ICP-Forests (International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests): Quality Assurance procedure in plant diversity monitoring†

Maria-Cristina Allegrini,* Roberto Canullo and Giandiego Campetella

Received 14th October 2008, Accepted 5th February 2009
First published as an Advance Article on the web 3rd March 2009
DOI: 10.1039/b818170p

Knowledge of accuracy and precision rates is particularly important for long-term studies. Vegetation assessments include many sources of error related to overlooking and misidentification, that are usually influenced by some factors, such as cover estimate subjectivity, observer biased species lists and experience of the botanist. The vegetation assessment protocol adopted in the Italian forest monitoring programme (CONECOFOR) contains a Quality Assurance programme. The paper presents the different phases of QA, separates the 5 main critical points of the whole protocol as sources of random or systematic errors. Examples of Measurement Quality Objectives (MQOs) expressed as Data Quality Limits (DQLs) are given for vascular plant cover estimates, in order to establish the reproducibility of the data. Quality control activities were used to determine the "distance" between the surveyor teams and the control team. Selected data were acquired during the training and inter-calibration courses. In particular, an index of average cover by species groups was used to evaluate the random error (CV 4%) as the dispersion around the "true values" of the control team. The systematic error in the evaluation of species composition, caused by overlooking or misidentification of species, was calculated following the pseudo-turnover rate; detailed species censuses on smaller sampling units were accepted as the pseudo-turnover which always fell below the 25% established threshold; species density scores recorded at community level (100 m^2 surface) rarely exceeded that limit.

Introduction

Monitoring programmes are designed to collect repetitive information over time, assuring the detection of eventual changes or the maintaining of a given standard. To achieve these aims the collected data must have certain characteristics: the quality of the data should be known, the data type and quality should be consistent and comparable, and the sets of data should be available and accessible.[1] In particular, the knowledge of accuracy and precision rates is important for long-term studies involving a number of surveyors. This is especially true in vegetation assessment by way of visual estimates of abundance and cover, where the influence of surveyors' subjectivity is relevant, as well as the influence of misidentification of species. These sources of error are usually underestimated. The need for control of vegetation survey quality has been recognised since 1940. It was recognised by Hope-Simpson[2] who described the term error as the "difference in subjective frequency symbol due to error or to causes which do not require to be considered in a general survey". In the description of vegetation there are many sources of error, two of which are dominant: cover estimates have been shown to be subjective and prone to observer bias;[3,4] the compilation of accurate and complete species lists, has been demonstrated to be a critical point.[5]

In Italy, the research groups of the "National Integrated Programme for Forest Ecosystems Monitoring" (CONECOFOR) are aware of the relevance of Quality Assurance in their monitoring procedures. In particular, vegetation assessment is included in evaluating eventual responses to environmental drivers, natural factors, occasional events. Therefore the vegetation data must be reliable and comparable, especially when dealing with species density and abundance attributes.[6]

The present study divides the whole procedure of CONECOFOR vegetation monitoring into different steps and identifies the main sources of random and systematic error. In particular, the aim of this paper is to estimate the errors introduced by visual estimation of plant cover and species misidentification; for the cover we considered the scores of the control team as "the true values", for the species richness the rate of pseudoturnover (PT).

The CONECOFOR programme

The Italian Ministry for Agriculture and Forestry Policy (National Forest Service) supports the "National Integrated Programme for Forest Ecosystems Monitoring" (CONECOFOR), on the basis of EU Regulation no. 1091/94, implemented to study the effects of atmospheric pollution, climatic changes, ozone effects on forest ecosystems and the loss of biodiversity. The Programme includes the development of two networks: the Level I network is based on a 16 × 16 km grid,

Univerity of Camerino, Dept. of Environmental Science, Sect. of Botany and Ecology, Camerino, MC, Italy. E-mail: mariacristina.allegrini@unicam.it; Fax: +39 0737-404508; Tel: +39 0737-404503

† Presented at TerraData Environmetrics 2008, a recent workshop on Quality Assurance in Ecological Monitoring held on the 7 March 2008, Siena, Italy.

