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Assessing the measuring time of forest plots

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Abstract Forests provide a wide range of ecosystem services and information requirements on forests have grown considerably. Nevertheless, collecting information in the forest is expensive and for this reason assessment of forest resources strongly relies on statistical sampling. However, plot measurement remains essential even when remote-sensing data are used, and field assessments are still among the costliest components of forest inventories. Studies on the costs for plots survey are limited and usually based on expert evaluation rather than on data. This article analysed the relationship between the time needed for measuring forest plots and their site-related characteristics (slope, terrain roughness), stand features (number of trees, subsample trees, stumps, coarse woody debris, understorey vegetation) and protocol-related procedures, by means of univariate and multivariate analyses. Analyses showed that the time needed for measuring plots depends on the workload or the intensity of fieldwork. Especially, the number of variables surveyed matters, because the variables explained the measuring time variation by an additive effect, suggesting that within a complex field protocol the total number of measurements taken may not represent properly the overall intensity of work. Marking in an effective way permanent plots is recommendable because the retrieval success of the pins buried into the ground was the most important explanatory variable. Presence of understorey vegetation was more important than the number of individuals measured. The results obtained are consistent and logical, but the variance explained was limited, suggesting that predictability of the measuring time under complex field protocols might be intrinsically limited by the interactions among factors with opposite effects and especially by the adaptation of the surveyors to specific circumstances. For example, effects of physical tiredness were not detected in the days when two plots were measured; conversely, measuring a second plot reduced the measuring time of the first, an event most likely dependent on the surveyors' behaviour. Under the conclusion that predictability is low by nature, the inference of studies based on simulation data and simplified protocols to practical applications was finally discussed.

Keywords: forest inventory, forest monitoring, fieldwork efficiency, measurement costs, forest mensuration, sample, survey.

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Introduction

Forests provide a wide range of critically important ecosystem services (Thompson et al. 2011, Brockerhoff et al. 2017, Felipe-Lucia et al. 2018) and national information needs on forests have grown considerably in recent years (Tewari 2016, Breidenbach et al. 2020, Gschwantner et al. 2022). Nevertheless, collecting information in the forest costs money, time and effort (Loetsch & Haller 1973). In forest management, restricting the measurements to sample areas has been early recognised as an-effective way to reduce costs; for large area forest inventories, such as for example regional or national inventories, it is what makes the assessment feasible also under the point of view of logistics. For this reason, assessment of forest resources strongly relies on plot-based statistical sampling. However, costs of forest surveys remain high and numerous statistical sampling designs have been developed by National Forest Inventories (NFI) in search of optimization, to have the lowest cost for a given precision or the highest accuracy and precision for a given budget. In this respect, the number of plots, their size and their configuration are among the alternatives considered. An advancement with strong implications also for costs has come with the use of remote-sensing data, historically represented by the aerial photographs, whose use is a common feature of all modern NFIs (Tomppo et al. 2010, White et al. 2016).

Despite the growing role of remote-sensing data, field assessments continue to be an essential component of forest inventories (Köhl et al. 2006) and measuring forest plots is almost always the costliest component of forest inventory operations (Köhl & Scott 1992).

Despite the continuous enhancement of the remote sensing methods after the development of new technologies, it is doubt if and to what extent remote sensing will be able to reduce the rate of the field survey costs over the total expenditure. In fact, the expanded role recognized to forests in the last decades has increased the number of variables surveyed, so it is likely that the gap between the variables that can be assessed remotely and those recordable only from field surveys will not be significantly reduced. For example, important aspects related to forest biodiversity, such as the detailed species composition of the vegetation storeys, the forest structure, the extent and characteristics of old growth forest cannot be assessed accurately with remote sensing data.

The precise assessment of volume increment and mortality on large areas and for very different vegetation types is also far from being provided just based on remote sensing, and field data are necessary to accurately describe forest resource dynamics. Moreover, the remote sensing itself needs field data. For example, the airborne laser scanning is capable of acquiring tree-level forest information with previously unexpected high accuracy, but it needs detailed reference data from sample plots (Vastaranta et al. 2009), that might also be larger and measured with more detail compared to plots employed as field data only (Tomppo et al. 2017). Another example is the REDD+ mechanism to reduce the greenhouse gas emissions from forest loss, under the UNFCCC.

The measurements and monitoring required can only be accomplished using satellite and aircraft views of landscapes that have been calibrated and validated with field and forest inventory measurements; field assessment also provides the potential for collecting additional relevant information on both social and biodiversity safeguards relevant for the sustainability of the REDD+ mechanism (Goetz et al. 2015).

Molinier et al. (2016) consider the cost of traditional forest plot measurements a bottleneck for data availability under the increasing need of in situ, up-to-date, reference data for the training and the accuracy assessment of models that make use of satellite imagery. To some extent, this seems a paradox: the more information we want from the enhanced remote sensing methods the more field measurements we need. The balance between the amount of information achievable by a new remote method and that to be provided through field measurements clearly plays a role in its success for practical applications.

A strategy for costs reduction might be more realistically seen in the harmonisation/integration of the monitoring programs, whose number has remarkably increased in recent years. Feasibility studies on harmonisation/integration exit. Gasparini et al. (2013) assessed consistency between sample points of the forest condition monitoring established after the first Italian NFI with the new forest area estimated by the second NFI, and the effect of the changed tree selection method (tree-based or plot-based); in Finland, Tomppo et al. (2017) investigated the possibilities to share the forest plots between the NFI and the forest monitoring inventory by adopting a common plot configuration, so reducing the overall costs for field measurements. Ultimately, whichever the level of integration/harmonisation achieved, the efficiency obtained with the statistical designs and the plots configuration, measuring plots remains essential and expensive.

Under this perspective, quantifying the costs for measuring plots is relevant because it might disclose new approaches to further improve the overall efficiency of a forest survey campaign. For example, identifying the variables that affect the cost for measuring plots would allow optimizing their allocation in a stratified random sampling to obtain the highest precision for fixed total sampling expenditure (e.g. Van Laar & Akça 2007) or achieving greater awareness about convenience in surveying a certain variable through a cost-benefit analysis.

