entire country. The size of the grid-mesh is 2 km^2. Plots are georeferenced using the Lambert II extended projection and New French Triangulation.

The whole grid is scheduled to be measured in 5 years. The 5-year sample is divided into five systematic annual subsamples consisting of square grids interpenetrating each square (fig. 1), covering the entire country (model also presented in Roesch and Reams 1999).

1.1. Adapting the Sampling Effort: A Multilevel Grid
Some collected data are required with a very high confidence level, even in small areas. For other variables, precision is only required at the national level or when an approximate value is sufficient. Some variables, such as the volume of growing stock, can be evaluated on all plots using models, volume measurements being only necessary on a subsample to calibrate the models.

Due to the diversity of precision requirements, a mechanism was found to adapt sampling intensity to each variable (or set of variables), by defining a system of nested subgrids from the basic one. If the entire annual sample is, say, of level 1, the level 2 subsample is obtained by taking out of level 1 every second plot in staggered rows (fig. 2). Level 3 is obtained in removing in the same way every second plot from level 2, etc. There are half as many plots at the level n as at the level n+1.

In this way, nested systematic annual samples are generated with a sampling rate divided by 2 at each level. Measurements are made at a defined level, depending on the expected result accuracy. For each variable, an observation level is defined, corresponding to the subsample on which it is to be observed.

1.2. Invariance Properties
The properties of interrelated systematic square samples are preserved at every level in an annual sample as well as in a 5-year sample (fig. 3). The only difference is the density of

Figure 1.—*A 5-year sampling grid divided into five annual interpenetrating sampling grids.*

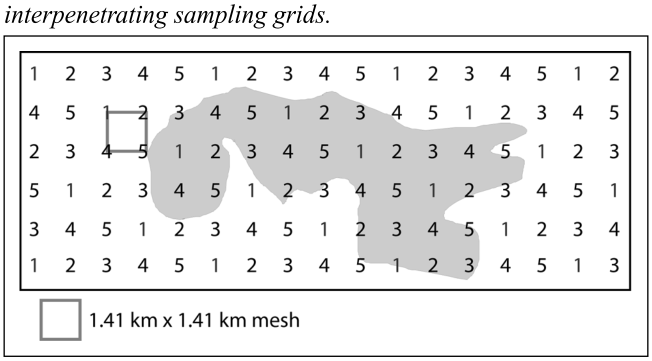
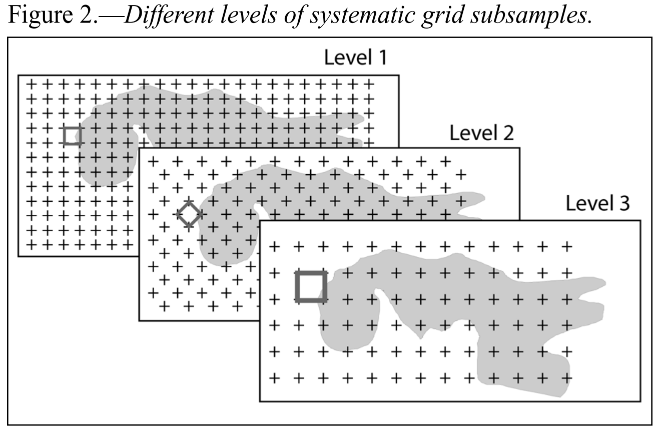


Figure 2.—*Different levels of systematic grid subsamples.*



sample plots. As a consequence, the same computation scheme can be used every year and for every level.

As years will go by, the density of the observations and measurements will increase. The use of several consecutive annual measurements will be interesting to enhance the precision of the results and to enable local reporting.

Spatial Adaptation of the Sampling Rate to Optimize Field Work

Delimited Areas With Reduce Sampling Rate

Some areas in France are very homogeneous, for example, the maritime pine (*Pinus pinaster)* massif in the Southwest. In such areas, fewer measurements are necessary to obtain precise enough results.

In other parts of the country, some forest ecosystems are not very productive and the economical use of the wood is of a little importance; e.g., green oak (*Quercus ilex)* or strawberry tree *(Arbutus unedo)* stands in the Mediterranean region or forests on steep slopes in mountainous areas. No detailed resource assessment is expected. Fewer measurements can be made to obtain estimations corresponding to the needs.

In both cases, the concerned areas (called forest zones) are mapped (fig. 4) and the density of the sample is adapted. Field operations are then carried out at a higher level subsample than the usual one, for example at level 3 instead of level 2 (fig. 5).