which has been in use since 1987; the Level II network is currently based on 31 permanent plots distributed throughout the whole nation (the sites for the plots are selected so as to include the major forest ecosystems), these plots are in a fenced area. On each plot (50 × 50 m wide) an intensive programme was started in 1995 within the framework of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests. Different kinds of monitoring is performed, such as the monitoring of: vegetation, crown condition, chemical content of leaves, soil, tree growth, atmospheric depositions and pollutants, climate and macroclimate, soil solution, tree phonology, ozone. Each research initiative must follow a specific UN/ECE ICP-Forest Sub-Manual, for its initial harmonisation and standardisation, which includes recommendations regarding the need for Quality Assurance procedures.[7]

Methods

Vegetation monitoring

The vegetation survey employs both fundamental approaches proposed by the UE Reg. no. 1091/94, incl. Manual compiled by the Experts Panel on Ground Vegetation:[8]

(1) At the community level, the survey is based on 100 m^2 sampling units, in which the percentage cover of vertical strata and related species are estimated; 24 sampling units are surveyed, 12 of which are arranged systematically in a chessboard pattern inside the permanent plot, with the other 12 located nearby (in the vast homogeneous area outside the fence). The surveys are conducted according to the Braun-Blanquet phyto-sociological method, based on the visual estimate of the cover by percentage intervals, with indices assigned to each species (r = rare; + = < 1%; 1 = 1–5%; 2 = 5–25%; 3 = 25–50%; 4 = 50–75%; 5 = 75–100%). The vertical stratification is classified as tree, shrub, herb and moss layers;

(2) At the population level, based on 0.25 m^2 sampling units, in which the coverage of species is given more precisely, and information on woody species regeneration, density and structural and functional characteristics are added; 100 sample units in grids in the fenced permanent plot, and includes the layer of vegetation below 1.3 m are surveyed. The cover of each species is estimated in cm^2, the number of individuals present is counted on the basis of the various functional typologies, and the presence of any damage is noted; for the woody species these elements are recorded individually.

The surveys examined higher plants, ferns, bryophytes and lichens. Species nomenclature follows Flora d'Italia,[9] Mosses of Europe and Azores[10,11] and local floras for the lichens. The related European coded reference lists have been prepared on the basis of the Flora Europaea[12] and Moos-und Farnpflanzen Europas.[13]

To facilitate uniform team methodology, especially for the field survey phase, a National Reference Manual has been prepared[14] defining the procedural and technical standard. The Vegetation Analysis project has adopted the ICP-Forests program guidelines,[15] which stress the necessity of using Quality Assurance procedures in each of the monitoring activities.

Quality Assurance procedures

The Quality Assurance (QA) defines all processes leading to the production of data that meet the standards of reliability and reach a defined level of quality, maintaining methodologically correct and defensible environmental data and defining the internal variability.[16] Quality definition includes various activities:[17]

A - Quality Management (QM) is the quality of organisational management; the most important processes defined in this activity are: the definition of an appropriate design and appropriate project planning of the vegetation surveys (field manual), team selection matching the requirements of the manual, detection of weak points, filing of data, definition of errors, their type and gravity. These steps help to reduce the sources of error, to implement quality control and to define the global assessment processes;

B - Quality Assurance (QA) ensures that all the planned actions systematically meet the set of quality requirements; in this process the Measurement Quality Objectives (MQOs) and the Data Quality Limits (DQLs) are defined, on the basis of the constrictions imposed by the survey method and of the expertise required;

C - Quality Control (QC) combines the technical operations and activities used to meet the quality requirements,[18] to state the statistical variation and to reduce the bias; the activities defined in the monitoring programme are: team training for the harmonisation of methods, surveyor inter-calibration to reduce the discrepancies, and field control.

The control activities were carried out at the training and inter-calibration courses and during field data collection. Throughout the theoretical and practical annual course, an expert surveyor demonstrates to the surveyor teams (each consisting of two trained field botanists) the correct procedures and assessment protocols of the National Reference Manual.