The primary sampling costs for plots measurements are generally attributed to travelling to and from the sampling unit location, and to measuring the unit itself (Zeide 1980, West 2004, McRoberts et al. 2015).

Focusing on the second aspect, the literature that reports on the costs for plots survey is limited. Some studies have considered such costs within broader analyses and not many have made specific reference to the costs for plots measuring, i.e. travelling excluded. Most important, the time required for the survey has often been based on expert evaluation rather than on factual recording. O'Regan and Arvanitis (1966) compared the cost-effectiveness of Bitterlich and circular sampling plots in the estimation of total number of trees and basal area assuming fixed measuring times per tree; Henttonen & Kangas (2015) analysed the effect of plot design (size and type) within a cost-plus-loss analysis to optimise efficiency and assumed 0.5 minutes to check a borderline tree, 0.5 minutes for callipering each tally tree and 4.5 minutes to measure a subsample tree; Berenguer et al. (2015) calculated the time effort for assessing the components of the carbon stock in tropical forests, but costs were not detailed; Westfall et al. (2016) considered the field work efficiency in terms of distances between the plots, i.e. the reduction of time spent travelling between plots by a two stage design, but for the survey of a forested plot (walking from/to the car included) they arbitrarily assumed 5 hours; Tomppo et al. (2017) recorded the time needed for the initial preparation, the tree measurements, the sample tree measurements and the stand-level measurements by the data logger; Habel et al. (2019) assumed a fixed time of 0.5 minutes for measuring each tree in the plot, except those near to the plot edge that would require 1 minute.

The aim of this study was to investigate possible relationships between the time needed for measuring a forest plot and its characteristics using real data, i.e. the time spent for plots measurement as recorded by two crews of the third Italian NFI (INFC2015) entrusted with the survey in the Province of

Trento, North Italy.

Materials and Methods

The Italian NFI is carried out by the Carabinieri Command of the Forestry, Environmental and Agri-food Units, with the scientific and technical contribution of the CREA - Research Centre for Forestry and Wood, Trento, Italy. In the autonomous Regions and Provinces, the survey is carried out by the local forestry service; Trento Province was the sole administration commending the survey to self-employed surveyors. As they were piece rate paid and free to plan their work on their own, without any logistical constrain, the data used in this study are peculiar compared to those from all the other NFI crews and brought potential for in-depth analysis. The two crews were asked to pay special attention to accurately enter the field works starting and ending times, and one of them also recorded the walking time (WT) from the car to the NFI plots, on a voluntary basis. The WT was available for 155 NFI points; the crew had an ordinary car, not an off-road vehicle, so it gives indication on the distance from vehicle accessible roads.

The Italian NFI sampling points: setting up, marking and retrieval

Starting with the second national forest inventory (INFC2005) the Italian NFI adopted a three-phase sampling design for stratification (Fattorini et al. 2006, Fattorini et al. 2011, Gasparini & Floris 2022).

Approximately 301,000 first-phase points were observed from orthophotos to classify the land cover/land use class. A subset of about 30,000 sample points was randomly selected for the second-phase survey, to be carried out in the field.

Second-phase points were located through a GPS navigation procedure (Colle et al. 2009) consisting of reaching an arbitrarily chosen end-navigation point (called F-point) under the best GPS reception conditions, 15-20 meters distance from the NFI sample point (called C-point). F-point was marked by driving a pin into the ground (F-pin). To facilitate future retrieval, one tree (called F-tree) was sprayed with paint, and one aluminium tag was placed under the potential cut section. The following data were recorded (F-info): F-tree species and diameter at breast height (DBH); angle from the F-tree to the F-pin and distance between the two.

The software in use calculated the distance and the angle between the F-point and the theoretical coordinates of the C-point, so that the crews could locate the C-point using a compass and a tape. A "temporary", iron, pin (C-pin) was driven into the ground and two tags were nailed at the base of two trees, facing the C-pin in such a way that the two half lines originating from them would cross right on the C-pin. C was adopted as the centre of a 25 m radius circular plot for the assessment of qualitative variables related to land use-land cover, forest stand attributes, legal status, site conditions, silviculture, forest health; the complete list of the variables assessed is given in Floris et al. (2022). A subset of about 7,000 of the 30,000 second-phase points was selected for the quantitative measurements in the third phase and in an additional supplementary survey on carbon stocks and soils (Rodeghiero et al. 2018).

Third-phase points were reached using GPS navigation, by setting the coordinates of the F-point as the target. There, the search of the F-tree started also with the help of the F-info recorded in the second-phase. The F-pin and C-pin were possibly retrieved using a metal detector. In points falling in forest land, the second-phase C-pin was replaced by a "permanent", aluminium, pin, which is expected to remain buried for many years. The C-point was adopted as the centre of the circular plots used for the quantitative measurements.

The third Italian NFI survey protocol

In the third Italian NFI (INFC2015), the crews visited three kinds of sample points: first-phase points, i.e. points not located on the ground before, reached navigating towards their C-point geographic coordinates; second-phase points, already marked with temporary C-pins in the second NFI; third-phase points, already provided with permanent C-pins. Figure 1 shows the GPS assisted navigation procedure recommended to find the points already established in the field. Photographs of the marks were taken at the end of the marking procedure.

In the third NFI, the assessment of the qualitative variables and the measurements of the quantitative ones were conducted in a single field campaign. Measurements were carried out only in high forests, temporary unstocked areas and plantations (sensu FAO, 2001). In the other vegetation categories, the survey was limited to assessing qualitative variables. In the extreme cases of points in no-forestry use (e.g. land use changed between the second and the third NFI) the crews recorded only few basic information and the survey was very fast to accomplish. Full details on the survey protocol are given in Floris et al. (2022).

