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Review article

Quality assurance (QA) in international forest monitoring programmes: activity, problems and perspectives from East Asia and Europe

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Abstract
• The quality of monitoring is defined by its ability to provide data that (i) allow estimates of the status of the target resource with defined precision level, (ii) permit change detection with defined power, and (iii) are comparable through space and time. To achieve these requirements a Quality Assurance (QA) perspective is essential.
• To what extent QA was considered and data quality achieved in international forest monitoring programmes in East Asia and Europe? What is missing?
• Past and present QA activity in forest monitoring in East Asia and Europe revealed that most attention was given to evaluate and promote comparability of measurements, with special emphasis on analytical chemistry. Much less attention was given to field sampling and to the overall monitoring design. QA approaches were unbalanced among the various investigations, and several problems with data comparability remained over years.
• Despite considerable work on data quality control, parts of the monitoring process are still poorly covered by QA and revealed weaknesses in design and implementation. More comprehensive, formal and stringent QA procedures are necessary in international monitoring initiatives. Steps currently being undertaken for a more comprehensive QA approach are presented.

Mots-clés :
Asie de l'Est /
Europe /
surveillance des forêts /
assurance qualité

Résumé – L'assurance qualité (AQ) dans les programmes de surveillance des forêts : activités, problèmes et perspectives pour l'Asie de l'Est et l'Europe.
• La qualité de la surveillance est définie par sa capacité à fournir des données qui (i) permettent des estimations de l'état de la ressource cible, définie à un niveau de précision, (ii) permettent la détection des changements de puissance définie et (iii) sont comparables à travers l'espace et le temps. Pour satisfaire à ces exigences d'assurance qualité (QA) la perspective est essentielle.
• Dans quelle mesure l'assurance qualité a été examinée de même que la qualité des données obtenues dans les programmes internationaux de surveillance des forêts en Asie de l'Est et l'Europe ? Qu'est-ce qui manque ?
• L'activité passée et présente dans l'assurance qualité de surveillance des forêts en Asie de l'Est et Europe a révélé que la plus grande attention a consisté à évaluer et promouvoir la comparabilité des mesures, avec un accent particulier sur la chimie analytique. Beaucoup moins d'attention a été accordée à l'échantillonnage sur le terrain et au modèle de surveillance globale. Les approches de QA ont été déséquilibrées entre les différentes enquêtes, et plusieurs problèmes avec la comparabilité des données sont restés au fil des années.
• Malgré un travail considérable sur la qualité des données de contrôle, des parties du processus de suivi sont encore mal couvertes par l'assurance qualité et des lacunes de conception et de mise en œuvre ont été révélées. Des procédures d'assurance qualité plus complètes, structurées et rigoureuses sont nécessaires dans les initiatives internationales de surveillance. Les étapes actuellement entreprises pour une approche plus globale d'assurance qualité sont présentées.

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"The results of inadequate monitoring can be both misleading and dangerous not only because of their inability to detect ecologically significant changes, but also because they create the illusion that something useful has been done" (Peterman, 1990)

1. INTRODUCTION

1.1. The need for quality assurance

There is a general agreement that monitoring is essential to obtain information about the condition of natural resources, its development in time and space, and to study its relationships with biotic/abiotic factors (Ferretti, 1997; 2004; Stevens, 1994). At the same time, considerable concern exists in the scientific community about the ability of monitoring programmes to provide the desired information (Legg and Nagy, 2006; Vos et al., 2000). The main reason for this is the poor confidence about the quality of the data, with most typical questions concerning the statistical basis of sampling design, the reliability and comparability of data, and data management (Elzinga et al., 2001; Ferretti, 2009; Legg and Nagy, 2006; Shampine, 1993; Vos et al., 2000; Wagner, 1995). This concern is justified especially for terrestrial monitoring with a large-scale coverage and a long-term nature, such as the international monitoring programmes. On one hand, the large scale coverage requires a high number of field observers (Cozzi et al., 2002), laboratories and instruments (Mosello et al., 2001) and this implies possible problems for data comparability across space. While this kind of problem may always occur with terrestrial monitoring over large areas (remote sensing techniques may be less influenced), they are exacerbated in international programmes when a joint effort of experienced institutions over several countries is necessary. On the other hand, the time "impacts how the work is viewed by the people collecting data, as well as the people who ultimately will use the data" (Shampine, 1993). In addition, change in personnel (in particular under the current labour market conditions) and change in methods (due to conceptual and technical improvement of methods, techniques and instruments) may lead to comparability problems at times of personnel/method changes.

There is an agreement that the quality of the monitoring can be evaluated in terms of its ability to provide data good enough to allow quantitative assessment of status and change/trend of the attribute of concern over the population of interest (e.g. Elzinga et al., 2001). Such an ability is related to a number of issues, but above all there are two major sets of requirements to be considered. A first set regards the statistical design of the monitoring, and a second one the precision and accuracy of the measurements. The former controls the ability of monitoring to provide precise estimates of status and effective detection of changes. The latter controls the reliability and comparability of measurements through time and space. A quality assurance (QA) system, i.e. "the organisational structure, the processes and procedures necessary to ensure that the overall intentions and direction of an organisation as regards quality are met and that the quality of the product or service is assured" (ISO) allows driving the monitoring design to ensure that the above requirements are met. Even though QA issues are nothing new in forest monitoring (e.g. Cline and Burkman, 1989; Innes, 1993), the extent to which a QA framework was adopted in designing and implementing international forest monitoring programmes is uncertain.