The subsequent phases of training and inter-calibration are essential for achieving the Quality Objectives; they consist in the following modules:

- Comparative tests of harmonisation of methods to ensure that the teams, faced with similar problems, will converge to the same decisions;
- Inter-calibration test to achieve acceptable levels of comparability. One common sampling unit (10 × 10 m) was used for cover estimates and species census at community level, while ten common sampling units (50 × 50 cm) were surveyed for population level records. A first exercise is done by each team and the results are compared to the overall results and to the output obtained by the control team;
- Debriefing and further discussion and explanation;
- Replication of the field exercise to achieve the definitive scores to be used for evaluation and field control.

Furthermore, on randomly selected permanent plots (10% of the surveyed plots) the control team carried out field controls on a related fraction of randomly chosen sampling units; this control is used to observe the difference in the values recorded by the control and the survey teams.

D - Quality Evaluation (QE) is the assessment of quality; it defines how data deviates from a given standard determining precision and accuracy.

Data analysis

Quality control activities are used to determine the "distance" between the surveyor teams and the control team; in this study the analyses concentrate on abundance and species richness estimates.

These data are acquired during the training course and the field surveys, by using certain relative indices.

An index of coverage (ICR) is adopted to standardise cover estimates, (a specific ICR) was calculated for each team's scores:

$$\mathrm{ICR} = (C_{\max} - C_{\mathrm{i}})/C_{\max}$$

where: $C_{\max}$ is the value of the greater specific coverage and C_{i} is the specific cover value in ten sampling units (50 × 50 cm).

It was considered appropriate to divide the species into three categories, these were commonly adopted in the field; though not imposed, in Kercher *et al.*:[19] narrow caespitose leaves; small leaves (precise estimate of each element); large leaves (geometric estimate).

For these three groups and each pair of surveyors the ICR average was calculated, both during the training course, to evaluate the overall data dispersion and the relative distance between each team (ten teams) and one control team of the same 10 sampling units for the population level in surveys I and II .

A second parameter deals with the biased differences in species composition, caused by species overlooking or misidentification. The pseudo-turnover rate is calculated during the training course; for the community level (excluding the single layer-scores) and for the population level (calculations made on the full species list score). Pseudo-turnover was introduced by Lynch and Johnson[20] in studies of birds for the sampling errors that artificially increase species turnover estimates; Nilsson and Nilsson[21] introduced it for vascular plants.

Pseudo-turnover (PT) can be estimated as:

$$\mathrm{PT}\% = [(A + B)/(\mathrm{SA} + \mathrm{SB})]100$$

where: A, B = number of exclusive species for teams 1 and 2; SA, SB = total number of species recorded by teams 1 and 2.

This value discriminates the efficient species richness estimates from the scores which must be interpreted with particular caution.

Quality Management (QM)

To perform vegetation assessments, the co-ordinating group at Camerino University defined a Quality Management Plan (QMP) represented by a flow chart (Fig. 1) which identified certain critical points to be considered for defining the Procedures for Quality Assurance.

Quality Management Organisation (QM) activities include: the survey protocol described by the field manual to be formally adopted implementing the related EC regulations, the choice of surveyors with appropriate curricula related to the research typology with more years of experience. In conclusion, data filing on pre-formatted electronic worksheets, in a specific data-base.

As far as error types are concerned, they are mainly linked to the biological and ecological representativeness;[21,22] the collected data must be relevant to specific information such as the taxonomic level, population, individual attributes, *etc.*[23]

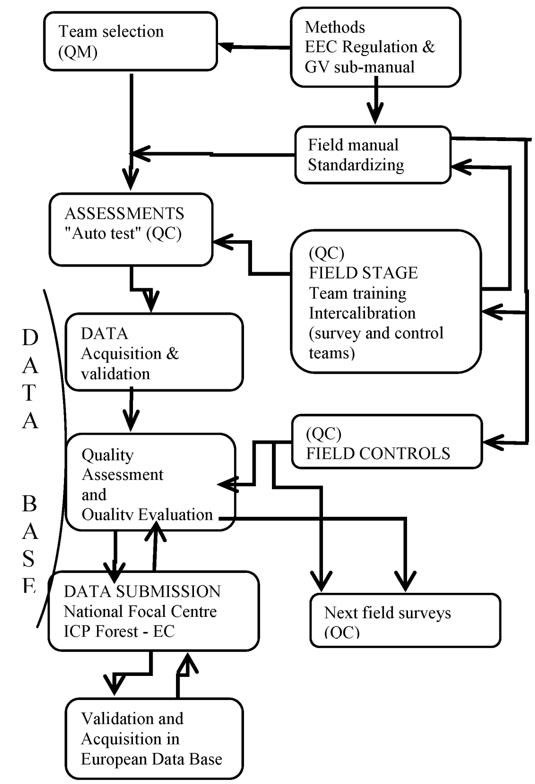

Fig. 1 QA/QC Flow Chart of the Vegetation Assessment in the CONECOFOR programme; from Canullo, modified.[25]

