Course 6

Text-only version

Quality assurance and quality control in a national forest inventory

The interactive version of this lesson is available free of charge at https://elearning.fao.org/

In this course

About the course

This course provides an overview of Quality Assurance (QA) and Quality Control (QC) procedures in forest inventory data collection and management.

Who is this course for?

This course is primarily intended for people who are involved in QA/QC of NFI field data, especially with an interest in the principles and procedures of quality assurance and reporting. Specifically, this course targets:

1. Forest technicians responsible for implementing their country's NFIs
2. NFI planners
3. National forest monitoring teams
4. Students, as curriculum material in forestry schools
5. Youth and new generations of foresters

Course structure

There are three lessons in this course.

Lesson 1: General considerations on QA/QC	describes the relevance of quality in all steps of an NFI, and outlines the responsibilities of all stakeholders towards maintaining it.
Lesson 2: QA/QC in planning and analyses	This lesson focuses on QA and QC in the planning and analyses phases and identifies suitable measures of QA/QC in them.
Lesson 3: QA/QC in immediate data sources	This lesson describes quality issues in field data collection.

About the series

This course is the sixth in a series of eight self-paced courses covering various aspects of an NFI.

Here's a look at the complete series:

Course	You will learn about
Course 1: Why a national forest inventory?	Goals and purpose of an NFI and how NFIs inform policy- and decision-making in the forest sector.
Course 2: Preparing for a national forest inventory	The planning and work required to set up an efficient NFI or a National Forest Monitoring System (NFMS).
Course 3: Introduction to sampling	Introduction to sampling
Course 4: Introduction to fieldwork	Considerations for fieldwork, plot-level variables and tree-level measurements.
Course 5: Data management in a national forest inventory	Data management in a national forest inventory
☞ **Course 6: Quality assurance and quality control in a national forest inventory**	**(You are currently studying this course)**
Course 7: Elements in data analysis	Typical approaches/calculations in data analyses and related topics.
Course 8: National forest inventory results: Reporting and dissemination	NFI reporting and the importance of reporting in the context of REDD+ actions.

Lesson 1: General considerations on QA/QC

Lesson introduction

NFIs are designed to produce meaningful data on forests and trees on a national level. As in any other production process, quality is therefore a major concern. The quality of the product should be as high as possible—but always within the limits of resources available.

Such feasibility in terms of resources is a relevant criterion. The other is that the quality of the product must be useful for the purpose for which it has been developed. Establishing the minimum quality requirements of and NFI data is difficult, not intensively researched—this is still a major research gap regarding NFIs.

Learning objectives

At the end of this lesson, you will be able to:

1. Describe the relevance of quality in all steps of an NFI.
2. Identify whose responsibility it is to monitor quality.
3. Explain why errors are omnipresent in empirical undertakings such as NFIs.
4. Outline the goals of a QA/QC process.
5. Explain the importance of setting and documenting quality standards.

What is quality and why is it relevant in NFIs?

The primary and raw products of NFIs are **data** for a comprehensive set of different variables, as defined in the inventory protocol. After analyses and interpretation, a further product is the **information**, where aggregated and analyzed data is converted into meaningful inputs for policy- and decision-making processes. Such information is commonly presented as results, in the form of tables, graphs, maps, and so on.

Contrary to some simple industrial products, however, the quality characteristics of NFI products are not immediately visible but need to be traced back from the production process, i.e. from all steps that make the data collection and analysis.

Definition of quality standards in an NFI

How do we define **quality** in the context of data and results? In an ideal (but unrealistic) measurement/observation campaign, the measurements/observations would correspond to the true values. However, in forest inventories, true values can never be known for any of the variables recorded, and this holds true for all empirical projects that involve measurements.

This is important to understand: there will always be random errors—and it is one of the guiding principles in NFIs to keep these random errors as small as possible and within defined limits. So **when** the **available resources meet the defined quality standards**, it can be said that the **data is of decent quality**. Here, defined quality standards means that the random deviations from the assumed true values are within those defined limits.

There is no general standard for data quality for any of the many variables recorded in an NFI. It is up to the NFI organizers to define standards—both regarding the target accuracy of the measurements as well as the measurement approaches/techniques. However, although the definition of the target accuracy is a challenging task; without such a definition, quality control will not be possible. Frequently, standards of former NFIs/NFIs from neighboring countries are used, where the major criteria is the marginal cost of generating higher accuracy estimates.

Note

Quality is an issue in all steps of NFIs, an overarching and cross-cutting topic that we encounter practically everywhere. Therefore, while we specifically dedicate this course to the topic QA/QC, the topic recurs and is addressed to some extent in all other courses of this series as well.

Definitions of QA/QC

Before we consider the major elements of QA/QC, let us look at the definitions of these processes.

Quality assurance (QA)	Quality control (QC)
Quality assurance (QA) embraces all planning and preparatory measures within the NFI process that contribute to maintain the defined quality standards. Quality assurance is a matter of planning and of the according implementation; it	Quality control (QC) refers to all those measures that are taken to check the quality of the products so that in case of unsatisfactory quality, countermeasures can be taken. Quality control comes **during** or **after** the data production

takes place **before** the data is produced, by setting the quality standards and defining procedures that allow us to adhere to them.

process, checking and making sure that the quality standards have been sufficiently met.

It is this distinction in definition that also defines the structure of this course—after the general observations in the first lesson, Lesson 2 deals with quality assurance measures during planning and analyses. Later, Lesson 3 focuses on quality control of data collection in the field and from remote sensing data sources.