This geographical adaptation of the sampling rate makes it possible to go through the whole sample in 1 year with a constant number of field crews.

A Higher Sampling Rate for Poplar Stands

Poplar trees are economically important in France. Plantations are usually small and felling cycles are rather short. To make a precise inventory of these areas, a higher density of plots is required in the parts of the territory where the poplar stands are often clustered (valleys especially). Therefore, observations are conducted on 16-plot square clusters instead of single plots. These clusters are systematic 1 by 1 km grids. The mesh is square with 250 m between plots. This process multiplies the

Figure 3.—*Invariance of the subsample properties every year and at every level.*

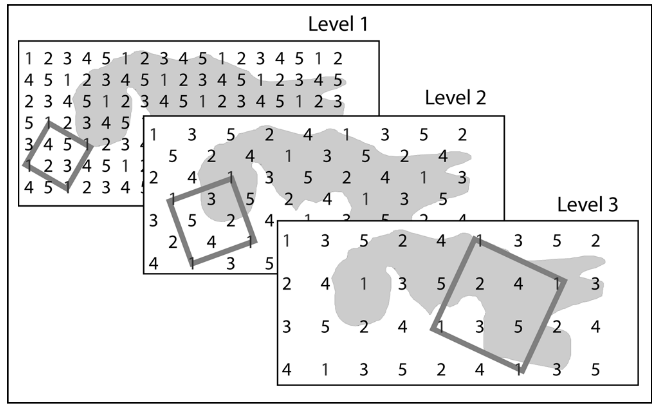


Figure 4.—*Map of the forest zones with a reduced sampling intensity.*

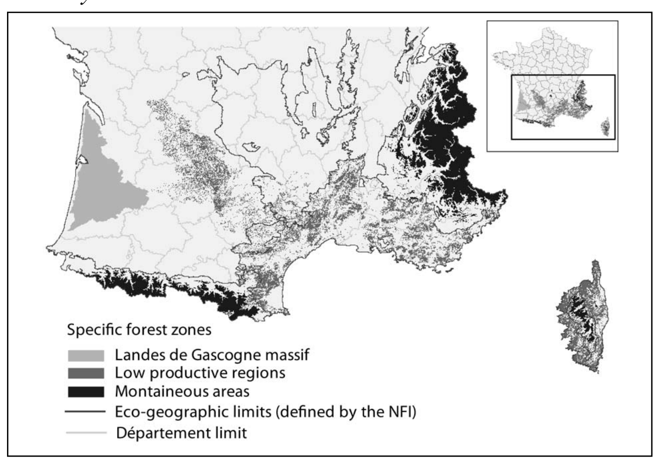
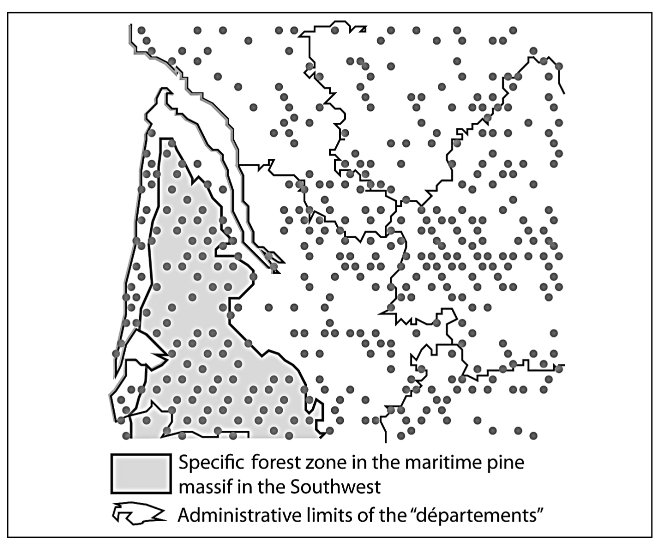


Figure 5.—*Example of reduced sampling intensity in the Southwest.*



number of observations on poplar stands. To limit this number, clusters are only used in areas where poplar plantations are localized. These areas, called poplar zones*,* are mapped (fig. 6). Whenever a knot of level 1 grid is located in the poplar zone, a cluster of plots is attached to the knot (fig. 7). All plots from the cluster are surveyed (even if they are out of the poplar zone).

As a conclusion, the 5-year sampling design divided into systematic annual samples offers much flexibility with its several levels of systematic subsamples and its clusters. The density of observations can thus be adapted, depending on the variable measured and on the area.