In these cases the random error is made when the results do not adequately describe reality, because of bad precision in the presence of sufficient accuracy. To remove, at least partially, this type of error an increase of replicates and a higher investment on training are required.[24]

When results do not meet the application of adopted methods, systematic errors arise, due to misunderstandings; data is expected to be sufficiently precise but has poor accuracy. To eliminate the bias, a more adequate surveyor training and harmonisation method is needed.

Quality Assurance (QA)

The Measurement Quality Objectives (MQOs) expressed as Data Quality Limits (DQLs), to establish the data reproducibility, are shown on Table 1. The general cover estimates at community

Table 1 Measurement Quality Objectives (MQOs) expressed as Data Quality Limits (DQLs) for some cover parameters of the CONECOFOR vegetation assessments[a]

Parameters	Unit/scale	DQLs
Total and layer cover (10 × 10 m)	%	90% @ ± 10%
Specific cover (10 × 10 m)	7 classes	90%@ ± 1 class
Specific cover—herb layer (50 × 50 cm)	%	90% @ ± 10%

[a] @ = agreement to the expected Control Team relative distance.

level must be estimated in 90% of cases according ±10% compared to the true value (by definition the performance of the control team), as well as the specific coverage at population level; the specific cover expressed by seven classes must be estimated in 90% of cases in accordance with ±1 class compared to true values. The MQOs, in practice, show the permissible distance in the observations between different surveyors, and the DQLs define the level of quality expected for the parameters; in our case a tolerance of 10% which is regarded as the error allowed. Further, the Quality Control field activities will verify if the data collected fall within the prescribed limits. The failure to reach the DQLs calls for retracing the assessments.

Results and discussion

Quality Control (QC) and Quality Evaluation (QE)

To assess the performance on the visual cover estimates, the results of four training course exercises, concerned with population levels (50 × 50 cm sampling units) were analysed. It can be seen from Fig. 2 that the average cover values were generally lower in the second exercise, due to the reduction of misinterpretations (in general, underestimates of intermediate coverings) after the intermediate debriefing. The ICR variance differs during the considered years in both the I and II intercalibration test: 2002: 0.018 – 0.016; 2003: 0.009–0.013; 2005: 0.03 – 0.03; 2006: 0.02 – 0.01, respectively confirming the role of the plenary discussion and explanation. The Coefficient of Variation, in Table 2, differentiates the 2005 teams performances by a higher value, this was caused by the dominance of large leaves; the mean variation of the years considered is 4%. The first inter-calibration test, performed in 2000, was higher than 9%. This fact demonstrates that repeated training courses are a determinant in increasing data comparability by reducing the

Table 2 Coefficient of Variation and number species per leaf type after the relative cover index from intercalibration courses

	CV (%)		No. species per leaf type		
	I test	II test	Narrow	Small	Large
2002	2.57	2.39	6	25	13
2003	1.25	1.85	9	18	14
2005	5.54	5.30	8	6	11
2006	2.87	1.14	8	18	16