QA/QC: The people involved

A major point of distinction between QA and QC measures is the **number and type of people**: in QA during inventory planning and analyses, a small group of experts are involved. In the best case, these are highly specialized experts, who work collaboratively, seeking feedback from their peers on design elements and analysis details. If these tasks are not covered by such experts, the entire NFI exercise may eventually be compromised.

Contrary to this, quality control refers (to a large extent) to data collection where many people with diverse backgrounds (field teams, image interpreters) are involved. In many cases, people working on only one aspect of the NFI may not feel directly responsible for the success of the entire project. To lay the foundations of their work, quality assurance measures are paramount; but systematic quality control is eventually required to make sure that the quality assurance measures are really taking effect.

While the quality of products is a collective responsibility of everyone involved in an NFI/NFMS, the responsibility for both QA and QC lies in the hands of the coordination team.

To reiterate, QA/QC with all its facets is one of the default components that needs to be considered in all NFI and NFMS planning. Lack of explicit QA/QC measures may be considered a serious failure in NFI planning.

It is a good practice to stress quality as a guiding principle very often in the NFI planning and implementation process. Particularly in those work steps that are lengthy and become routine, it is important to repeatedly remind everyone involved that quality standards need to be adhered to. This refers mainly to inventory field work and to visual/manual work in remote sensing interpretation.

Reality check

Those who are responsible for QA/AC are also responsible for creating a culture of dealing with mistakes and confusions. Lack of clarity in methods and potential mistakes should be immediately addressed and solved—not hidden and perpetuated. It is all too human to commit errors—but it is not so smart to conceal and/or repeat them.

Risks to quality in NFIs

The people in charge of planning and supervising the NFI need to always be aware that deficient data quality will inevitably compromise the quality of the results. In data science, this is also referred to as the **GIGO** (Garbage In – Garbage Out) **principle**: the output can only be as good as the input is. The major risks to quality in NFIs include:

- *Lack of sufficient focus on quality* - This refers to all phases and activities in the NFI, including methods, data, analysis and reporting.
- *Being happy with large quantities of data collected at modest cost* - This means sacrificing quality or methodological soundness in favor of rapid and/or less costly data generation. It is usually much better to have lesser but quality-controlled data, than masses of data without serious quality control.
- *Underestimating project planning and human resources, including the role of team motivation* - Various tasks in NFIs are tiring, lengthy and time-consuming, and can become quite monotonous after a while. Unthinking routine can be an enemy of quality. This means that while field data collection might be considered less academically demanding than planning or analyzing an NFI, the overall quality of the results depends critically on the quality of what the field teams collect.
- *Incomplete inventory protocols or field manuals* - Incomplete elements that leave room for 'individual adjustments' during data collection, or what's worse, the lack of a field manual documenting details of the NFI. Standard Operating Protocols (SOPs) for all data collection steps are nowadays increasingly implemented across countries.

- *Considering an NFI essentially as a mapping exercise with a major or exclusive focus on remote sensing and GIS* - While remote sensing data is becoming a critical data source in NFIs and GIS is becoming a valuable tool in NFI planning and analyses, there are various other data sources and tools that are also as relevant.

It is evident from these that NFIs possess all the major characteristics of typical empirical studies —the points on risks to quality hold equally well for any other empirical scientific study.

The inventory protocol as a pre-requisite for QA

As a repository for all design details, definitions, measurement procedures, and analysis approaches of an NFI, the inventory protocol is a basic prerequisite for any quality consideration. It is therefore also the reference point for any methodological questions on the NFI and an important element of overall transparency.

The inventory protocol and its relevance have already been mentioned in other courses, most notably in **Course 4: Introduction to fieldwork**.

The field protocol is binding for all inventory actions. Not adhering to the definition of procedures in the inventory protocol can compromise the consistency and quality of the data. Given this crucial role, it is recommended that sincere effort be invested into authoring the inventory protocol, and ensure that it is complete, consistent and transparent.

Because there is no such thing as a best-practice guide for NFIs (simply because there is no single best or generally applicable approach), it is important to include details on all defined design elements and justifications for their use.

Reality check

Many of the QA/QC measures described in this course can translate to extra efforts that carry extra cost. If, for example, 5-15 percent of all field sample plots are to be re-visited by a control team (see Lesson 3), these extra field days need to be planned for, as does extra data analysis.

The same holds for the observation of ground truthing sample points during the accuracy assessment of remote sensing products. Also, when an advisory board is established (see Lesson 2), costs for meetings and honorarium need to be planned for, as are travel costs to meetings of regional NFI networks—if they exist.

Summary

Before we conclude, here are the key learning points of this lesson.

- Quality is an issue in all steps of NFIs, it is an overarching and cross- cutting topic that we encounter practically everywhere.
- QA takes place before the data production process, and embraces all planning and preparatory measures within the NFI process that contribute to maintain the defined quality standards.
- QC occurs after the data production process, and refers to all those measures that are taken to check the quality of the products so that in case of unsatisfactory quality counter-measures can be taken.
- While the quality of products is a collective responsibility of everyone involved in an NFI/NFMS, the responsibility for both QA and QC lies in the hands of the coordination team.
- The inventory protocol documents all design details, definitions, measurement procedures, and analysis approaches of the NFI, and is a reference point for any questions on NFI methodology.

Lesson 2: QA/QC in planning and analyses

Lesson introduction

This lesson focuses on QA/QC in planning and analyses.