1.2. Monitoring objectives, design and results

Since the quality of monitoring depends on its ability to quantify status and change of a given resource, expectation in these respects must be specified without ambiguity by monitoring objectives. The connection among objectives, design and results is clear when considering that quantifying status and changes require monitoring data (i) to allow estimates with known and documented precision of the population's parameter of interest for the attribute of concern; and (ii) to be able to detect change and trends of the variable of concern over defined time windows with and known confidence. Thus, to be succesfull, monitoring should be designed to fit the above requirements, and this is only possible if they are formally defined by the monitoring objectives. Two examples will suffice. The precision of the estimate can be expressed in terms of the width of confidence interval in relation to the value of the estimate (e.g. confidence interval calculated for $P = 95\%$ should not be larger than 10% of the value of the estimate) and depends very much on the sampling design. Thus, when an expected precision level is set by monitoring objectives, sampling is designed to minimize sampling error by acknowledging the inherent characteristics of the population of concern (extent, variability, spatial arrangement) and identifying the adequate sampling scheme (allocation of sampling units over the population of concern) and sample size (number of sampling units). Although different inferential approaches exists (e.g., model-based and design-based, see Stevens, 1993), the design-based approach offers considerable advantages. It is worth noting that sample size and parameter estimators varies with the sampling scheme. Several textbooks exist that may help in this respect (e.g. Cochran, 1977).

Change detection is of particular interest for monitoring. Implicitly, almost any attempt to detect change is an hypothesis testing exercise, with the null hypothesis being no change occurring. However, to some extent, change is inherent to forest ecosystems, and the interest is therefore to detect those changes exceeding some limits, say "acceptable" limit. When the hypothesis testing is of concern, the statistical power (power = 1.0 minus the probability of a Type II error) of the test becomes important (for a discussion about Type I and Type II errors see e.g. Di Stefano, 2003; Field et al., 2004; Mapstone, 1995; Peterman, 1990). However, the power

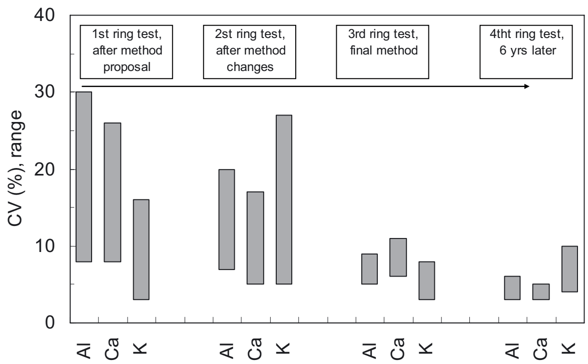

Figure 1. Ranges of coefficients of variation (%) in 4 ring tests 1997–2007 for the elements Ca, Al and K; total digestion method (ring tests with 6–10 humus and soil samples; 13–18 participating laboratories).

depends on effect size (the change the monitoring is requested to detect), survey design and statistical test applied, sample size and the Type I error rate. Again, all these details should be specified taking into account the expectation set by the objectives. A frequent problem is that monitoring objectives often omit to report the precision level required and - even more frequently - no statement is made about acceptable change, minimum detectable change and the power that the monitoring should have in change detection analysis (Legg and Nagy, 2006).

1.3. Data quality and monitoring results

Besides sampling design, the control of measurement error is an important issue for monitoring programmes. Although it refers to a national exercise, the example of the German soil survey is useful to elucidate the benefits arising from a QA perspective when several laboratories are involved in the same investigation. In 1989, the heads of the German forestry research laboratories formed a working group to ensure the comparability of analytical data of the German Soil Survey and their evaluation (König and Wolff, 1993). The comparability of concentration data was clearly improved after comparison of digestion methods, with a subsequent joint development of a total digestion method, together with the unambiguous specification of methods to be used (Fig. 1). Furthermore, error sources during the different stages of the analyses were identified by a newly developed ring-test method that permitted to evaluate separately each analytical step. By this way, the influence of the different analytical measurement methods was obvious: for some elements, differences in results arose from two measurement techniques (inductively coupled plasma spectrometer, (ICP) or atomic absorption spectrometer, AAS) and not from problems with the digestion method.

Another question with measurement error is its impact on change/trend detection. While the power of the statistical test is essential in detecting temporal changes in ecosystem attributes, such an ability can, however, be blurred by the imprecision of the data. The importance of data quality on trend detection was highlighted in a recent study by Sulkava et al. (2007) who made both theoretical computations and computations using results of "Needle/Leaf Interlaboratory Comparisons Tests" conducted by Forest Foliar Coordinating Centre of ICP Forests (in co-operation with European Commission). Their results showed that, when harmonized method is assumed to reduce the variability due to sampling, poor quality of the instrumental analysis blurs the data to the extent that the ability to detect trends is lost. Considering that the actual change in the data (i.e., sulphur concentrations in pine needles) took place within 15 y, delay in detecting this kind of change would affect the whole meaning of monitoring, with an impact remaining undetected, and a wrong message to policy makers.