Figure 6.—*Map of poplar zones.*

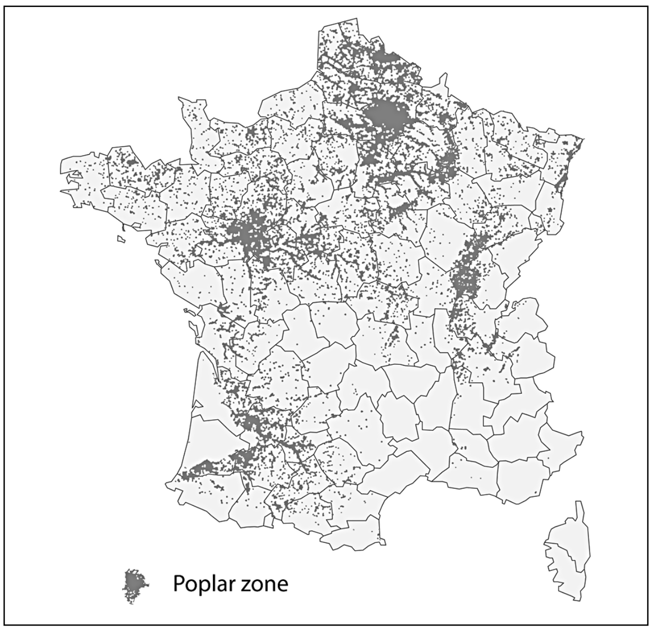
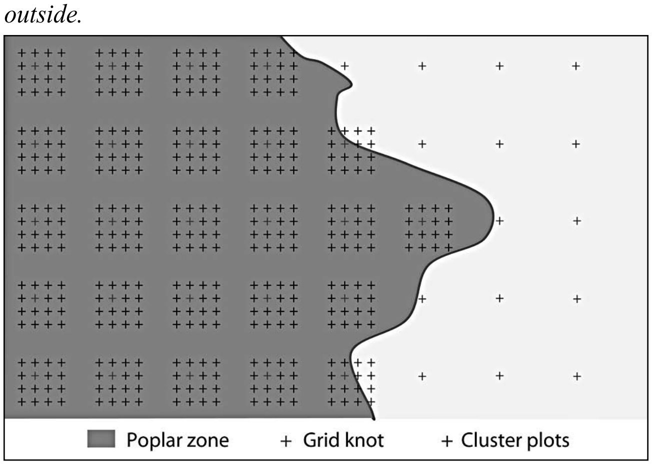


Figure 7.—*Use of clusters inside poplar zones and single plots outside.*



Level for Data Collection

Photointerpretation

The whole annual sample (level 1) is observed on the French aerial orthophoto map called BD Ortho, which is a product of the French National Geographic Institute. Land cover and use is determined on each knot of the grid. Land cover nomenclature consists of open forest, dense forest, heath and moorlands, artificial or natural area without vegetation, other artificial areas and water. In case of doubts, controls are made in the field.

Poplar plantations are included in forest since November 2005, but they are still singled out during the photointerpretation. Their occurrence is detected in plots from clusters in poplar zones and also in plots from the level 1 annual sample out of poplar zones.

The photointerpretation produces results about land cover. It is also a key operation to determine the type of measurement that will be conducted in the field.

Field Measurements in Forests

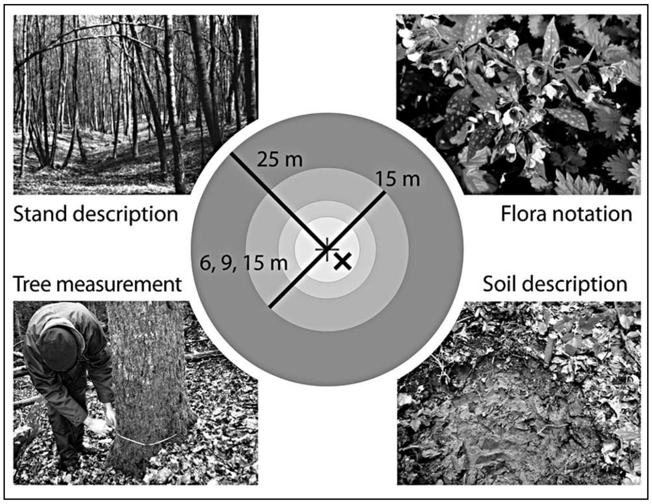
Field observations are conducted on plots determined as forest on the photographs at level 2 or 3. A forest is defined by the French NFI as a stand of more than 0.05 ha and wider than 20 m in which crowns from forest trees or noncultivated trees that can reach 5 m *in situ* cover more than 10 percent of the area. To fit the FAO definition, it is determined whether the stand is larger than 0.5 ha.