Relevant to this article, the protocol requires that before finding at least one mark, both the surveyors work together but after that they are more flexible, although a partially mandatory order is suggested in surveying the variables. The crews start lying out the 25 m radius plot for checking and updating the qualitative data recorded in the past NFI campaign or for carrying out a novel qualitative variables assessment, in case of sample points not surveyed before. Quantitative measurements should start measuring the understorey vegetation, before possible damages to small plants might cause inaccurate measurements. It should proceed laying out the two concentric circles, marking the borderline trees before callipering, and so on. The two crews declared that under specific circumstances the order was changed. On steep and slippery slopes, one surveyor measured any relevant object along an itinerary arbitrarily chosen to limit the walk, to reduce the risk of injuring. In sparse forests, edge trees were not marked; instead, the location of possible borderline trees was checked while callipering. In fact, laying out sample plots of a specific area is clearly time consuming (Spurr 1952). Even in ordinary circumstances, differences may exist between crews. One crew declared that after the pins had been found, one surveyor cared about the markings while the other cored the five trees closest to the plot centre; the surveyors of the

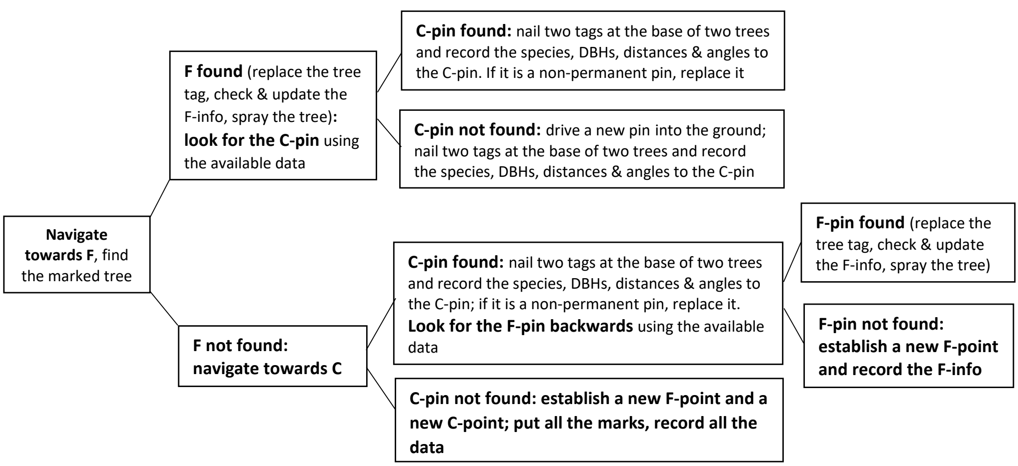

Figure 1 Third Italian NFI procedure for finding and marking the points established in the second NFI.

other crew generally establish the F and C points together.

The callipering is carried out in two concentric circular plots with radius 4 m (trees with DBH $\geq$ 4.5 cm) and 13 m (trees with DBH $\geq$ 9.5 cm). Each tree is classified according to the species, the origin (high tree, coppice shoot, standard) and the integrity-health status. In the case of standing dead trees, data are complemented with the wood decay status, visually assessed. The height of broken trees, either alive or dead, is measured with a Vertex Haglof.

Ten subsample trees are selected to measure total tree and crown base height. These trees are cored with a Pressler increment borer and the last five rings width is measured using a magnifier and a ruler. Rings width measurements can be postponed to the office, but they were accomplished during the plot survey by the two crews considered in this study. Whenever possible, cores are recommended to be at least 15 cm long and one of the largest trees should be cored to the pith; reaching the pith was the most frequent case with our data. The protocol allows a reduced number of subsample trees in plots with a high rate of trees with reduced vitality.

The survey of the understorey woody vegetation consists of counting woody plants higher than 50 cm but with DBH<4.5 cm, in two satellite plots with 2 m radius, 10 m distance from the plot centre Eastward and Westward. Plants are counted by species and dimension class (class1: 50 cm < H < 130 cm; class 2: 0<DBH<2.5 cm; class 3: 2.5≤DBH<4.5 cm). In the event of tangles impossible to access, the counting can be replaced by a conventional code indicating "uncountable". To limit as much as possible uncounted vegetation, that code can be used also for quarters (one, two or three) of a satellite plot while the plants in the remaining quarters are measured. Flexibility is further permitted to push to measure; it includes measuring the plants in a slice of a satellite plot and then multiplying the value by the number of slices similarly crowded.

Stumps with diameter ≥9.5 cm are measured within the 13 m radius plot. Measurements consist of recording the species, two cross sectional diameters, the shortest and the longest height and the decay status. Coarse woody debris (CWD) is measured within the 13 m radius plot. For each piece, two perpendicular diameters are measured at the two end sections as well as the distance between the two sections. Long pieces are ideally divided into fragments no longer than 2 m, or less if irregularly shaped. The species group (conifers or broadleaves) and the decay status are recorded.

Ground roughness (the micro-morphology of the terrain determined by the presence and size of boulders, rocks, ditches, and sinkholes that condition logging operations) is visually assessed in the 25 m radius plot, which is consequently classified as not-rough, rough or very-rough. The slope is measured using a clinometer from the C-point to the 25 m plot ring along two directions, uphill and downhill.

The time recording introduced with the third NFI consists of entering the time before and after the survey in each plot, in the software application for the field data recording. The starting time is entered once in proximity of the NFI plot (about 20 m), after the end of the GPS navigation towards the F-point marked in the past NFI, or in a point suitable for establishing the F-point in sample units not located before. The starting time is mandatory to allow the software to work. The second time is entered once the survey is accomplished; it is mandatory too, since it enables the data sending to the database. By nature, the first time is always correct while the second might not be as accurate as the former, e.g. when the crew forgot to record it and entered it later, based on memory or reconstruction.

The data

The time needed for surveying a plot (ST) was obtained by the two times that the crews recorded before and after the survey; fifteen minutes were deducted when the time spent in a plot was long and crossed the lunch time. For plots with also quantitative measurements, such a time has been named measuring time (MT); thus, the plots provided with a MT are a subset of those provided with a ST. For days with only one plot surveyed, the two recorded times coincided with the day working time (DWT). For days with more plots surveyed, the DWT started with the first time recorded in the first plot and ended with the second time recorded in the last plot visited; it included the transferring time from one plot to the others and, generally, the time for the lunch. DWT does not include neither the driving time to get close to the first plot nor that for driving from the last plot home. DWT was easily calculated for the days with complete plots measurement. In case the workday did not finish completing the survey of a plot (i.e. the survey in the plot was suspended) that day was provided with only the starting time, so the DWT was not computable. However, when the workday finished accomplishing the survey previously suspended in a plot as the second plot measured in the day, both the starting and the ending times were available, and the DWT could be computed. Under these conditions, the DWT was known for 177 days.