1.4. Objectives of the paper

Much concern in the past was devoted to data quality in national forest monitoring programmes (e.g. US FHM, see Palmer, 1992; national forest inventories in Italy, Japan, Switzerland and USA, see Gasparini et al., 2009; Kitahara et al., 2008; Kaufmann and Schwyzer, 2001; Pollard et al., 2006). In this paper we considered Quality Assurance (QA) issues in two major international monitoring initiatives: the UN/ECE International Co-operative Programme on Assessment and Monitoring Air Pollution Effects on Forests (ICP-Forests) in Europe and the Acid Deposition Monitoring Network in East Asia (EANET). It is worth noting that these two programmes are just examples of a variety of other international monitoring initiatives (e.g. Parr et al., 2002). We will report about QA/QC components and activity carried out within the UN/ECE ICP-Forests and the EANET and discuss recent progress in order to suggest a possible way ahead.

2. METHODS

2.1. Monitoring programmes considered

The ICP-Forests (developed under the United Nation Convention on Long-Range Transboundary Air Pollution) has been implemented since 1986. Now the programme includes ca. 6 000 plots for large-scale forest condition monitoring (so-called Level I) and ca. 800 plots for intensive forest ecosystem monitoring (Level II) distributed across 41 participating countries (UN/ECE, 2007).

The acid deposition monitoring network in East Asia (EANET) started its preparatory-phase activities with ten participating countries in East Asia – China, Indonesia, Japan, Malaysia, Mongolia, the Philippines, Republic of Korea, Russia, Thailand and Viet Nam in 1998. The EANET began its regular-phase activities in January 2001 and now comprises 13 participating countries including Cambodia, Lao PDR, and Myanmar. Its monitoring programme consists of monitoring of wet deposition at 50 sites, dry deposition at 40 sites, inland aquatic environment at 11 lake catchments and 5 rivers, and forest soil and forest vegetation at 25 forest plots in 17 areas.

2.2. Review and evaluation of the QA activity

Information about QA activity was obtained from different source: manuals of the ICP-Forests and EANET (Tab. I), internal reports of

Table I. Overview of the subject covered by the Manuals and guidelines adopted by the ICP-Forests and the EANET.

ICP-Forests	EANET
Visual assessment of crown condition	Guidelines for acid deposition monitoring
Sampling and analysis of soil	Technical manual for wet deposition monitoring in East Asia
Methods for soil analysis	QA/QC program for wet deposition monitoring in East Asia
Soil solution collection and analysis	Technical manual for monitoring on inland aquatic environment in East Asia
Sampling and analysis of needles and leaves	QA/QC program for monitoring on inland aquatic environment in East Asia
Estimation of growth and yield	Technical manual for soil and vegetation monitoring in East Asia
Sampling and analysis of deposition	QA/QC program for soil and vegetation monitoring in East Asia
Meteorological measurements	Data reporting procedures and formats for acid deposition monitoring in East Asia
Assessment of ground vegetation	QA/QC program for the air concentration monitoring in East Asia
Phenological observations	Technical document for filter pack method in East Asia
Monitoring of air quality	Sub-manual on forest vegetation monitoring in EANET
Assessment of ozone injury	
Sampling and analysis of litterfall	

the two programmes, and papers published on peer reviewed journals. Reference will be given as appropriate. Results are reported in terms of QA elements adopted by the two programmes, nature (field sampling, field measurements, laboratory analysis) and coverage (investigations, years, countries and labs involved) of QA/QC activity. Examples of possible QA problems as identified in manuals and exercises, lack of QA coverage and inconsistencies are given alongside.

3. RESULTS

3.1. QA in the ICP-Forests in Europe

3.1.1. Main QA components

Early attempts in taking care of data quality in the UN/ECE ICP-Forests programme can be traced back to 1987, when the first version of the ICP-Forests manual was prepared and the field intercalibration exercises for crown condition assessment were organized. Although not consistently structured, five main QA components may be identified within the ICP-Forests:

(i) The Expert Panels, groups of experts that are in charge for developing, reviewing and updating methods for the different investigations, to identify data quality requirements, and avenues for data analysis (http://www.icp-forests.org/BodStruc.htm);

(ii) The SOPs (Standard operating procedures) reported in the ICP-forests manual, that now has different sections (http://www.icp-forests.org/Manual.htm), each dealing with a specific investigation (Tab. I). The Manual describes field sampling methods, measurement methods and data reporting rules. Manuals dealing with chemical analysis also cover method regulation for extraction and digestion methods, selection of suitable methods for element detection, ring tests and tolerable limits, use of reference material and control charts, quality checks for analytical data, and analytical info sheets (http://www.icp-forests.org/WGqual_lab.htm). Tolerable ring test limits were identified and continuously reviewed.

(iii) The intercalibration exercises for field measurements and ring-tests for laboratory measurements. These are a tool for improving the quality of the data produced by the participants (observers, laboratories) over time. Besides crown condition intercalibration exercises, other quality control initiatives aimed at comparing results obtained from different agencies/countries started during the 1990s (Tab. II).