Remember that we will cover quality issues in field data collection separately in Lesson 3. The reason we separate these two domains of QA/QC into different lessons lies in their different characters.

Field data collection and the visual parts of remote sensing image interpretation are done by many people—including non-experts—who need to be trained on consistency. While many of those working over a longer time period acquire a certain routine, in planning and analyses it is mainly a few specific experts who cover the work. QA/QC is, therefore, quite different for these two domains.

Learning objectives

At the end of this lesson, you will be able to:

- Appreciate the role of QA/QC in the planning and analysis phase of an NFI.
- Identify the measures of QA/QC in the planning and analysis phase of an NFI.

QA/QC in preparation, planning and designing the NFI

Planning for and designing an NFI/NFMS is a specialized task and the very first thing in quality assurance is to find experts with the right background, experience and networks. The importance of planning in an NFI is often underestimated, and its complexity not acknowledged—this step requires a lot of knowledge and insights into various fields including sampling statistics, forest mensuration, statistical modelling, remote sensing, GIS, and project planning and communication. Planning and analyses usually occur in either of two situations:

An NFI already exists	An NFI needs to be designed
In this case, one needs to double check the current NFI design, as well as analyze the experiences and suggestions for improvement from those who were involved in the implementation, in order to find ways to integrate possible emerging new topics	This could occur when a country prepares for its first NFI, or the design of a previous NFI was so deficient that it becomes easier to design a new one than trying to modify the earlier design. In this case, a **new design** needs to be developed that complies with the

into the NFI system. Maintaining **consistency** is a major issue in this case.

stakeholders´ expectations towards coverage (of topics), products and precision (of estimation) and with the options that the budget eventually allows.

As a standard means of QA/QC in the planning phase, it is good practice to present the overall conditions for and expectations from the NFI to other experts from local universities, regional NFI networks or international organizations such as FAO. Feedback from independent experts serves as QA and QC of the NFI design at the same time.

There is also the possibility to formalize such feedback requests and invite external independent experts into an NFI advisory board. It is usually not easy to invite such experts and it also involves a cost factor with respect to travel costs and honorarium. But it is likely to be the best QA to have such an expert platform when avoiding flaws in the inventory design. An NFI advisory board may consist of 3-5 experts with NFI experience, possibly also from neighboring countries with similar overall conditions.

Reality check

A challenge is not only to find and constitute such a board but also to find time slots for meetings. Evaluating an NFI requires time and dedication by the advisory board members and usually involves a lot of discussions.

This can, of course, be done over email, but a meeting is the most efficient and productive way of discussing an NFI design and the underlying conditions and expectations. Online meetings are possible, but in-presence meetings offer the additional possibility to make field visits— which is in many cases instructive or sometimes even serves as a revelation!

Integrating an advisory board also requires some organizational efforts by the NFI planners: the board needs to be established and informed, and meetings need to be coordinated, prepared, held and documented. In the NFI design planning phase, there may be at least two meetings:

- an early meeting where the design had been preliminarily drafted; and
- a second one to present and discuss the tentative final design.

In any case, it may be considered a good certificate of quality of the NFI design to have the "blessings" from such an advisory board. Of course, the board may accompany not only the initial planning but also the further steps in analyses and reporting. It is the responsibility of the NFI directors to keep the advisory board "alive". Sometimes it so happens that the board is convened once and then practically forgotten, causing considerable annoyance to the members.

QA/QC when using available data and models

The use of available data

While planning an NFI, it is usual to capture all types of data that may serve to facilitate NFI planning or implementation. This includes the use of forest inventory reports from subnational or local inventories, the use of topographic or thematic maps, and data regarding the costs of fieldwork and remote sensing image analyses (e.g., nowadays global, or regional spatial products at relatively good resolution are also available to provide available data to be used to inform initial steps in the design, although proper validation protocols need to ensure the information is indeed reliable for the country at hand).

In this context, QA/QC implies the standard measures that are applied when using available data in any scientific study: one needs to know where the data came from, have access to the definitions used and to the field protocol and—in the best case—also have the possibility to get into contact with those who collected the data. Available data should be used only when one understands the data completely and can be sure that the data quality is sufficient to be useful for the NFI project.

For some products (e.g. officially issued topographic maps), one may assume that their quality has been double checked by the issuing institutions, so an extra control is usually not necessary.

The use of statistical models: using available models

Models used in NFIs are statistical models that predict a variable from the observations of other variables. Typically, such statistical models are not built within the NFI, but are taken from scientific literature, frequently technical reports of forest research institutes or from theses at universities. As such, the identification of these models—and all related quality considerations— are all part of inventory planning. Many of the models published in the scientific literature are currently available in the **GlobAllomeTree platform**.

While using models, it must be considered that they predict mean values and not the true value of the variable to be predicted. The fact that we work with mean values instead of the actual values, of course, introduces some residual variability as compared to a direct measurement of a variable. When referring to the use of available models, quality issues refer only to the selection of the model to be used and to the suitability check that is being done.