For studying the relationship between the MTs and site and vegetation features, only the information from plots measured in a single day were used, because for suspended survey plots the MT included the interruption. Based on this assumption, data were available for 284 plots. The variables considered for their effects on the MT were: F-pin and C-pin finding success; ground roughness and slope; the number of measures for any quantitative variable; for the understorey vegetation, also the number of satellite plots in which it was recorded was considered.

Preliminary analysis

Exploratory data analysis showed that MTs did not meet normality distribution even after transformations. For this reason, the assumptions for parametric tests were checked repeatedly and the following analyses were carried out through parametric or non-parametric tests, as appropriate. All the statistical analysis were run in R (R Core Team 2014). Analysis started assessing whether the MTs of the two crews could be joined in a single sample. The plots were classified as single plot surveyed in the day or according to their order of survey, for days when more plots were surveyed. In case of plots measured after accomplishing the measurements in previously suspended survey plots or before surveying a plot with survey later suspended, we ranked the plot as if the survey in the suspended survey plot had been fully accomplished (i.e. the possible ranks are one, two or three); such conditions occurred 12 times for crew one and 9 times for crew two.

Univariate analysis

Effects of F-pin and C-pin finding success on MT was tested using the data of the 282 NFI sampling points measured both in the 2nd and in the 3rd NFI, that is excluding the two first-phase points. We tested the difference in MTs between plots where the F-pin or the C-pin were found or not through Wilcoxon rank sum test. Then, we classified each NFI point according to the number of pins (one or two) found and tested MTs difference through Kruskal-Wallis Anova. For the Anova, the two first-phase plots were considered as if both the pins were found, that is the most favourable condition, because setting up and marking a new sample unit does not require a long time.

The relationship between MTs and ground roughness was studied comparing the MTs in the three classes through Kruskal-Wallis Anova. The relationship between MTs and slope was assessed plotting the MTs against the slope values, to identify possible trends.

The MTs were plotted against the number of measured DBHs, stumps, CWD (and fragments), tree-heights, subsample trees, broken trees, tree-cores taken, to identify possible trends to test. Some of the listed variables are a subset of others or are somewhat related. For example, broken trees are also among the DBHs and the tree-heights measured, although subsample trees also require the measurement of the crown base height.

The impact of surveying the understorey vegetation was considered in two ways. The first was categorizing the plots by three classes, corresponding to the number of satellite plots where the vegetation was measured, which could range from 0 to 2, and testing the difference through non-parametric Anova. The second way was considering the number of individuals measured. The analyses was limited to the cases of actual measuring and excluded the cases when the counting was replaced by the code “uncountable” in the whole satellite plot, due to thick and impenetrable vegetation; in our data, these events were rare and limited to the first two dimensional classes. The MTs were plotted vs the number of measured individuals to assess possible trends to be further studied.

The plots were classified as fast, medium or long to measure based on the MT tertile and for each class the mean value of any possible explanatory variable above described was computed. The difference between the mean values in the classes was tested with the appropriate statistical test.

As the preliminary analysis showed that the mean MTs differed with the order of the plot surveyed in the day, we tested the difference between the plots measured as the single or the first in a day and those measured as the seconds; these cases occurred 178 and 100 times, respectively. The plots measured as the thirds were excluded from this analysis because the number of observations was limited. This analysis aimed to detect any possible difference between the MTs due to physical tiredness that could slow the measurements, extending the MT of second plots. Ranking the order of the plots measured in the day, all the three kinds of plots (only qualitative variables to be recorded, quantitative measurements carried out, quantitative measurements not completed i.e. suspended survey plots) were considered comparable, assuming that a surveyed plot tires equally, regardless the work done in it. Post-hoc analysis was carried out through non-parametric comparison test.

Regression analysis

The joint effects of the variables investigated on MTs were studied through regression analysis, following a backward approach. Starting with all the quantitative variables, we selected the variables that were significant and minimized the AIC. A maximum variance inflation factor of 5 was stated, as some variables were correlated. The qualitative variables were then added, alone or in combination, as dummies. Interaction was tested at various steps, but it never improved the model, either in terms of consistency or increased rate of explained variance. The analysis was finally repeated on MTs square roots transformed values.

Results

Table 1 shows the number of plots measured, classified by crew and order of the survey in the day; the mean MTs are also given.

Crews one and two measured 141 and 143 plots, respectively. Wilcoxon rank sum test showed that the mean MTs of the two crews are similar (W = 10818, p-value = 0.2875). Two-way Robust Anova (Table 2) showed that MTs

Table 1 Number of plots measured by type (single surveyed in the day, or order of the survey in the day) and mean measuring time (MT, minutes). Statistics are given by crew and total.

	Plot measured in the day									
	Single		1st of 2		2nd of 2		3rd of 3		Total	
	n	MT	n	MT	n	MT	n	MT	n	MT
Crew-one	25	192	56	159	52	145	8	120	141	157
Crew-two	31	172	58	155	52	134	2	126	143	151
All crews	56	181	114	157	104	140	10	121	284	154

Table 2 Two-way robust Anova. Results on the difference between the mean measuring times (MT) of the two crews, the MTs for surveying the first and the second plot in a day, and interactions.

	Degrees of freedom	RD	Mean RD	F	p-value
Crew	1	71.07439	71.07439	2.65349	0.10450
Order of plot surveyed	2	457.29384	228.64692	8.53630	0.00025
Crew x Order of plot surveyed	2	32.74120	16.37060	0.61118	0.54346

did not differ between the crews also when the plot order is considered. Based on these results, the data of the two crews were joined for the following analyses.

Number of pins found

Mean MT was 150 minutes for the plots where the F-pin was found (256 plots) and 191 minutes where it was not (26 plots). The difference between the medians (143 and 180 minutes) was significant (Wilcoxon rank sum test with continuity correction W = 4443, p-value = 0.0049). Mean MT was 152 minutes for plots where the C-pin was found (255 plots) and 165 minutes where it was not (27 plots), and the medians were just the same (144 minutes). In seventeen plots only the F-pin was found while in sixteen plots only the C-pin was found; the mean MTs were 140 and 181 minutes respectively, the medians were 142 and 171 minutes. In 10 plots (3.5%) both the pins were lost. Figure 2a shows some statistics about the MTs for plots based on the number of pins found. The Anova showed that the differences are not significant (Kruskal-Wallis chi-squared = 4.9907, df = 2, p-value = 0.08247).