(iv) The ICP-forests helping programme for laboratories with analytical problems. Close cooperation between these laboratories and laboratories with good laboratory practices is considered to be an effective way of improving laboratory proficiency. The assistance consist of a few days visit to the laboratory, as well as a return visit, in order to identify easily detectable problems in laboratory organization and/or specific analytical processes.

(v) The Working group QA/QC in laboratories (QA-QC Lab), which covers all aspects related to chemical analyses within the ICP-forests (http://www.icp-forests.org/WGqual_lab.htm)

Today every investigation carried out within the ICP-forests is covered by some QA/QC activity. In general, laboratory measurements and data transmission rules are well covered, while much less attention has been paid in providing sound instructions for effective sampling design, to field measurements and to set unambiguous objectives. In addition, huge difference exists within and between sections of the manual and this asks for an harmonization effort of the QA/QC activity.

3.1.2. QA/QC activity in field sampling methods

Little formal activity was carried out to compare sampling designs under field condition and to estimate their effect on monitoring results. Most information can be obtained from questionnaires (e.g. Cozzi et al., 2002; http://www.icp-forests.org/EPbiodiv.htm) and only one formal exercise at international level was carried out (deposition sampling, see Draijers et al., 2001). Considerable differences were reported for target population, plot type and sample trees selection for crown

Table II. Overview and timing of the intercalibration-intercomparison activity carried out within the ICP-Forests since it was launched in 1985 up to 2007. In brackets: informal exercises. The symbol + identified exercises carried out within ICP-Forests; the symbol § indicates the exercises to which ICP Forests labs took part, but that were organized within different projects (AQUACON–MedBas Subproject No. 6 and "Acid rain" and Subproject No. 7 "Freshwater"); the symbol * indicates the depositon sampling intercomparison exercise, actually carried out between October 1999 and April 2000 (Draijers et al., 2001).

Reference year	Field-based measurements					Chemical-physical measurements			
	Crown condition	Tree growth	Ground vegetation	Tree phenology	Ozone visible foliar injury	Foliar analysis	Soil chemistry	Deposition chemistry	Meteorology
1985									
1986									
1987	+								
1988	+								
1989	+								
1990	+								
1991	+						+		
1992	+								
1993	+					+			
1994	+						+		
1995	+					+			
1996	+							§	
1997	+					+		§	
1998	+							§	
1999	+					+		*	
2000	+				+			§	
2001	+				+	+			
2002	+				+		+	+	
2003	+				+	+			
2004	+		(+)		+	+			
2005	+				+	+	+	+	
2006	+			(+)	+	+			
2007	+				+	+	+		

condition assessment in Level I plots (Cozzi et al., 2002), sampling design for assessment of ground vegetation on Level II plots (http://www.icp-forests.org/EPbiodiv.htm, Tab. III) and design and number of collectors, and sampling scheme for deposition on Level II plots (Bleeker et al., 2003; Draijers et al., 2001; Erisman et al., 2003). Sampling issues have also been investigated for the Level I network (crown condition assessment, Köhl et al., 1994) and for individual Level II plots (soil variables: Kirvan et al., 2005; deposition: Houston et al., 2002) and reviewed by Thimonier (1998) for deposition.

3.1.3. QA/QC for field surveys

Since 1987, the core of QA/QC activity for field surveys was the comparison of tree crown condition assessment (Tab. II) that has been carried out in a series of international exercises held throughout Europe. Soon after the initiation of ICP-forests it becames obvious that there was an high degree of variation among countries mostly due to differences in assessment methods and reference standards (Cozzi et al., 2002; Dobbertin et al., 1997; Innes et al., 1988; 1993). More recently, a new format of international intercomparison exercises was developed, the International cross-comparison courses (ICCs, Ferretti and Mues, 2002) within which crews returned on the sample plots at time interval in order to allow not only the evaluation of data comparability among different crews, but also their ability to consistently observe time changes. However, even recent results from ICCs revealed that a considerable number of significant differences still exists between national reference teams from several countries and under several assessment conditions (Mizoue and Dobbertin, 2003; Mues, 2005). Several international training and intercalibration exercises were also carried out for the assessment of visible ozone injury (e.g., Bussotti et al., 2003; 2006) (Tab. II). Again, large and significant differences were observed among field crews from different countries. To our knowledge, no formal exercise has been carried out to compare tree growth measurements accuracy, ground vegetation and phenology assessment. In addition, no formal data quality objectives (DQOs) were identified for most of field surveys, and this limit the possibility for an evaluation of data quality and its monitoring over time.

3.1.4. QA/QC for laboratories

Several exercises were undertaken to compare chemical measurements performed within the ICP-Forests (Tab. II). For example, 10 foliage, 5 soil and 2 water ring tests were implemented and evaluated from 1991 to date (Tab. IV). Over the years, more than 90 laboratories have been involved in the

Table III. Main monitoring methods for ground vegetation adopted by countries participating in the ICP-forests. For each method, number of countries, number of plot per country (range), number of field crews per country (range), number of subplots per plot (range) and size of subplot (range) are reported (compiled after: Anonymous, " ground vegetation survey in the ICP Forest level II plots in all countries", available on the official web site of the ICP-Forests, National http://www.icp-forests.org/EPbiodiv.htm.). Note: one country may adopt more than one method.