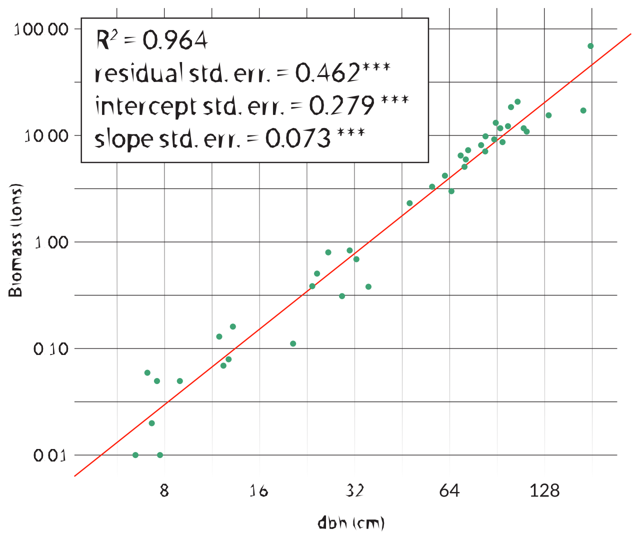
The use of statistical models: building your own models

Although not very common —after all, there are so many NFIs and large area forest inventories, each with their own models—it may happen that a suitable model is not found for a specific NFI. If this occurs, one may consider investing the time and resources to build one's own models. This can efficiently be done in collaboration with forest research stations or universities. Then, all quality-related considerations are in the hands of the model-maker:

- Number of sample trees;
- Selection of sample trees (species, geography and regarding the coverage of the range of the independent variables); and
- Implementation of measurements (including wood sample processing in the case of biomass or carbon models).

The internal quality of a regression model is frequently described by the standard error of estimation, the coefficient of determination and the significance level of the estimated regression coefficients. These measures quantify how well the model adjusts to the sample data that were used to build the model.

How well the prediction from the model adjusts to independently selected sample trees is the second question of quality control. To check this, one needs to have sample tree data that were not used in model building so that an independent validation of the model can be done. Such independent validation has the same character and function as the suitability checks of available models; they would also need to be evaluated by an independent set of sample trees. Typical models developed for use in NFIs are tree biomass, height and volume models.



QA/QC in data analysis

Data analysis in NFIs is also a specialized step in which only a few people are involved. Quality control extends then to the following points:

1. Data quality from field sampling can partly be checked in real time directly during field work via the software installed on the mobile data loggers. Plausibility checks and cross checks are integrated into the software and the extent of quality checks is determined by the performance of these applications. Usually, severe errors can be avoided and for unlikely data inputs a warning can be triggered.

2. Some issues of data or model quality, however, become apparent only when analyses are being done. This may refer to implausibly high plot biomass values or to biomass functions that have been applied outside the range of validity. This cannot be controlled during data acquisition in the field but requires some data analyses and processing. This means not only for the input data to be checked for plausibility, but also the results. Then, however, as with many other errors, only those errors can be identified which have the character of outliers. Small deviations will remain undetected. For example, algorithms exist for the detection of unlikely data (outliers) to guide the analyst towards decisions as to how to approach their inclusion in the analysis.

Example

Subnational inventory in Central America

An interesting example is given here from a subnational inventory in Central America. Results had been published for different strata and diameter classes. What may call one´s attention here is the relatively high growing stock (volume) estimated for example in stratum I of 76.872 m³ in the small *dbh* class 5-10 cm, while the number of trees had been estimated at 643.420 trees per hectare.

That is: the mean volume tree per tree would be 76.872/643.420 = 0.12 m³ - which appears high. In forestry, a form factor is a correction factor to be applied to estimate the volume of a tree, taking a perfect cylinder as a reference. This correction is due to what is call the taper: the characteristic of most trees where the diameter of the stem section at a particular height decreases with stem height. Assuming a mean diameter of these 643 trees of 7.5 cm and a form factor of 0.5, one would calculate (following the formula v = basal area * height * form factor) an average height of h = 49.2 m, which is impossible for those diameters. Something went wrong here and the results are all not trustworthy once you have identified this mystery.

Net volume per hectare by development class and by stratum

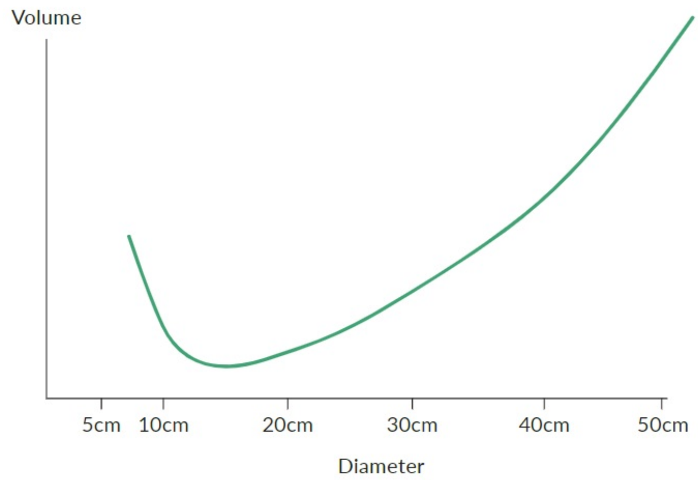
Type of Development	Definition (dbh in cm)	Trees per ha. by development class and stratum. ALL SPECIES.				
		I	**II**	**III**	**IV**	**V**
Regeneration	5 - 9.9 cm	643	553	385	602	645
Pole stand	10 - 49.9cm	645	568	413	609	754
Mature trees	≥ 50 cm	17	14	18	8	6
Total		**1306**	**1135**	**817**	**1219**	**1406**

Trees per hectare according to development stage and by stratum (all species)

Type of Development	Definition (dbh in cm)	M3/ha Strata				
		I	**II**	**III**	**IV**	**V**
Regeneration	5 - 9.9 cm	76	66	47	74	80
Pole stand	10 - 49.9cm	227	273	198	271	318
Mature trees	≥ 50 cm	45	28	51	19	17
Total		**350**	**368**	**297**	**365**	**416**

While it remains unknown to us what the exact reason was in this particular case, one possible explanation is the application of a volume model to small trees that had been built for larger trees – and where the course of the volume function is untypical for the lower diameters (outside the range of validity of this model); as depicted below in a schematic graph: here, the volume function had been constructed for trees with *dbh* values between 20 and 50 cm—and in that range, the volume function has exactly the shape that one would expect.