Terrain features

Most plots laid on no-rough terrain (163 plots). The remaining plots were unevenly distributed between rough (81) and very-rough terrain (40). Figure 2b shows some statistics about the mean MT in the three classes. Both means and medians were close and the Anova confirmed similarity (Kruskal-Wallis chi-squared = 4.1821, df = 2, p-value = 0.1236).

Table 3 shows some statistics on quantitative variables in the plots of different ground roughness; it also shows the percentage of plots where no pins, the F-pin and the C-pin were found. Plots on very-rough terrain experienced more failures in the retrieval of the pins buried into the ground; particularly important is the percentage of cases in which both the pins could not be found (10%). In rough and very-rough terrain, the C-pin got lost more than the F-pin. This is consistent with the freedom of choosing a relatively safe place for F and the constraint to drive the C-pin into the ground at pre-ordered coordinates. Relevant for the MTs, on very-rough terrains less measures were carried out, especially for stumps and woody fragments.

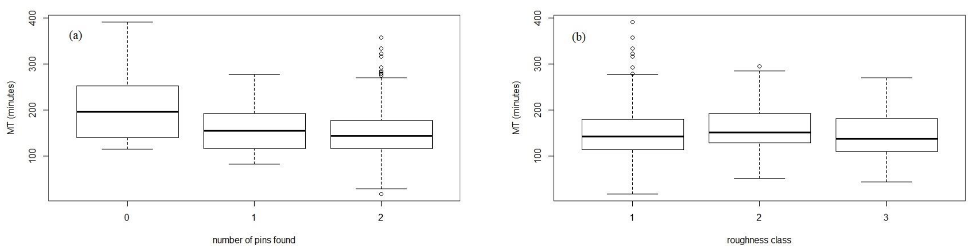

Figure 2 Time needed for measuring plots (MT, minutes) when no, one (F-pin or C-pin) or two pins were found (a), and in the three classes of ground roughness (class 1 = not-rough; 2= rough; 3 = very-rough) (b). The boxes mark the upper and lower quartiles of the data; the inner lines represent the median. The whiskers indicate the lowest and the highest values after excluding the outliers (small circles).

Table 3 Statistics on the number of objects measured for some quantitative variables, percentage of plots with understorey vegetation, slope and pins retrieval success by terrain roughness class.

	Terrain roughness		
	Not-rough (plots n = 163)	Rough (plots n = 81)	Very-rough (plots n = 40)
DBHs (n)	34.9	36.3	31.0
Stumps (n)	6.5	5.2	1.9
Woody fragments (n)	8.5	9.7	5.8
Measured tree-heights (n)	10.6	10.9	10.2
Plots with understorey vegetation (%)	77.9	82.7	75.0
Slope (mean, degrees)	25.0	30.3	32.6
Plots with 0 pins found (%)	3.1	1.2	10.0
Plots with the F-pin found (%)	89.0	95.1	85.0
Plots with the C-pin found (%)	92.6	91.4	75.0

Slope ranged from 0 to 52 degrees; the 70% of plots were on slopes between 20 and 40 degrees and only the 9.5% on slopes of 40 degrees or more. The scatterplot of MTs over the slope values showed that MTs and slope were not correlated (the fitting line was surprisingly flat - data not shown). Yet, scatter plots of slope vs any other measured variable did not show any trend (data not shown). Slope did not affect the possibility to find the pins, since mean slope values for plots that differed in the pin retrieval condition did not follow any trend. Data in table 3 show that slope increased with the roughness class.

Table 4 shows the minimum, mean, median and maximum values of the quantitative variables measured in the plots. It also reports the statistics for the total number of measurements.

Figure 3 shows the MTs plotted against the number of measurements carried out in a plot, for some variables. Figure 3 shows week relationships, if any, between the MTs and the number of measurements. An increasing trend is observable for the number of trees but only up to 20 trees measured. The MT did not increase regularly with the number of tree-heights measured; however, the mean MT for plots with maximum 10 tree-heights measured was 149 minutes (st. dev. = 51.4) while it was 158 minutes (st. dev. = 61.5) for those with

Table 4 Left: main statistics (minimum, mean, median and maximum) for the quantitative variables measured in the plots. Right: mean values of the variables for plots categorised as fast, medium and long to measure.

Variable	Statistics for the plots measured				Mean values for categorised plots		
	Min	Mean	Median	Max	fast	medium	long
Slope (degrees)	1	27.6	29.0	52	27.3a	27.9a	27.6a
DBH (n*)	0	34.8	30.0	115	24.8a	36.9b	42.6c
Stumps (n*)	0	5.5	3.0	76	3.7a	5.4b	7.4b
DWD (n*)	0	6.5	4.0	45	3.2a	7.1b	9.1b
Woody fragments	0	8.5	4.5	61	4.1a	9.5b	11.7b
Measured tree-heights (n*)	0	10.6	10	23	9.1a	11.0b	11.8c
Subsample trees (n)	0	9.3	10.0	10	8.4a	9.7b	9.8c
Broken trees (n)	0	0.0	1.3	13	0.7a	1.2b	2.0c
Tree cores (n)	0	8.2	9.0	10	7.6a	8.7b	8.4ab
Understorey woody plants (n)	0	16.3	7.0	109	12.8a	11.4a	18.6a
Total measurements (n)	2	57.3	53.5	140	40.8a	60.3b	70.8c

Note: (*) variables summed up for computing the total measurements number. Letters (a, b, c) show the statistical differences tested thought the Kruskal-Wallis Anova and the post hoc pairwise Wilcox test.