Assessment method	No of countries	Plots per country, range (n)	Crews per country, range (n)	Subplots per plot, range (n)	Size of subplot, range (m^2)
Coverage	13	1–53	1–17	1–200	0.25–2500
Braun-Blanquet	9	7–15	1–17	1–24	75–400
Contact point	3	3–8	1–3	8–24	0.5–1

Table IV. Details about number of countries and laboratories participating to the ICP-Forests ring-tests for labs since the ICP-Forests was launched in 1985 (after Cools et al., 2007; Fürst, 2008; Marchetto et al., 2006; Mosello et al., 1997; 1998; 1999; 2001; 2002; Mues, 2006). The symbol * indicates the number of countries and labs (=sampling systems) that participated to the depositon sampling intercomparison exercise (Draijers et al., 2001). § Indicates the exercises to which ICP Forests labs took part, but that were organized within different projects (AQUACON–MedBas Subproject No. 6 and "Acid rain" and Subproject No. 7 "Freshwater").

Reference	Foliar analysis			Soil (solid phase) analysis			Water analysis (deposition and soil solution)		
year	Exercise, No.	Countries, n	Labs, n	Exercise, No.	Countries, n	Labs, n	Exercise, No.	Countries, n	Labs, n
1985									
1986									
1987									
1988									
1989									
1990									
1991				1	22	22			
1992									
1993	1	21	24						
1994				2	25	26			
1995	2	25	39						
1996								14§	18§
1997	3	29	51					13§	40§
1998								20§	53§
1999	4	29	52					20*	17*
2000								20§	42§
2001	5	29	53						
2002				3	27	52	1	27	59
2003	6	26	46						
2004	7	23	43						
2005	8	30	52	4	28	52	2	27	52
2006	9	28	53						
2007	10	29	54	5	29	48			

different ring tests. Results revealed the benefit arising from this kind of exercises. The percentage of non tolerable results in the needle/leaf ring tests decreased during the last 8 years (Fig. 2) (Fürst, 2008). The results of the 2005 working ring test (WRT, 2005) for deposition and soil solution samples were much better then those from the WRT 2002 (Fig. 3) (Marchetto et al., 2006). Controversial results were obtained for soil (solid phase): in the 5th soil ring test the CV (coefficient of variation) has improved for some variables (particle size distribution, carbonates, total nitrogen, exchangeable cations and aqua regia extracable elements), but remained at the same level or was even worse for other (pH, organic carbon and acid oxalate extractable Fe and Al) (Tab. V). This is only a very rough comparison since it concerns the average of different soil samples and the CV largely depend on the kind of sample. When a comparable sample was used, as it was done in the 4th and 5th ring-test, a decrease of the coefficient of variation was obvious (see Cools et al., 2007 for details). Great differences may also occur between laboratories with respects to their internal QA methods and quality checks. For example, control charts were used by 49% of the participating laboratories in the WRT 2005 (Marchetto et al. 2006), and by 98% of the participating laboratories in the needle/leaves ring test 2008 (Fürst, 2008).

The interlaboratory tests helped laboratories to identify possible problems in their methods and the tests were used to undertake actions to improve the quality or to reject unsuitable methods. In some cases problems were solved by exchanging experience, visits in and training with other labs. In some other

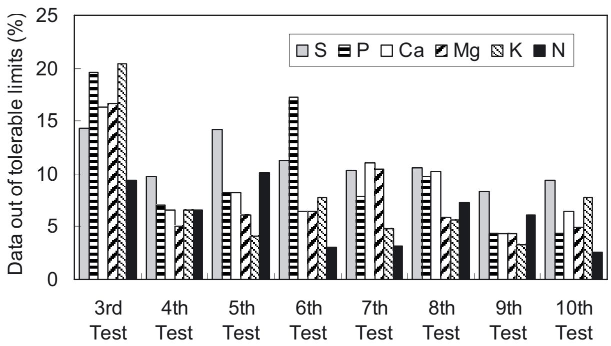

Figure 2. Progress in data quality reported as percentage of non tolerable results (by courtesy of Alfred Fürst, see also http://www.waldwissen.net/themen/inventur_monitoring/oekosystemmonitoring/bfw_ringtest_2009_DE). Tolerable limits are set by ICP-forests (expert panel on foliage and litterfall) and have been tightened during the course of time. For example, for N the limit has been 10% deviation from the mean in the ring test from 1999 onwards (for other elements see Fürst, 2008). See Table IV for details about the tests.

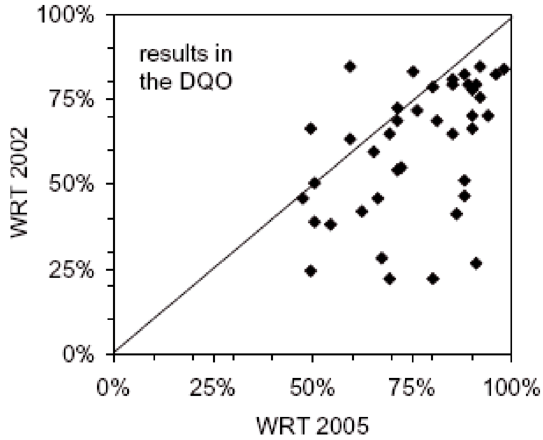

Figure 3. Frequency (%) of results falling within the DQOs for each laboratory participating in the working ring test for deposition and soil solution samples in 2002 and 2005 (after Marchetto et al., 2006). See Marchetto et al., 2006 for DQOs.

cases, recommendations were made to abandon certain methods formerly suggested in the Manual.