The fieldwork, including stand description, tree, soil and ecological measurements, is done on four concentric circular plots (fig. 8):

- On a 25-m radius plot, the stand is described: land cover, land use and stand description (composition, structure, age, logging possibilities, etc.).

- On a 15-m radius plot, flora species (woody and nonwoody plants including pteridophytes and bryophytes) are identified and their abundance is noted.

Figure 8.—*Data collected in forests on four concentric circular plots.*



- Trees are measured on three concentric plots, depending on their circumference at 1.3 metres. Trees more than 23.5-cm circumference are measured on a 6-m radius plot. Trees more than 70.5-cm circumference are measured on a 9 m radius plot. Trees more than 117.5-cm circumference are measured on a 15-m radius plot. Trees less than 23.5-cm circumference are not measured.

On every forest plot observed in the field, the species, shape, and the number of stems of the tree are noted. Simple measurements are made: circumference at 0.1 m and at 1.3 m, total height, diameter and height increment during the last 5 years, and wood quality classes. Additional measurements such as timber height, mid-diameter, and mid-timber diameter are made on level 4 subsample plots. The results are used to fit volume estimation models.

Soil observations are conducted on a 1-m deep soil pit in a representative part of the plot. Humus (structure, litter, type) and soil (texture, carbonation, moisture) are described. Other information is collected, such as topography, exposure, parent rock, etc.

Heaths or Moorlands

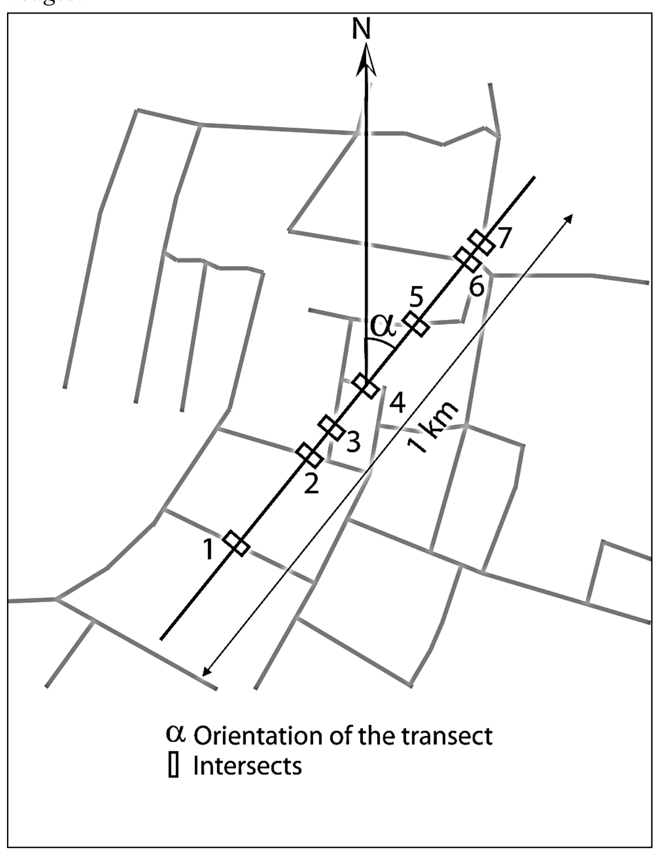
Heaths surveyed by the NFI are covered with noncultivated vegetation. Their size exceeds 0.05 ha and their width is more than 20 m. The crown of noncultivated trees covers less than 10 percent. Part of these heaths belongs to the other wooded land FAO category.

Heaths are inventoried in the field on every plot from the level 3 grid. Soil and topography are described. Their ecological type determination is based on shrub cover and type of soil. These data are the only statistics about heaths available all over France.