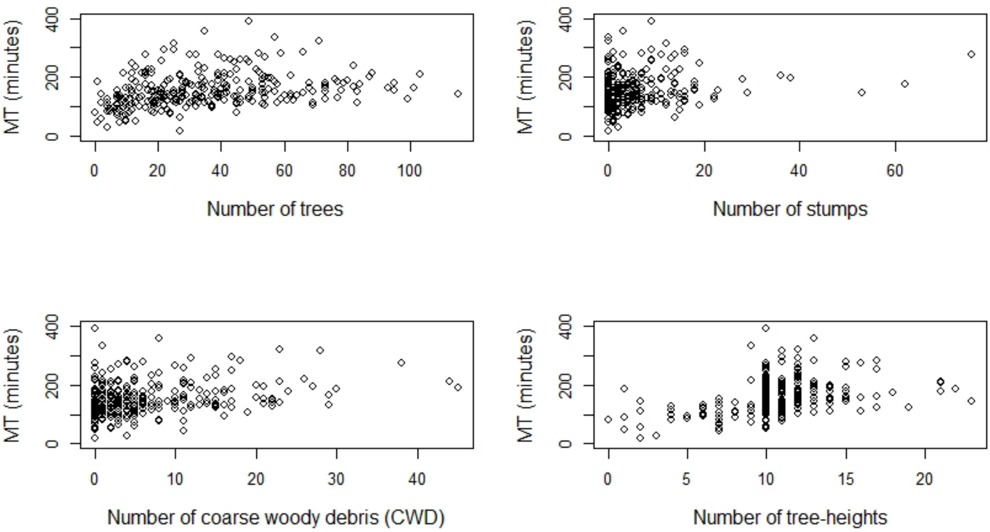

Figure 3 MTs plotted against the number of callipered trees and measured stumps, coarse woody debris (CWD), tree-heights.

more than 10 tree-heights recorded. Possible additional graphics (MTs vs number of: woody fragments, cored trees, understorey individuals, total measurements) are not given because they did not provide further information.

Figure 4a shows some statistics on the MTs in NFI plots with no understorey woody vegetation or with vegetation to measure in one or two satellite plots. The mean MT was 135 minutes in NFI units with no understorey vegetation and 159 minutes in units with understorey vegetation either in one or two satellite plots; the medians were 135, 145 and 147 minutes, respectively. Kruskal-Wallis Anova confirmed that what makes the difference is the presence/absence of understorey vegetation (chi-squared = 6.8715, df = 2, p-value = 0.0322) while, in terms of MT, it is unimportant if small plats have to be measured in only one or in both the satellite plots. However, MTs variability increased in the NFI sample units where understorey vegetation was present in two satellite plots compared to those where it was measured in only one plot.

Plot categorization

The statistics for the variables studied by the three measurement speed classes are shown in Table 4. The categorization corroborated some results of the univariate analysis and showed some further trends. Slope had similar mean value in the three classes, remaining unimportant in explaining the MT. The only other variable with similar values in the three classes was the number of understorey individuals; this supports the finding that presence/absence is more important than the number of subjects. For all the other variables, the categorization suggested that the number of elements to measure affects the MTs, despite the lack of notable trends in figure 3. In fact, the increase of the mean number of total measurements carried out increased significantly across the plots fast, medium and long to measure. Tree-height measurements also showed significant differences between all the three classes; the same is true for the two other variables strongly correlated, i.e. the number of subsample trees and that of broken trees.

Plot order

Wilcoxon rank sum test showed that the MT median of the plots measured as first in a day significantly differed from that of plots measured as seconds (W = 11418, p-value = 9.067e-05). The medians were 154 and 131 respectively, indicating that it took longer to measure one or the first plot than a second. The mean MTs were 164 and 138 minutes, respectively; the median and the mean for the third plots were 111.5 and 116.0 minutes, respectively. To explain this result, we calculated the mean values of the quantitative variables for the plots categorized according to the order of measurements. The data are shown in Table 5.

Table 5 shows decreasing numbers of mean values for all the measured variables going from the class single or first plot measured to the class second plot measured; this occurrence explains, at least in part, the decreasing MTs. Focussing the analysis on the days with only one plot measured (mean MT = 173 minutes; median = 157 minutes) and those with two plots measured (1st plot mean MT = 152 minutes, median = 149 minutes; 2nd plot mean MT = 140 minutes, median = 131 minutes) has revealed that the mean MTs of plots measured as single vs first in the day differed by 21 minutes, and MTs of the two plots measured in a same day were confirmed to decrease, although the difference got closer and reduced from 26 to 12 minutes.

Regression analysis

Pearson chi-square normality test showed that replacing the MTs observations by their square root values distribution got closer to normality (P = 27.69, p-value = 0.04869). The regression was thus run on the squared values of the dependent variable. The model obtained was as follows:

$$MT^2 = a_0 + b_1\ nDBH + b_2\ nTreeHeights + b_3\ nStumps + b_4 nDeadwoodFragments + d_1\ OnePinFound + d_2 TwoPinsFound + d_3\ OneSatelliteplotUnderstoreyVeg + d_4\ TwoSatelliteplotsUnderstoreyVeg + d_5\ SecondPlotMeasured$$

where a_0, b_1, b_2, b_3 and b_4 are the parameters under estimation for the quantitative variables (number - n - of measurements taken for each); d1, d2 and d3 are the parameters under estimation for the dummy variables accounting for the levels of the qualitative variables. Table 6 shows the parameter estimates of the multiple linear regression model and related statistics (standard error, standard coefficients, t-value and p-value). Residual standard error = 1.887 on 264 degrees of freedom; adjusted R-squared: 0.33; F-statistic: 16.05 on 9 and 264 DF, p-value: < 2.2e-16.

The results in table 6 are interesting for several reasons. Variability was explained by explicitly considering some measured variables, suggesting that what matters is not simply the total number of measurements

Table 5 Mean number of measurements, by variable and total, per plots categorized as the single or first measured in the day, or their order (second and third).

	Single or first plot measured in the day	Second plot measured in the day	Third plot measured in the day
DBH (n)	36.3	31.8	38.5
Tree heights (n)	10.7	10.3	12.7
Stump (n)	6.1	5.0	4.0
CWD (n)	6.9	5.7	4.0
Deadwood fragments (n)	9.0	7.7	5.8
Total measurements (n)	59.9	52.4	59.2
Plots with two pins found (%)	86.0	85.0	50.0
Plots with understorey vegetation in both the satellite plots (%)	50.6	45.0	33.3

Table 6 Parameter estimates of the multiple linear regression model and related statistics.