3.2. QA in EANET

3.2.1. QA components

The regular-phase monitoring activity of EANET started in 2001 and is conducted according to the Guidelines, Technical Manuals/Documents and the QA/QC Programmes, which are continuously reviewed and updated (EANET, 2006; Task Force on Soil and Vegetation Monitoring of EANET, 2006) (Tab. I). The QA/QC programme in EANET cover all activities from site selection to data reporting. The main components in EANET QA/QC programmes include:

(i) Development of national QA/QC programs. Each participating country should develop its own QA/QC programs taking national conditions into consideration.
(ii) Clear assignment of responsibility. A national QA/QC manager is designated in each country to assist the network manager in implementing the monitoring activities. Personnel in charge of data management and reporting should also be appointed in the respective laboratories and/or organizations in charge of field surveys.
(iii) Development of SOPs. SOPs are the procedures to be used in the monitoring, in the field, laboratory, and data management areas. Based on the technical manuals and QA/QC programs listed in Table I, the laboratories and field-survey organizations should prepare their own SOPs that meet actual conditions of respective laboratories/organizations. The SOPs should be sufficiently specific and easy to understand for analysts and surveyors.
(iv) Data quality objectives (DQOs). The DQO values define the desirable levels of accuracy and precision of the measurements. They varies according to the investigation: for example, required DQO for wet deposition and inland aquatic environment are 15% of deviation from prepared value (Network Center for EANET, 2006).
(v) Training programmes. According to the QA/QC programmes (EANET, 2006), EANET has conducted three training courses for surveyors and analysts who are working for the national centers and relevant organizations. The Japan international cooperation agency (JICA), in cooperation with EANET, conducted the 3rd country training programme in Thailand (two weeks) and the JICA training course on EANET in Japan (ten weeks) to provide training on acid deposition and air quality management. Acid deposition and oxidant research center (ADORC) as Network Center (NC) conducted also the Individual Training Course (four weeks).
(vi) Inter-laboratory comparison projects. The inter-laboratory comparison projects of EANET have been carried out by NC for wet deposition, soil, inland aquatic environment, and for dry deposition (filter pack method) (Tabs VI, VII). As for the project on soil, the data submitted to NC were statistically analyzed and the inter-laboratory precision was calculated as coefficient of variation (CV, %).
(vii) Audit to sites and laboratories by the national centres. The audit includes field training, advice on sample handling and analysis, check of analytical instruments, and information exchange of QA/QC activities in the laboratories. In case of forest soil monitoring in Japan, experts visit to forest plots managed by local governments every five years (i.e., the soil sampling interval) to check sampling and analytical procedures in the respective plots and laboratories.
(viii) Data control and reporting. Data are checked by the respective laboratories. In case of wet deposition and inland aquatic environment, ion balances and theoretical values of the electric conductivity are assessed for all measured data. The data is checked again and compiled

Table V. Group CV's (coefficient of variation, %) of the 2nd, 3rd, 4th and 5th soil ring test by Forest soil coordinating centre (FSCC), after elimination of the outliers (after Cools et al., 2007).

	2nd FSCC RT	3rd FSCC RT	4th FCSCC RT	5th FSCC RT
Group 1: Particle size distribution	NA	53	37	23
Group 2: pH	3.25	3.5	3.1	3.2
Group 3: Carbonate content	NA	206	129	45
Group 4: Organic carton	41.5	18	13	16
Group 5: Total N	25	17	27	17
Group 6: Exchangeable cations	52	71	54	49
Group 7: Aqua regia extractable elements	35	47	33	26
Group 8: Total elements		21		9
Group 9 : Acid Oxalate extractable Fe & Al	NA	44	12	20

NA: not available.

Table VI. Overview and timing of the inter-laboratory comparison projects and field exercises carried out within the EANET since it was launched in 1998.

	Inter-laboratory comparison projects				Field exercises*		
Reference year	Wet deposition (artificial rainwater)	Dry deposition (impregnated filters for the filter pack method)	Soil (soil or soil extract solution)	Inland aquatic environment (artificial inland water)	Soil profile description, and soil sampling methods	Observation methods for forest vegetation	Sampling methods for inland waters
1998	+				+	+	+
1999	+		+		+	+	+
2000	+		+	+	+	+	+
2001	+		+	+	+	+	+
2002	+		+	+	+	+	+
2003	+		+	+	+	+	+
2004	+		+	+	+	+	+
2005	+	+	+	+	+	+	+
2006	+	+	+	+	+	+	+
2007	+	+	+	+	+	+	+

* Field exercises were carried out as a part of the JICA training course.

Table VII. Details about number of countries and laboratories participating to the EANET inter-laboratory and field exercises.