However, if a higher order polynomial model had been chosen, it may occur—as in the depicted case—that the shape of the model is mistaken; here, it would lead to a tremendous overestimation of the volume of small trees, where a tree of about 7.5 cm *dbh* would have a predicted volume like one with a *dbh* of about 30 cm. This is certainly an extreme case, but it serves here as a schematic illustration only.



It is not enough to just produce the results but also to have a closer look at intermediate results. For example, when determining the mean biomass per hectare, one may produce the point and interval estimates and if they appear acceptable, one should be happy.

However, it may be that in these results, still some errors are hidden, which might be detected with intermediate steps of analysis. One good option is to graph the distributions of the input values, for example plot-wise estimates of biomass per hectare.

If, within such distributions, outliers are detected (either very high or very low values), it is worthwhile to go back to the plot data to find out whether the value is correct or based on errors. Not all outliers are errors, though. And not only outliers are suspicious—but errors can also be hidden in values that look entirely plausible; but these latter cannot be individually identified in the analysis phase.

Quick tips!

Probably the best measure of QA/QC is to task two different experts to do analyses of the core results. Then the comparison of the two results will reveal either a full, partial or no match—and regardless of the result, the process will be instructive.

If this duplicate analysis is done, one should make sure that both are working with the same data. Detectable errors or inconsistencies in data need to be eliminated before such duplicate analyses are done, because they serve to check for the consistency/quality of the analysis and not any more to check for the quality of the data.

In this context, filtering the data correctly (e.g. excluding dead trees in some cases or excluding specific trees from model building, like height curves) if of utmost importance. If models are involved, it is also about the choice of these models. Therefore, proper documentation of all data cleansing and filtering steps needs to be made and shared among the experts, if accurate comparisons and validations are to be followed also in the future, particularly when possibly new experts may need to redo the analyses.

Summary

Before we conclude, here are the key learning points of this lesson.

- A standard means of QA/QC in the planning phase is to present the overall conditions for and expectations of the NFI with experts, regional NFI networks or international organizations.
- NFI planning captures all types of data that can facilitate NFI planning or implementation, including forest inventory reports, data from subnational or local inventories, the use of topographic or thematic maps, and also data from remote sensing image analyses.
- When referring to the use of available models, quality issues refer only to the selection of the model to be used and to the suitability check that is being done.
- Data analysis in NFIs is a specialist's work in which only few people are involved. QC in the data analysis is determined by the plausibility checks and cross checks that are integrated into the software and the extent of quality checks is determined by the performance of these applications.
- The best measure of QA/QC is to task two different experts to analyze the core results - then the comparison will reveal either a full, partial or no match – and regardless of the result, the process will be instructive.

Lesson 3: Quality issues related to data from field sample plots

Lesson introduction

In NFIs, all available and useful *a priori* information is used for design planning and the corresponding quality issues have been addressed in Lesson 2 of this course. Typical for these is that few people are involved, and these are usually experienced NFI experts who are entrusted with the overall planning and who bear the responsibility for the exercise.

Then, to assess the current situation in detail, during NFI implementation much of the original data is gathered, frequently from hundreds of field sample plots and larger sets of remote sensing imagery. These data are core to any NFI as they provide information about the current state of forests in the country and—in case of repeated NFIs within a National Forest Monitoring System—they quantify the actual changes that had taken place between the current and the previous NFI.

Contrary to the planning and analysis phase of an NFI (where experienced NFI experts are entrusted with the overall planning and responsibility of the exercise); in field implementation/data gathering there are commonly many people involved, organized in field teams who are largely independently (albeit communicating on a regular basis) working in the field.

Also, if visual interpretation of remote sensing imagery is to be done, various interpreters are involved. Both field sampling and visual remote sensing interpretation campaigns, therefore, require thorough training of all those involved and QC assumes a different dimension than in design planning.

In this lesson, we address the major points of QA and QC in both field sampling and remote sensing visual analyses.

Learning objectives

At the end of this lesson, you will be able to:

1. Identify the complexity of assuring quality in field measurements
2. Explain how data quality may be affected during field work: the sources of errors.
3. Recognize the common measures of QC in field work—and measures to be taken in case of inferior quality.

General observations

In NFIs, data for many variables are gathered in the field usually by many different field teams. This embraces all types of variables: metric variables, categorical variables, nominal variables, and so on.

Even when these variables are very clearly defined in the inventory protocol and measurement procedures, various sources of uncertainties remain that may affect the quality of the collected data. This is true both in terms of their absolute accuracy and in terms of consistency between field teams. These quality issues (errors and uncertainties) may stem from:

1. the inherent residual variability which accompanies all empirical measurements;
2. misunderstandings of the inventory protocol; and
3. deliberate neglect of the inventory protocol, for example by field teams who are tired or who believe they can make their field work more efficient by deviating from the inventory protocol.

It is the first of these three points that we wish to address here. The second one points to an imperfectly written inventory protocol—and that can be avoided by carefully crafting and testing it and asking for critical feedback from experienced NFI colleagues.