Parameter	Estimate	Std.error	Std.coefficient	t-value	p-value
a_1	10.841177	0.732832	0.000000	14.793545	1.7752E-36
b_1	0.018379	0.006185	0.185196	2.971577	3.2359E-03
b_2	0.216664	0.046788	0.293258	4.630796	5.7219E-06
b_3	0.045322	0.013447	0.170412	3.370431	8.6271E-04
b_4	0.037146	0.011690	0.166565	3.177581	1.6618E-03
d_1	-1.858704	0.703320	-0.248145	-2.642757	8.7148E-03
d_2	-2.590439	0.623234	-0.392783	-4.156446	4.3717E-05
d_3	0.730147	0.327569	0.146576	2.228987	2.6657E-02
d_4	0.719993	0.304292	0.156125	2.366129	1.8698E-02
d_5	-0.643444	0.239644	-0.135508	-2.685004	7.7121E-03

taken, a variable not selected among the explanatories. Yet, both the finding of the F-pin or the C-pin tested as dummy variables during the step procedure were not significant (data not shown) while it is the number of pins found. The standard coefficients show that the retrieval of both the pins is the most influential event affecting the MT but also the finding of only one pin is important (third value in decreasing order). The number of tree-heights measured is the most influential quantitative variable, second in the general order of importance. The impact of all the other quantitative variables is similar, as showed by their regression standard coefficients. Lastly, the understorey vegetation lengthens the survey and what matters is its presence rather than the number of individuals measured. The regression detected the effect of measuring a second plot in the day in reducing the MT, a result which, to some extent might depend on the data in hand but which holds food for thoughts of general validity.

Day working time

Figure 4b shows some statistics about the DWT. DWTs ranged from 14 to 598 minutes. On average, the crews worked 322 minutes, but the median was 349 minutes. As expected, DWT increased consistently when more than one plot was measured. Interestingly, it was rather independent on how many plots were measured after the first one, and whether the

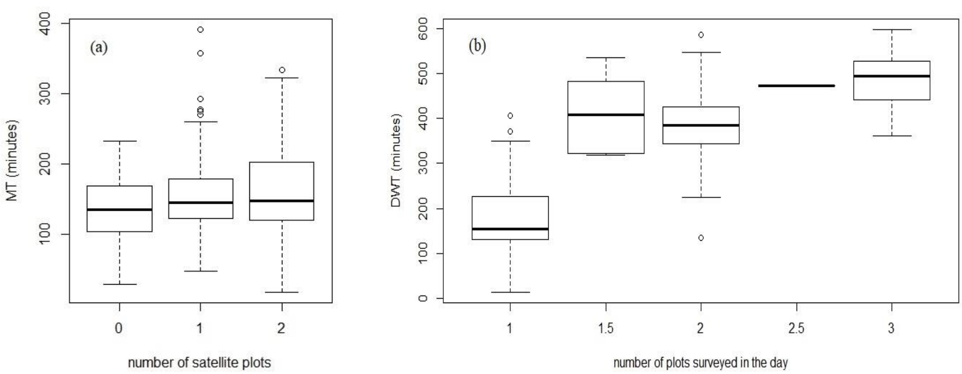

Figure 4 Boxplots of MTs (minutes) for NFI plots with no understorey vegetation or presence in one or the two satellite plots (a), and of the day working time (DWT, minutes) for different numbers of NFI plots measured in a same day (b). The boxes mark the upper and lower quartiles of the data; the inner lines represent the median. The whiskers indicate the lowest and the highest values after excluding the outliers (small circles).

following had already been partially measured (suspended survey plots) or not, showing that the travelling and walking times have a major importance.

Walking time

The mean WT from the car to the plot was 15 minutes; the 50% of the plots were reached within 21 minutes (median), while the most 25% demanding required from 30 to 120 minutes walking. The statistics on the WTs can be assumed valid also for the other crew since the road net is rather uniform across the province (Pedrolli 1989) and both crews had an ordinary car. There was not any relationship between the WTs with the DWTs. More relevant for our analysis, any relationship was detected between the WT and the MT (data not shown).

Discussion

The data used for this study are particularly valuable for several reasons. The time needed for measuring forest plots also depends on the measurers (Vastaranta 2009). In our case, not only the two crews performed similarly, but the plots they measured had been surveyed in the second NFI by a single crew. For this reason, the two crews checked qualitative data and used information (e.g., F-info) of same accuracy, which lets us assume comparable efforts and times to validate/update pre-existing data and to find the marks and pins. Being free from any constrain due to office directives (e.g. limited extra work per day, mandatory breaks, departure and arrival from/to the office) they could work rather long in a number of days sufficient to have data for comparing MTs of plots measured as first or second in the day. Surveying two plots per day was also possible thanks to the good network of forestry roads in the province, as stated by the limited WTs. Both crews measured the DBH increment in the field, which is relevant for the accuracy of the MTs. One crew recorded the WTs, a variable not recorded by any other NFI crew. Finally, these were the only two crews being piece rate paid, a condition that favours efficiency in working times.

The analysis started under some expectations. One was based on the common sense that the more you do the longer it takes. The time needed for measuring depends on the workload or the intensity of fieldwork (Molinier et al. 2016; McRoberts et al. 2015). In the literature cited throughout the text, fieldwork intensity was generally expressed by the number of trees measured or the plot size as a proxy of it (e.g., O'Regan & Aryanitis 1966; Zeide 1980). However, field surveys often address measuring several variables. The regression analysis showed that the number of variables surveyed matters, since they explained the MT by an additive effect. This advises that the total amount of measurements taken within a complex field protocol might not appropriately represent the overall workload of field surveys.