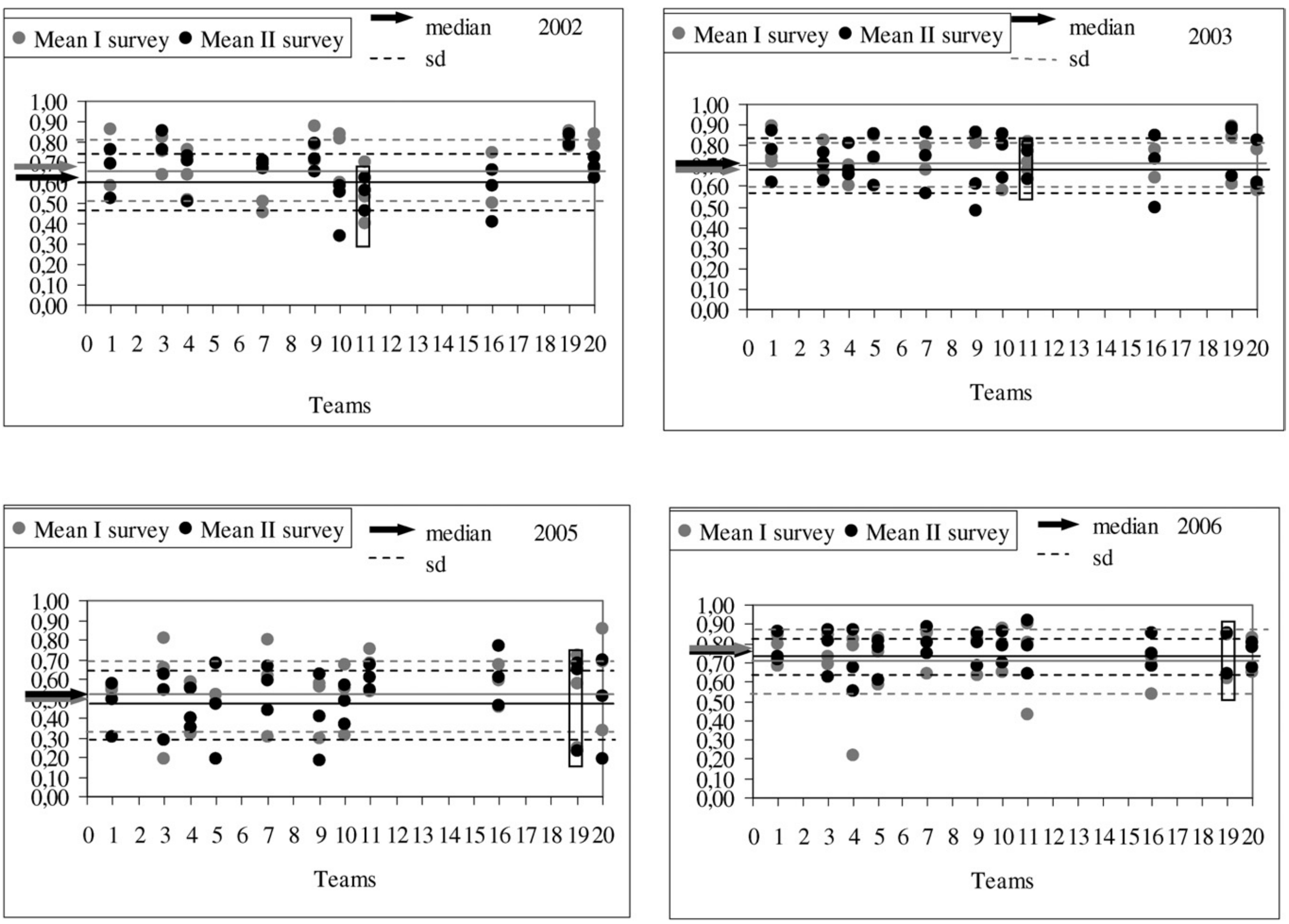

Fig. 2 Index of relative coverage (ICR) for three categories of leaves from the I and II training course survey carried out in four different years by ten teams and control teams (11, 19 teams) involved on CONECOFOR vegetation assessments. Grey: surveys after the first theoretical training; black: surveys after the debriefing on the results of the first exercises. The control team scores are highlighted (points included in the rectangle). Lines indicate the average mean values and related SD (dotted).

range of interpretations and the dispersion of the estimated values.

Moreover, the control team scores are placed at the average performance level of all teams, slightly differing from the median value only in 2002, the year in which the harmonization of teams was still not stable.

After the inter-calibration exercises, we considered the scores of the control team as the "true value". These references must be set each year, as the composition of the control team could not be stable and the common sample area is not always the same. The mean value of pooled years can be possibly used as the "CONECOFOR team reference", since the CV remains at a low percentage (Table 2). Thus the mean random error for cover estimates of the considered group of species is 3.99% CV. The intercalibration test in general did not improve data quality from 2002 to 2006 suggesting that the intercalibration test produced an effective reduction of observer errors only on the first couple of years.