Year	Wet deposition			Dry deposition			Soil			Inland aquatic environment			Field exercises
	Sample	Countries	Labs	Sample	Countries	Labs	Sample	Countries	Labs	Sample	Countries	Labs	Trainees***
	n	*n*	*N*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*	*n*
1998	2	10	24										8
1999	2	10	21				2	10	15				8
2000	2	10	24				2	10	15	1	7	13	8
2001	2	10	23				2**	10	16	1	8	14	10
2002	2	10	24				2	10	14	1	8	14	9
2003	2	12	27				2	10	14	1	8	15	10
2004	2	12	28				2	10	14	1	9	16	10
2005	2	13	30	6*	9	19	2	9	14	1	9	17	10
2006	2	13	31	6	10	20	2	9	14	1	9	18	10
2007	2	13	32	6	9	19	2	10	16	1	10	19	10

* Three sets of samples for acid- and alkali-impregnated filters and blank filters were sent;
** The soil extract solutions were sent to the laboratories in the 2001 project.
*** The trainees in the JICA Training Course participated in all the field exercises on soil, forest vegetation, and inland water.

Table VIII. Frequency (%) of data within DQOs after the EANET inter-laboratory exercises (after Network Center for EANET, 2008).

Year	Wet deposition (high) conc. (%)	Wet deposition (low) conc. (%)	Dry deposition (%)	Inland aquatic environment (%)
1998	78.3	75		
1999	92.4	85.7		
2000	92.3	85.5		87.6
2001	93.5	83.9		88.6
2002	86.2	70.3		84.4
2003	85.7	81.8		81.2
2004	89.3	87		79.5
2005	90.6	80.4	80.4	90.4
2006	93	83.9	91.5	79.7
2007	93.4	85.9	81.8	86.8

by the national QA/QC manager. All the data obtained in the previous year is expected to be submitted to Netwotk center (NC) by the end of June. The monitoring data submitted to NC is checked by ad hoc data verification groups, which consist of experts in the respective study fields. The verified data can be disclosed as the annual Data Report of EANET.

In addition to the QA/QC programs above, the Senior technical managers' meeting is held annually to enable close communications. Such close communication with local experts of the countries helps to improve the quality of the data. Moreover, to share technical issues with surveyors or analysts in the respective countries, NC sends missions to the countries every one or two years.

3.2.2. *QA/QC activity in field sampling and field surveys*

EANET does not have formal inter-calibration courses for field sampling and field surveys (soil, tree growth, species composition of the understorey vegetation). However, a part of the JICA Training Course may have some role on this issue. For soil sampling and assessment of forest vegetation monitoring (SV), one-day field training was conducted in addition to two-day lectures. In the field exercise for soil sampling soil profile descriptions, design of the sampling plots and subplots, and sampling procedures were practiced in the forest. The procedures on sampling and analysis were standardized by using the experience gained during these exercises. Most of the trainees are expected to work as key persons on sampling or analysis in the respective countries after the training courses. NC technical missions to the respective countries are also effective in order to share technical issues with surveyors or analysts.

It is worth noting that the statistical model proposed by the QA/QC for SV considered a multi-stage sampling design with several sampling levels, including area, soil type, plot, subplot, and horizon/layer, as follows:

$$X = \mu + \theta + c + a + s + p + i + \varepsilon$$

where X is a measured value; μ is a mean value; and θ is the fixed effect of horizon on a soil profile, while there are random effects of country (c), area (a), soil type (s), plot (p), and subplot (i), as well as (ε), which is an error term under the repeatability condition. A variance at each sampling level and its contribution to the total variance could be estimated by the analysis of variance (ANOVA). This evaluation may permit to estimate the contribution of sampling to the total variance, to validate monitoring data and to improve sampling design. For example, the pH, Ex-Ca, and Ex-Al contents varied with soil type, and the Ex-Ca and Ex-Al contents with country, but they did not vary from area to area and plot to plot (EANET, 2006). Contribution of sampling at plot and subplot levels to the total variance was significantly small, 3–7%.

3.2.3. *QA/QC for laboratories*

NC promoted standardization of analytical procedures, and most laboratories have followed the standard procedures. Moreover, by using digital formats, calculation errors were reduced. Different interlaboratory comparison projects have been carried out (Tab. VII). Results revealed an increase of data within DQOs for wet deposition over the period 1998–2007, while for dry deposition and inland aquatic environment no clear trend is obvious (Network center for EANET, 2008) (Tab. VIII). For soil, the coefficient of variation (CVs, %) was slightly improved compared with the early tests, although the CV of Ex-Ca was still relatively large (Network Center for EANET, 2008). Figure 4 shows the relationship between the sample concentrations and the inter-laboratories precision (CV%) for Ex-Ca and Ex-acidity in the past inter-laboratory comparison projects on soil. Ca concentrations in the samples may have large effects on the precisions: the CV% for Ex-Ca was still large even in the latest results in 2006 compared with those for Ex-acidity.