Likewise, the third point should not occur at all: the field teams must know what is expected from them and ignorance towards the inventory protocol must be understood to be a no-go: it may— once detected and considered significant—lead to the immediate dismissal of such a field team.

Uncertainties from NFI field data collection refer to:

- establishing the plot;
- measuring/making the variables; and
- recording the data.

A good inventory protocol, of course, defines and addresses all critical issues for all three points.

The field manual as a basic reference for QA

The field manual (field protocol) is a core document in all forest inventory field work. It describes all details of the fieldwork, ideally in such completeness that no questions remain—ideally, all field situations are covered, with a defined approach on how to deal with them. This facilitates work for the field teams, who do not need to make their own individual (and perhaps conflicting) decisions.

Strict adherence to the field protocol should guarantee high quality of data collection which includes high accuracy viz. small measurement/observation errors. This requires complete familiarity with definitions and procedures so that the default steps are being implemented correctly without constantly having to refer to the field protocol. The field manual will then need to be mainly consulted only in special and less common cases.

By the same token, it is equally relevant to produce a field manual for the QA/QC control team.

Training the field teams is also QA

Comprehensive training is another default measure of QA. The fieldwork step of every NFI begins with training the field teams. Some of the teams may have long standing experience in fieldwork for forest inventory, others do not. It is important to bring all field team members to a level of skill such that they can fulfill their assigned roles according to what is stipulated in the field protocol.

Any NFI training for fieldwork needs to go step by step through the field protocol and present and practice every step, from preparatory work prior to going out to the field, searching and reaching the plot, observing safety measures, doing measurements and recording the data.

Even if the field team members often have low salaries, they have one of the most relevant tasks, because the quality of data depends on them.

Therefore, as stressed repeatedly in these courses, training should also serve to make the field team members proud to be part of this relevant exercise and motivate them. There is no point in aggressive pushing, even when the inventory schedule may be tight.

Did you know?

Here's an interesting insight from CHANCE magazine, Vol. 17 No. 4/Fall 2004

"The government is extremely fond of amassing great quantities of statistics. These are raised to the nth degree, the cube roots are extracted, and the results are arranged into elaborate and impressive displays. What must be kept in mind, however, is that in every case, the figures are first put down by a village watchman, and he puts down anything he damn well pleases."ir Josiah Charles Stamp (1880-1941)

Typical errors in fieldwork

For both domains, i.e. establishing the plot and doing plot observations, let's now consider some typical points that need to be observed when overall quality is an issue.

Establishing the plot

Plot locations are usually determined by a dimensionless point from where the sample trees are included along a specific rule (plot design), and where other variables are observed like those related to topography, stand structure, and biodiversity.

The plot locations are usually found by Global Navigation Satellite System (GNSS) receivers and the quality of the receiver determines the accuracy of finding the predefined coordinate. When it is only about field data collection (without integration of remote sensing-based models), the absolute accuracy of determining the correct sample position is of minor concern—at least when we talk about accuracies of about 5-20 m of absolute position.

Important however, is that finding the point is exclusively done by the GNSS device—and that all subjective preferences in favor or against a particular plot location are excluded; that might lead to a selection bias.

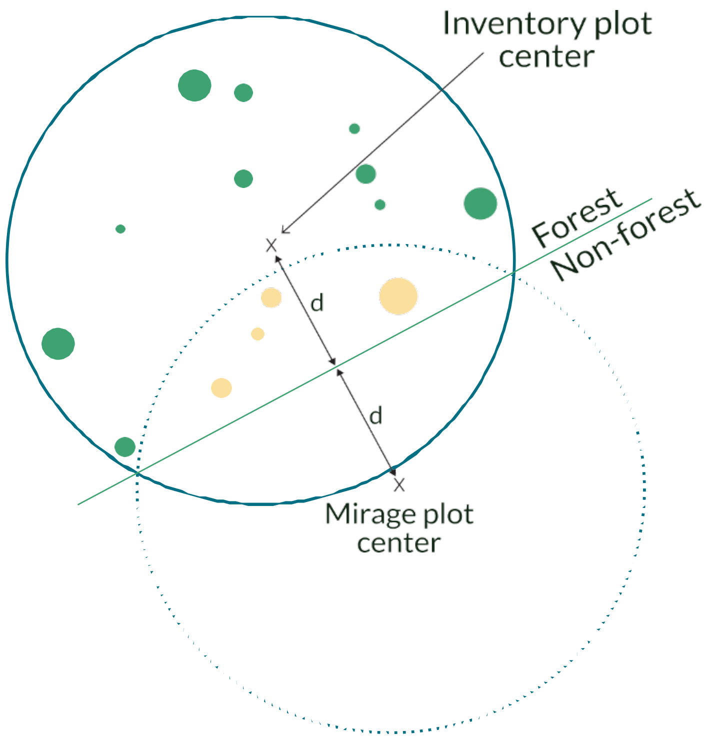
However, this changes completely when the field observations are to be used to feed into remote sensing-based models: then, an accurate as possible match (co-registration) of field plots with the remote sensing plots is essential to make these models of high quality; the more valuable the integration of ground data and remote sensing data becomes for monitoring and assessing forest resources on a large scale. High accuracy GNSS devices are then to be used. In case the remote sensing-based modelling aims at individual tree characteristics, e.g. by airborne laser scanning, a very high accuracy of co-registration is required so that individual trees in the field can reliably be attributed to crowns as identified in the remote sensing image.