Table 3 describes the results obtained from the pseudo-turnover evaluation. The comparison of the different teams in the first and second inter-calibration test shows a significant reduction of the pseudo-turnover rate in the 50 × 50 cm plots (binomial test, $p < 0.05$), while in the 10 × 10 m plots the performance of teams did not produce a significant reduction; expertise and the increase of familiarity with the local flora after the intermediate debriefing, are the obvious factors of explanation. The annual training also allowed noticeable reduction of species misidentification and overlooking: in the field vegetation assessments in the CONECOFOR Level II network, from 10% (1998) to 3.1% (2006), these rates were calculated dividing the number of misidentified species (the species name is wrong) or identified at genus only (incomplete identifications) and the total number of species. The plant cover, morphological type and experience of the botanist are some the factors which can influence the overlooking and misidentification.[29,30,31]

The maximum percentage of pseudo-turnover accepted in the literature, so that no richness discrepancy between different observations is foreseen, ranges from 12 to 36%[26,27] as both of the extremes refer to woodlands, for this study we set 25% as the target of first experiments.

The pseudo-turnover rate for surveys at population scale level (50 × 50 cm sampling units) always falls below the 25% threshold, while at community level (10 × 10 m) a few times the pair-wise comparisons exceed 25%. The smallest sampling units allow for greater accuracy in detecting species, while the precision in determining the species is almost stable in both the survey systems. At the population level the results can be safely used in further evaluation of significant changes in vascular plants richness; interpretation of trends or richness variations at the community level should be carefully examined in the light of our results.

The error linked to the species census can be considered as a systematic error, varying in the extent of accuracy; it can be estimated, as a "CONECOFOR team performance", of about 18.66% at the community level and 4.19% at the population level.

The CONECOFOR sampling design establishes that the sampling units surveyed on each permanent plot represent the total vascular plant richness. This determines another source of

Table 3 Pseudoturnover rates (%) in the two sampling systems during the 2006 intercalibration course on forest vascular plant censuses for the CONECOFOR vegetation teams

	10 × 10 m plot		50 × 50 cm plot			10 × 10 m plot		50 × 50 cm plot	
Teams	I survey	II survey	I survey	II survey	Teams	I survey	II survey	I survey	II survey
1–3	20.00	15.79	13.79	5.08					
1–4	21.57	24.53	17.24	3.33	5–9	25.58	21.74	16.98	5.56
1–5	20.83	19.23	12.28	5.08	5–10	20.00	21.57	12.28	7.27
1–7	19.23	8.20	11.86	3.33	5–11	13.04	14.89	11.54	9.09
1–9	26.53	26.92	21.43	3.39	5–16	22.45	18.37	10.71	3.57
1–10	14.29	15.79	10.00	5.00	5–19	19.15	16.00	7.14	3.64
1–11	23.08	24.53	16.36	3.33	5–20	14.89	20.00	10.34	7.14
1–16	16.36	9.09	5.08	1.64	7–9	23.40	27.27	20.00	3.64
1–19	16.98	10.71	8.47	1.67	7–10	25.93	20.00	11.86	1.79
1–20	20.75	21.43	8.20	4.92	7–11	20.00	17.86	18.52	3.57
3–4	15.38	15.38	10.71	5.45	7–16	24.53	17.24	17.24	5.26
3–5	14.29	9.80	9.09	7.41	7–19	25.49	15.25	20.69	5.36
3–7	24.53	13.33	12.28	1.82	7–20	25.49	25.42	10.00	5.26
3–9	24.00	29.41	18.52	1.85	9–10	29.41	33.33	21.43	1.82
3–10	8.77	10.71	10.34	0.00	9–11	27.66	31.91	17.65	7.27
3–11	9.43	11.54	20.75	5.45	9–16	28.00	22.45	20.00	1.79
3–16	14.29	14.81	12.28	3.57	9–19	37.50	24.00	20.00	1.82
3–19	11.11	12.73	15.79	3.64	9–20	25.00	24.00	19.30	1.79
3–20	11.11	16.36	8.47	3.57	10–11	18.52	23.08	12.73	5.36
4–5	15.56	10.64	12.73	5.45	10–16	15.79	18.52	11.86	3.51
4–7	26.53	21.43	15.79	7.14	10–19	12.73	20.00	15.25	3.57
4–9	26.09	19.15	14.81	3.64	10–20	12.73	16.36	4.92	3.51
4–10	13.21	26.92	13.79	5.36	11–16	24.53	20.00	18.52	5.26
4–11	18.37	16.67	16.98	7.14	11–19	13.73	13.73	18.52	5.36
4–16	19.23	24.00	12.28	1.75	11–20	13.73	17.65	17.86	8.77
4–19	16.00	21.57	19.30	1.79	16–19	11.11	9.43	6.90	0.00
4–20	8.00	13.73	8.47	1.75	16–20	22.22	16.98	10.00	3.45
5–7	17.39	16.36	14.29	9.09	19–20	15.38	18.52	13.33	3.51