Another expectation was that difficult conditions, caused for example by steep and rough terrain, lengthen the MT. The topographic conditions and the terrain features have been indicated affecting the primary sampling costs (Van Laars & Akça 2007, McRoberts et al. 2015). It was not detected any clear relationship between MTs and slope but slope might have slowed the measuring indirectly, because steepness is a cause of soil instability, that may make it difficult or impossible to find the pins, and it is often a concurrent cause of terrain roughness, which was shown to stand reduced success in pins retrieval. It is difficult to assess if and to what extent roughness was influential itself because the balance between the gain due to the reduced number of measurements and the time-consumption for finding or establishing new F and C-points is unknown. Considering the major role of the pins' retrieval success on the MT, it is maybe possible to infer that roughness should not necessarily be considered a cause of longer MTs when the field protocol does not require the finding of previously buried marks. Such conclusion is valuable for its practical implications in case of temporary plots. Marking permanently a sample plot is needed to be able to find it in a future inventory (Düggelin et al. 2019). The regression equation showed that success in finding the pins reduced the MT. Yet, the univariate analysis suggested that F is the most important mark, and this is consistent with the aim itself for it was designed. This study demonstrated the importance of carefully marking NFI plots also to increase the probability of fasten future survey. In this respect, it stimulates testing improved protocols to mark NFI units laying on unstable grounds and rocky slopes, where the pin retrieval is unlikely (surveyors' personal communication).

The number of tree-heights measured was the second most relevant variable. This variable includes the number of subsample trees and that of the broken ones. The third Italian NFI enlarged the number of subsample trees compared with the second NFI, when such number could vary from five to ten (Gasparini et al. 2017, Floris et al. 2022). Such a change was long discussed at the time of the protocol finalization because it was expected to lengthen the MTs, especially due to the tree coring. The analysis could not fully discover the impact of the increased number because the two crews sampled always the maximum required, as stated by the mean subsample trees number of 9.3 in table 4, thus the variation was mainly due to the less stable number of broken trees. Presence of understorey vegetation was expected to extend the MT. Although the flexibility allowed by the survey protocol to avoid fully enumeration in exceptionally crowded subplots might have partially affected the influence of the understorey vegetation plants number on the MT, the importance of simply the presence of understorey vegetation in the satellite plots is meaningful. Presence of small plants implies setting up the satellite plots and the time needed for this is maybe not negligible compared to that for counting the plants, also because setting up the satellite plots required the cooperation of both the surveyors. The regression model suggested that presence in one or two satellite plots made little difference. In this respect, presence of understorey vegetation may slow the survey not only by increasing the workload but also making it difficult to walk across the plot and measuring stumps and coarse woody debris.

The second plot MTs were shorter that the firsts' but they were also marked by less objects to measure. Interestingly, when a second plot was measured in the day, also the MT of the first was shorter. This finding may have different explanations. One is that when the first plot took longer than expected, the crew did not move to a second plot. Another is that when a crew considered measuring a second plot in the day feasible, it worked more rapidly. However, the decision to measure a second plot also depends on the distance, the weather changing but also on reasons external to the job. Of general validity, the results allow to exclude tiredness or hasten effects that may speed or slow down the measurements in a second plot, which seems particularly worth of mention considering that NFI protocols are nowadays rather demanding. Lack of relationships between the WT and the MT confirms absence of considerable tiredness effect. Hence, such a conclusion is valuable also for other forest surveys prescribing measuring many variables.

The regression model produced sounds results. It is also noteworthy that the variance explained was limited and this might have disclosed inherent limits of studies on MTs. For example, addressed research based on timing each operation might provide suitable data to assess the importance of specific variables measurement and reveal possible interactions among them. However, variables are rarely measured one after another as in an exercise. Adaptations to specific circumstances is common in the practice. Adaptations occurred especially in difficult/ demanding circumstances, which may represent a considerable percentage of cases in extensive field campaigns. Considering our data, the most demanding 25% plots took from over 417 minutes to be measured. For this reason, while it remains unknown how much variance could be further explained by addressed research based on timing operations, the blind and unpredictable adaptations to the real conditions make uncertain the effective inference of the results of such studies to practical applications. This brings into question if a high rate of variance is explainable in data collected from complex protocols and extensive campaigns. Under the hypothesis of a naturally limited rate of explainable variance, to be confirmed by future studies, the value of analysis based on representative data is mainly in the consistency of the results. Our results may well complement the findings of simplified exercises based on simulated forest plot data, which considered few variables and fixed/standard MTs. In fact, the effective transferability of simplified studies results to practice stands the same considerations made for possible exercises carried out recording separately the MTs for each variable. In this respect, it is worth noticing that this study made use of data that cover the range of variation occurring across forests of an Alpine province, recorded by crews each with two surveyors. This study did not research the importance of stand structure, a variable that is thought to affect the MT (Vastaranta et al. 2009), because the categorization would have produced classes with few observations.

One undiscussed theme in the article is the importance of the availability of data collected over wide areas and statistically representative of forests, besides their utility for the NFI process and other hopefully harmonised/integrated programmes. NFIs data are more and more used in the research and evaluating their potential for further use increases the usefulness of their availability (e.g. Bosela et al. 2016). For this reason, still pursing efficiency, the costs for the field survey should not necessarily discourage adoption of protocols that are not minimal and which are strictly limited to the data whose use is already foreseen.

Conclusions

Costs for measuring plots are well known to be a relevant part of the overall expense of forest monitoring programs. Measuring time as a proxy of costs allows easer comparison between different economies and avoids adoption of cost items, which are often based on assumptions that brings uncertainties or have limited value in time. So far, the assessment of measuring times has generally been founded on studies that adopted simplifications such as fixed times for carrying out stated operations, and has been limited to the measuring of few variables basically based on the tally trees, i.e. the basal area, the volume or the number of trees per hectare. However, monitoring programmes, like for example the national forest inventories, generally record data on many variables, including deadwood, regeneration, and tree growth, so that the adoption of fixed times is a simplification that may severely impact the results. This article analysed the measuring times under a real and complex field protocol and made use of data that cover the range of variation occurring across forests of an Alpine province. The results obtained confirm the impact of the workload but also show that workload is also due to the number of variables measured and not only to the number of the items measured. Predictability of the measuring times in extensive field survey campaign is discussed because the factors that play a role in fastening or lengthening the field measurements are complex and interact also with the crews' ability to adapt case-by-case, a variable unpredictable and difficult to include in any model. On the other hand, if predictability under real circumstances is limited by nature, also the inference of the studies based on simulated data and few variables to practical applications should be reconsidered. In this perspective, studies like this, consistent in the results, well complement those founded on substantial simplifications, since together they may allow building sound reasoning.

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