From the sample point, sample trees are included into the plot according to a specific rule that defines the plot design. It is most important to make sure that exactly those trees are included as sample trees that comply with the plot design rules. Omitting in-trees or including out-trees may affect the estimation more than some measurement errors. Care in the field needs to be exercised for those trees that are close to the plot boundary and where it is not obvious whether they are in or out!

In the end, this is all about accurately measuring horizontal distances from the plot center to the point that defines the position of the tree according to the inventory protocol.

Slope correction is relevant, in any plot design, also in the so-called “plotless” designs. When—in sloped terrain—a correction for slope is not applied—one will produce a large systematic error when many forest plots are on relatively steep slopes. That means that carefully measuring the slope angle is important.

Plots that extend beyond the forest boundary need to be correctly dealt with. That is: not omitting and not shifting these plots that are only partially within the forest or the particular forest stand. The best option is here to apply the **mirage technique** (see, e.g., Ducey et al., 2004).



1. Measure distance d from center of inventory plot to forest boundary.
2. Carry on distance d on the other side of the forest boundary to locate the center of the mirage plot.
3. From the mirage plot center draw the plot.
4. The trees on the region that overlaps both the inventory plot and its mirage (in orange) are enumerated twice, while the trees outside the overlaying area (in green) are enumerated only once.

While non-response is a common issue in NFIs, in particular when reaching the plot position is too dangerous, risky or time-consuming, or when access is denied, field teams should not easily decide against reaching a difficult plot but do everything possible to access it—within safe work procedures, of course.

Fieldwork is physically demanding and in some cases, field teams have had the bad idea to make up data for difficult plots, ones they knew supervision teams would not visit. Experienced field teams may be able to produce such fake data that will be difficult to identify. Such fraud is also known from population surveys where it has been called **curb stoning—**sitting on the curbstone and fake-filling the questionnaires by the interviewer. The temptation to act like that can best be avoided by good and regular communication with the field teams and by a relationship between supervisors and field teams that builds on mutual trust and mutual respect. One may also consider recording by default timestamps and coordinates of plot measurements.

> *“I answered an advertisement and attended a course. In a surprisingly short time I became an official enumerator. My job was to visit apartments that had not mailed back their census forms. As identification, I was given a black plastic briefcase with a big red, white, and blue sticker that said US CENSUS. I am a gangling six-foot-four-inch Caucasian; the government sent me to Chinatown.*
>
> *Strangely enough, I was a failure. Some people took one look and slammed the door. One elderly woman burst into tears at the sight of me. I was twice offered money to go away. Few residents had time to flll out a long form.*
>
> *Eventually I met an old census hand. "Why don't you just curbstone it?" he asked. "Curbstoning", I learned, was enumerator jargon for sitting on the curbstone and filling out forms with make-up information.”*
>
> *- Mann, 1993*

Conducting measurements

Quality issues refer to all measurements and observations, as already emphasized in our lesson on measurement errors:

- For metric variables this may be a deviation of the actual default measurement from the more careful repeat measurements of a supervision field team.

- For nominal variables it may be a confusion of names—for example in tree species identification. When NFIs are explicitly expected to also produce reliable data on tree diversity, special care must be exercised with respect to species identification. This can be done by hiring botanists to accompany the field teams (which is usually an expensive investment) or by collecting specimens for later identification in an herbarium (which is a logistical challenge to get the samples, preserve them in the field and get them in time to the herbarium).
- For categorical variables, it may be a confusion of classes/categories.
- It is good practice when the field team member doing the measurement/observation, shouts the value so that the others can hear and check. It is also a good practice—when doing measurements of heights, distances, diameters, to flrst make a visual estimation and then do the measurement. It helps one to identify if the stated measurement presents inconsistencies with the initial guess and if so, review it in place.

Quality issues related to the data sources used in NFIs: remotely sensed data

Remote sensing data are being increasingly integrated into forest inventory projects. In particular in smaller areas and forest management inventories, single tree analyses resulting from ever-higher resolution imagery and airborne laser scanning are gaining more relevance.

Also, in many NFIs, remote sensing plays an outstanding role, even though there continue to be many NFIs that rely completely on field assessments.

Before remote sensing imagery can be used for any analysis and interpretation purpose, the corresponding pre-processing of the imagery—that is all geometric and radiometric correction— must have been done. This is a task for experts in remote sensing image analysis and will not be more elaborated here.

The integration of remote sensing refers mainly to satellite remote sensing over larger areas (e.g. from Landsat, Sentinel), including:

- Estimation of forest area and changes in forest area, the latter from the analysis of time series.
- Pre-stratification into forest types to prepare stratified sampling.
- Producing thematic maps, for example on biomass or carbon, which are crafted using remote sensing data as carrier data for regionalization.

The common approaches to quality assurance and control apply as they are used in remote sensing image analyses.

For area estimation (forest, forest types, stratification) the common accuracy assessment applies (Map **Accuracy Assessment and Area Estimation**) where the interpretation result is compared to ground truth observations. The outcome of this comparison is listed in a so-called confusion matrix. The percentage of correctly classified points is then the “overall accuracy”. The accuracy can be broken from the confusion matrix also in accuracies of the individual interpretation classes.

It must be emphasized here, that this overall accuracy is not a measure of precision of estimation as we know it from statistical sampling studies but it is rather a quantification of **measurement error**. It is, therefore, correctly named **accuracy** and not **precision**.