error which was partially controlled by asking the surveyors for a list of "additional species" to be recorded within the plot but outside the sampling units to fill in for the "expected richness". This reference allowed us to state that more than 80% of the total number of species is recorded by the sampling system.[6]

As a control of data consistency and plausibility, our specific data-base played a very important role. Data acquisition undergoes validation through data-base procedures.[25] The first part of this importing procedure is the validation of all species' names according to Pignatti's Italian flora[9] using an apposite database. The database performs certain controls for each attribute, verifying its correspondence with the upper and lower limits previously set by the system Administrator. Further controls on data integrity are also performed for observations both at community and population levels, by means of about 12 different crosschecks. The final tool of data acquisition and validation is the automatic association between the Italian flora archive and the coded archive of Flora Europaea.[28] At the end of the controlling procedure, the full set of data is acquired.

Conclusions

Quality assurance is an important issue for long-term environmental monitoring programs. Dealing with vegetation monitoring in forest ecosystems, field manual adoption, surveyor team selection, team training and inter-calibration, field controls and data-base functions represent the main critical points. The annual training adopted by the vegetation assessment group of the CONECOFOR programme proved to be effective in harmonising and recalibrating sampling procedures and observers' performances.

The Measurement Quality Objectives (MQOs) expressed as Data Quality Limits (DQLs) were set to accept only reproducible data.

An index of relative average cover (ICR) was used to assess the overall data dispersion and the relative difference between each team and the control team for the same sampling unit. The mean random error of the period between 2002–2006, calculated by morphological groups, is estimated to be around 4% CV; at the starting point in 2000 it was more than 9%, this proves the effectiveness of repeated training courses.

The species pseudo-turnover rate threshold was prudently fixed at 25% as a target following the first experiments; the output at the detailed population scale was always below the limit with a systematic error of around 4%; at the community level the threshold was often exceeded (the systematic error averaged 19%) advising us to make an attentive interpretation of dynamic data on vascular plant richness.

The specific data-base improved the final steps of data validation, through completeness consistency and plausibility checks allowing the final data acquisition.

A final note must be added; a danger in the application of QA procedures may be represented by incorrect surveyor perception: often they feel questioned as far as their abilities or skills are concerned, rather than if they are involved in a key aspect of monitoring, designed to improve consistency in the collected data. Thus, we have to improve the teams' awareness of the relationship between faults, errors and quality.