Hedges and Tree Rows

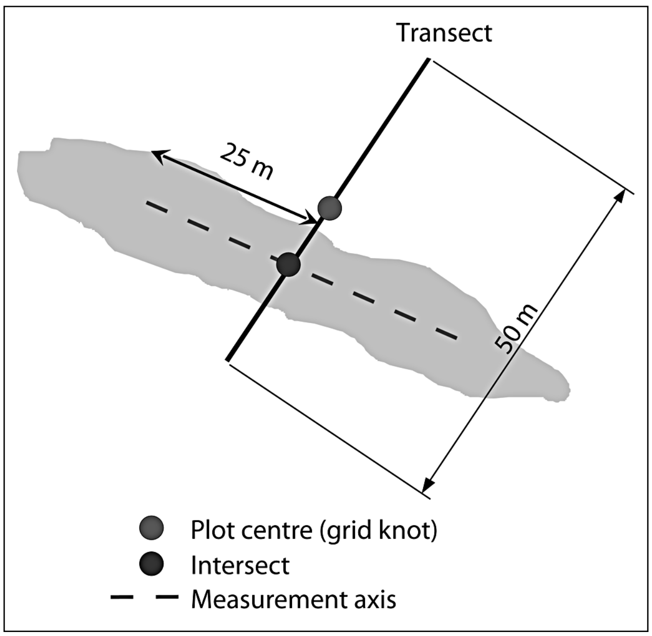
Hedges and tree rows are observed on orthophoto maps during photointerpretation on every plot from the level 1 sample. A transect method is used. A 1-km long line transect is centred on each grid knot with a randomly varying orientation. The number of intersects (fig. 9) between tree rows or hedges and the transect is counted to evaluate the length of these alignment in the territory.

Figure 9.—*Example of a photointerpreted transect intersecting hedges.*



In the field, operations are conducted on every alignment intersected at less than 25 m from the transect centre at a specific level (fig. 10). The type (hedges with or without trees, trees row with forest trees or poplar), species (tree, shrub and bush), the length, the width, the coherence with other linear elements (wall, river, etc.) are noted. The shape and ligneous species are observed and the permeability is evaluated. Specific measurements are conducted on trees at level 5 to evaluate the volume and the increment of growing stock.

Figure 10.—*Example of a tree row plot.*



Estimation and Computing Methods

Every year, at every level and for all inventoried structure, data are collected in the same way. Consequently, estimation procedures are the same in all cases for annual results.

Results, Details, and Precision

As a result of the annual sampling plan, sufficient precision will be obtained with data collected in 1 year on large areas only, for example, one-fifth of France or the whole territory. It is interesting to mention, however, that the possibility of annual national reporting allows fast countrywide update of the results in case of major disaster. It also gives the possibility to follow regularly the evolution of forest and other wooded areas and to highlight general trends.

Results can be obtained at a more local level and/or with more details using observations from several consecutive annual campaigns. A general estimation shows that regionwide results are available in 3 to 4 years. For the département level, at least 8 years of survey may be required, depending on the variable and the forest area.

Geographical Restitution Unit

With a systematic sampling design, the number of plots in a studied area is directly related to its size. Results will be more precise on larger areas. If data are required on small areas, two possibilities are offered by the new sampling design: (1) wait until enough data is gathered to compute the results, or (2) increase the level of annual collection for data that must be better evaluated in a given area.

The precision of the evaluation of a variable is also related to its variability in a given domain. This statistical property is interesting, because areas where less variability for some variables is expected can be delimited. It leads to the possibility of using post-stratification to enhance the precision of the results.

Computation Principle: A Yearly Computation Using Post-stratification

The French NFI maps forests and moorlands. In its Geographic Information System, the limits of administrative units such as département and ownership are also integrated. These are pieces of information that can be used to compute the results. Firstly, at the département or the region level, decisions to develop and encourage specific sylvicultures are taken. Secondly, the French national forestry board manages public forests differently if it is state forest or other public forest. Private foresters also have another behaviour. Thirdly, the forest type is determined on stand types, main species, structure, etc. As a result, in stands located in the same area, with the same forest type and ownership, less variability is expected.

Results from the French NFI will be computed using map post-stratification by département, stand type, and ownership category. This processing method will enhance the precision and the consistence of the results at the local and the national level. For totals, national results are then the exact sum of results calculated in each strata. This ensures, for example, that national results equal the sum of département results.

Results will be computed for every campaign. When the combination of several campaigns is necessary, the information will firstly be computed on the given area for each annual slice, actualized if necessary, and then averaged (Johnson and Williams 2004, McRoberts 2001).

For specific results on specific areas, two possibilities will be offered: (1) use the established post-stratification, or (2) establish a new post-stratification adapted to the area and to the variable that must be evaluated.

Conclusions

The new sampling design of the French NFI offers new opportunities. It is a flexible tool working annually at the national level and able to produce results on any part of the country. The NFI can compute results on smaller part of the country after a number of years depending on the area, the variability of the variable to be considered, and the sampling rate. This new tool allows fast reaction in case of exceptional events. Thanks to an efficient post-stratification, the loss of precision at the local level compared to the older method should be limited.

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