If the ground truthing data had been collected along a statistical sampling scheme, one may use the results of the confusion matrix to come up with corrected estimates of the areas of the individual classes and for these corrected classes, standard errors can be estimated. This is an interesting approach that had been introduced by Olofsson (2014). Again: such correction for area is strictly only valid when the selection of the ground truthing points followed statistical sampling.

While there are standard approaches for the assessment of accuracy in image interpretation, there appears not to be a standard approach when it comes to quantifying the accuracy (or even precision) of the estimation of changes from the analysis of a series of images. There is still quite some research potential in that area. Although too wide to be covered here, Oloffson (2013, 2014) provide a good introduction to the topic.

When aiming at producing maps from remote sensing imagery, one needs to link the field observations to the imagery data in order to establish the required models that can be used to “expand” the data from the field plots to all other parts of the image. Here, the co-registration between field plots and remote sensing imagery is important for the accuracy of the resulting map. That means: the GNSS measurement of plot location has a much higher relevance than in purely field based inventories. For the latter, the GNSS position serves mainly for documentation and to flnd the plot again at repeated inventories—but when matching the remote sensing pixels to the field plot area, the position accuracy has obviously a much greater importance. One may assume that as the models improve, the more accurate the matching (the co-registration) is.

There are hardly any remote-sensing maps in which the map is independently validated by new field data, but the model accuracy (based on the statistics of the model) is being used as a measure for the overall quality of the map.

Typical measures in QC in fieldwork

General principles of quality control in NFI field sampling

Quality control for NFI fieldwork is implemented by checking the measurements of the field teams. A supervisor team who is supposed to make the best possible measurements is either accompanying a field team (**hot checks**) or searching already measured plots (**cold checks**).

Commonly between 5 and 15 percent of the field plots undergo a quality check in any well-implemented forest inventory. Of course, the strategy of quality checking must be made known to the field teams, which may be an incentive to work very carefully. Also, the concrete quality targets need to be known to the field teams, as well as the consequences of not complying with them.

The number and mode of selection of plots to be controlled is done by the NFI coordination team. It is meaningful to make the selection such that all field teams are controlled. Also, if difficult and not so difficult field plots can be distinguished, both should be covered. The exact number of plots to be controlled is a management (and cost-based) decision. It is recommended to start with the control measurements early, i.e. not only at the point in time when all plots are measured and the field teams no more under formal contract.

One may organize the control efforts in several campaigns, where the flrst one may take place after a few weeks of field work: then, there is a much better chance to identify issues and possibly organize another training session for some or all field teams.

Cold checks as a measure of QC

By **cold checks**, we mean the visit of already completely measured plots by a supervisory control team, an activity also called **check cruising**. The independent control team goes to the field and measures a plot that had been completed by a regular field team. Cold checks have exclusively a control character. This means that their measurements are in principle **not** going to be part of the whole inventory, although they can be used to help detect biases and outliers in the regular field team data.

The control (supervisor) team checks all measurements on the plot and compares them to the accuracy requirements. In addition, the control team has the chance to check how well the plot location has been documented and how easy it is to find the permanently marked plots. This is actually a critical point in field measurement, because a plot is essentially a failure if it cannot be found at later points in time.

It is then good practice to give feedback to all field teams controlled. If necessary, that can be done in a 'plenary' session of all field teams. Field teams with clearly unsatisfactory performance should be called for a discussion to identify the causes of inferior performance and on ways to reliably improve.

Hot checks as a blended measure of QA and QC

By **hot checks**, we mean the visit of a plot to be measured where the control team goes out together with the regular field teams. Hot checks have a blended character of quality control and quality assurance, they may also turn out to have the character of an advanced training.

Hot checks are usually perceived as a less strict means of control as the regular teams know that they are being observed and controlled. This may bias the result towards better quality but may also raise motivation of the regular field teams when they receive immediate and constructive feedback.

Hot checks allow one to control the process of finding the position and permanent marking of a plot—but they do not allow checking how well these plots are found when doing repeated measurements—as opposed to cold checks.

Measures to be taken

There are actually not many measures that can be taken when field teams do not comply with the accuracy requirements. It may happen that non-compliance has to do with an imperfect field manual or training. In such cases, an update of the field manual may be indicated, or another training is necessary. This would be a typical consequence of very early control measurements. If control is done only after having completed all plots, these findings will mainly benefit future NFIs.

1. If the accuracy targets are seriously not met, the field teams would need to remeasure all their plots since the last control campaign. The criteria for such a hard measure must be known before. A reason may be when systematically some trees are not recorded even though part of the plot.
2. if there are even worse performance issues like made-up plot data, the dismissal of field teams may be considered. This, as well, needs to be made clear from the outset and such announcement should be part of the training.
3. It is also very important that frequent backups (preferably daily) are sent by field crews to a central server to avoid loss of information, and that an officer is in charge of double-checking

these backups as part of que QC process, so that there is time to send the teams back to the plot if information was loss or clearly erroneous before they have moved too far from it.

Summary

Before we conclude, here are the key learning points of this lesson.

- Even when the variables of an NFI are very clearly defined in the inventory protocol and the measurement procedures, the scope of uncertainties always remains in the accuracy of data from field sample plots.
- The field manual is therefore a core document in all NFIs, and all field teams should adhere strictly to documented protocols.
- Any NFI training for field work needs to include a thorough explanation of the field manual.
- Quality control for NFI field work is implemented by checking the measurements of the field teams - through accompanying a field team ("hot checks") or searching already measured plots ("cold checks").
- Commonly between 5 and 15% of the field plots undergo a quality check in any well-implemented forest inventory.