References

1 M. H. Hellawell. in *Monitoring for conservation and Ecology*, ed. F. B. Goldsmith, Chapman and Hall, London, 1991, 1–14.
2 J. F. Hope-Simpson, *J. Ecol.*, 1940, **28**, 13.
3 A. D. Smith, *Ecology*, 1994, **71**, 437.
4 J. M. Sykes and A. M. J. Lane (eds.), 1996, *The United Kingdom Environmental Chenge Network: protocols fo Standard Measurements at Terrestrial sites*: The stationery Office London.
5 J. M. Sykes, A. D. Horrill and M. D. Mountford, *J. Ecol.*, 1983, **71**, 437.
6 R. Canullo, G. Campetella and M.-C. Allegrini, *Ann. Ist. Sper. Selv.*, 2006, **30**(Suppl. 2), 29–41.
7 F. Bussotti, M. Schaub, A. Cozzi, N. Kräuchi, M. Ferretti, K. Novak and J. M. Skelly, *Environ. Pollut.*, 2003, **125**, 81–89.
8 Dan Aamlid, *Part VIII. Assessment of Ground Vegetation. Expert Panel on Ground Vegetation Assessment*, 2002, 3–19.
9 S. Pignatti, 1982. 1–3. Edagricole, Bologna.
10 M. F. V. Corley and A. C. Crundwell, *J. Briol.*, 1991, **16**, 337–356.
11 M. F. V. Corley, A. C. Crundwell, M. O. Mull and A. J. E. Smith, *J. Briol*, 1981, **11**, 609–689.
12 T. G. Tutin, V. H. Heywood, N. A. Burges, D. N. Moore, D. H. Valentine, S. M. Walters and D. A. Webb, 1964–1980, 1–5, Cambridge University Press.
13 W. Frey, J.-P. Frahm, E. Fischer and W. Lobin In: *Kleine Kryptogamenflora*, 1995 Vol. IV. 6th ed. - Gustav Fischer Verlag, Stuttgart-Jena-New York.
14 R. Canullo, M.-C. Allegrini, G. Nicoletti, G. Campetella, S. Allavena, R. Isopi, B. Petriccione, and E. Pompei, 1999. Università degli Studi di Camerino. Latest version: R. Canullo, M.-C. Allegrini, G. Campetella, B. Petriccione., 2003, Università degli Studi di Camerino.
15 Th. Hauβmann, M. Lorenz, R. Fischer, 2000. *Federal Research Centre for Forestry and Forest Products (BFH)*, Hamburg.
16 I. Millers, D. Lachance, W. G. Burkman and D. C. Allen. *North American Sugar Maple Project – cooperative field manual*. USDA, Canadian Forest Service, 1994, 51pp.
17 S. P. Cline and W. G. Burkman, 1989. Eds. J. B. Bucher and I. Bucher-Wallin. *Proc. 14th Int. Meetingfor Specialist in Air pollutation Effects on Forest Ecosystem*, Inerlaken, Switzerland, Oct, 2–8, 1988, Birmensdorf, pp. 361–365.
18 W. J. Shampine, *Environ. Monit. Assess.*, 1993, **26**, 143–151.
19 S. M. Kercher, C. B. Frieswyk and J. B. Zedler, *Journal of Vegetation Science*, 2003, **14**, 899–906.
20 J. F. Lynch and N. K. Johnson, *Condor*, 1974, **76**, 370–384.
21 I. N. Nilsson and S. G. Nilsson, *Oecologia*, 1982, **53**, 128–133.
22 R. A. Lewis. US MAB Report No. 12, US Department of the Interior, National Park Service, 1987, 182 pp.
23 R. Klein, M. Paulus, G. Wagner and Müller, *Ökotox*, 1994, **6**, 223–231.
24 R. Koch, *Fresenius Environ. Bull.*, 1992, **1**, 682–687.
25 R. Canullo, G. Campetella, M. C. Allegrini and V. Smargiassi, *J. Limnol.*, 2002, **61**(Suppl.), 1100–105.
26 I. N. Nilsson and S. G. Nilsson, *J. Ecol.*, 1985, **73**, 65–70.
27 K. J. Kirby, T. Bines, A. Burn, J. MacIntosh, P. Pitkin and I. Smith, *J. Ecol.*, 1986, **74**, 123–131.
28 ICP-Forests, *Expert Panel on Biodiversity and Ground Vegetation*, 2007, http://www.icp-forests.org/EPbiodiv.htm, (accessed november 2007).
29 L. Klimeš, M. Dancak, M. Hajek, I. Jongepierova and T. Kucera, *Journal of Vegetation Science*, **12**, 699–704.
30 W. A. Scott and C. J. Hallam, *Plant Ecology*, 2002, **165**, 101–115.
31 F. Archaux, F. Gosselin, L. Berges and R. Chevalier, *Journal of Vegetation Science*, 2006, **17**, 299–306.