4. DISCUSSION

There are some questions related to QA in EANET and ICP-Forests that deserve attention:

(i) Both programmes developed SOPs for the various investigations and considered training sessions. However, the various SOPs were not always consistent in terms of structure and issues covered. The coverage given to

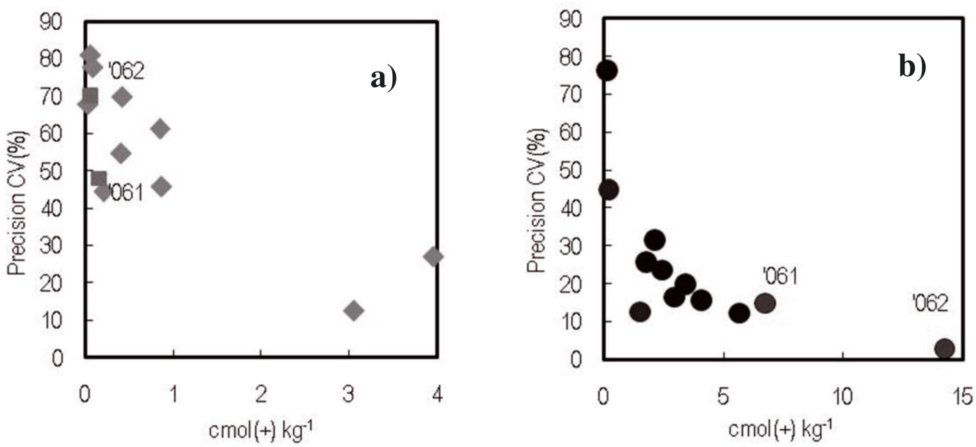

Figure 4. Relationship between the sample concentrations and the inter-laboratories precision (CV%) for (a) exchangeable Ca and (b) exchangeable acidity in the past inter-laboratory comparison projects on soil. The numbers, '061 and '062, indicates the samples for the latest project in 2006.

QA/QC issues in the ICP-Forests Manual varies strongly among sub-manuals, and – for example – not all the investigation defined their own DQOs. In addition, while EANET formally requires participating Countries to develop national QA/QC programmes, it is not so for the ICP-Forests.

(ii) Both programmes concentrated on the comparability of measurements, with special emphasis on crown condition (ICP-Forests) and chemical analyses (ICP-Forests and EANET). The activity in this field was valuable and permitted to document – and sometimes to control – measurement errors, which is an important component of the whole error budget of a given investigation (Köhl et al., 2000). Unfortunately, much less concern was given to other measurements (e.g. tree growth, assessment of ground vegetation and meteorological measurements) and these subjects should be improved in the future.

(iii) Field sampling was not properly addressed by the two programmes. This is unfortunate, as field sampling has been shown to account for the largest part of error in monitoring (e.g., Bargagli, 1998; Bleeker et al., 2003; Erisman, 2003; Kirvan et al., 2005). This goes together with the little attention given by both programmes in providing explicit and formal definition of monitoring objectives, in term of expected precision level of estimates and change/trend detection. A considerable effort is needed in this field.

(iv) Both programmes need to establish explicit links between the quality of sampling, the quality of measurement, and the quality of monitoring. Adequate sampling design and reliable measurement methods should go together, and should be well balanced in the overall monitoring design: sophisticated, time-consuming sampling design with imprecise, unreliable measurements will lead to a tremendous effort in the field and much error in the lab. On the other hand, even flawless analytical protocol will be useless if the sampling design is biased and if field operations are carried out carelessly.

To achieve the above goals, it is important that (i) all the steps within the investigation are considered, not only the measurements, and (ii) all the investigations carried out within monitoring programmes are covered by QA in a comparable and standard format. In Europe (ICP-Forests), some efforts to make progress in this direction have been made recently: (i) the set up of the Working Group for Quality assurance and Quality Control in Laboratories (QA-QC Lab) and (ii) set up of the Quality Assurance Committee (QA-C). The QA-QC Lab consists of the leaders of the relevant expert groups dealing with laboratory analyses, ensure contacts with staff member of the various labs and co-ordinates activities aimed at ensuring high quality of analytical data. The QA-C (http://www.icp-forests.org/QAC.htm) is made up by the leaders of all the expert groups, coordinating centres and data managers: it aims at providing a common conceptual frame to harmonize the QA/QC approach within the ICP-Forests. Objectives, definitions, data quality requirements, data storage, processing and reporting will be covered by the activity of the group in a coordinated fashion.

5. CONCLUSIONS

The quality of monitoring is subject to many influences that need to be fully and formally considered when implementing current, and designing future, monitoring programmes. This is already acknowledged by funding agencies, and for example the US EPA requires that "... all work funded by EPA in which environmental data will be collected, evaluated, used, or reported ... have approved QA Project Plans" (EPA, 2002, p. 2). In the past several QA/QC activities were carried out in Europe and East Asia, from the manual development to field observations and inter-laboratory comparisons, with particular emphasis on the analytical aspects. Other issues, like formal definition of objectives and field sampling has received so far much less attention. For this reason, it is not possible to assess the overall quality of monitoring, simply because monitoring objectives were never defined in operational terms. Building on the experience gained in the past, we believe that a more comprehensive QA approach is needed and this may apply also to many other international monitoring initiatives. Improving and documenting the quality of monitoring is not only possible, but also necessary. Failure in doing so will render results questionable, weaken the basis for decision making and disrupt the confidence in the role of science in environmental monitoring and management.

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