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Testing field methods for assessing forest protective functions for soil and water

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Abstract

Forests play a significant role in soil and water protection. Sustainable forest management in addition to other benefits contributed to sediment-related disaster resilience and water security. Although it is recognized that forest, specially the floor cover, protects the soil from degradation and erosion and enhances purification of water, there are not many studies on how forest protects soil and/or water. Besides, there is a lack of assessment, documentation and reporting methodologies and field practices in this subject. With a view to fill this gap, the Food and Agriculture Organization in collaboration with the Government of Japan has tested and evaluated four different methods for assessing forest protective functions in order to identify a scientifically sound, economically feasible and practical method for implementation. The four tested methods are *visual floor cover assessment*; *forest canopy and floor cover assessment*; *line-point transect forest cover assessment*; and *forest floor biomass assessment* methods. Field tests were carried out to cover a wide variety of forest in Mexico, Nepal and Vietnam during the summer of 2014. Data on erosion evidences, forest cover parameters, information on the time for data collection and the expenditures incurred for field tests were gathered and analysed. Analysis of variance of forest cover and time taken to collect the data demonstrated that the line-point transect forest cover assessment method was the most reliable and least time consuming at $\alpha = 0.05$; and the cheapest with only 13 percent of the total running cost of all the methods. Therefore, this method was further modified and improved into *line-point transect forest cover and erosion assessment method* which now is inclusive of forest cover and soil erosion evidences as an indicator of soil and water protective function of forest.

Keywords: [national inventories, sustainable forest management, evidence-based policy, water security, proxy indicator for protective functions, digital picture analysis]

Introduction, scope and main objectives

The protective function of forest is one of the seven thematic elements of sustainable forest management identified by the United Nations Forum on Forests (UNFF). Soil and water protection is one of the most significant contributions of forest (FAO, 2008; Neary, Ice and Jackson, 2009). Trees, forest litter and undergrowth maintain high-quality water through reduction of erosion and filtering of pollutants. By limiting runoff and ensuring predominantly subsurface flows, forest help moderate peak flows and prolong base flows. Conversely, removal of trees leads to increased risk of flooding and drought.

The Global Forest Resources Assessment 2010 (FRA 2010) (FAO, 2010) reported that 330 million hectares of forest are primarily designated for protective functions, including soil and water conservation, avalanche control, sand dune stabilization, desertification control and coastal protection. This area increased by 59 million hectares or 8 percent, between 1990 and 2010, primarily owing to large-scale plantation in China. Regional differences were notable and are due to differences in reporting and defining criteria for evaluating this function (FAO, 2010).

In seeking to assess the soil and water protective function, the question is not only how to collect the information, but which information to collect. In the past, most methodology focused on measuring canopy cover (Robards *et al*., 2000). Recognizing the role of understorey vegetation and forest floor cover in soil and water protection, Suchar and Crookston (2010) studied the understorey cover and biomass indices as potential indicators of the soil and water protective function of forest. There were no known studies, however, on the measurement of understorey vegetation for assessing these functions of forests.

To improve data collection and reporting to FRA and national inventories, with the ultimate aim of better evidence-based decision- and policy-making, FAO developed this study "Improved Information to Promote Forest Management for Protection of Soil and Water". Implemented with the support and cooperation of the Forest Agency of Japan (FAJ), the study sought to identify an easy, low-cost forest floor cover data collection method useful for developing countries in assessing the soil and water protective function of forests. This method would provide the basis for guiding developing countries on planning and conducting measurements in forest areas intended for soil and water resource protection.

Methodology/approach

The study compared four methods for gathering data relevant to soil and water protective function (Table 1):

Table 1 Summary of methods

Method	Key elements	Variables	Equipment/supplies required
1. Visual forest floor cover assessment	Visual judgment and photographs for verification	Floor cover (%) Boulders and rocks (%) Erosion evidence (%)	Clinometer Measuring pole Measuring tape
2. Forest canopy and floor cover assessment	High resolution satellite images, canopy structure from the ground Forest floor pictures	Canopy (%) Canopy development class Species composition Point sampling of volume Forest floor cover (%)	High resolution satellite images Sampling for volume Prism or angle gauge Forest floor digital photographs OpenForis software (provided by FAO)
3. Line-point transect forest cover assessment	GRS Densitometer™	Overstorey and understorey forest cover	GRS Densitometer™
4. Forest floor cover biomass assessment	Quadrat sampling	Forest cover (%) Litter, dead material, debris Biomass	Frame for measuring Weighting scales Bags GRS Densitometer™ Tripod

Each method was tested on multiple sites in three countries – Mexico, Nepal and Viet Nam. The term "site" refers here to the general location for the field test. Each site was defined as an area of approximately 2 500 ha. Each collaborating organization selected sites based on the following attributes. Sites should:

• be forest designated for soil and water protection;

• be covered under national forest inventory, with adequate descriptive data available including soil type, vegetation type, dominant species list and general forest structure;

• be easily accessible by those conducting the field test, e.g. close to a road and to the offices of field staff;
• have an array of understorey densities, ideally ranging from sparse to dense forest floor cover;
• be covered by existing high resolution satellite.

Within the sites, 20 m × 20 m plots were established for the measurements. All four methods were tested on the same plots. For ease of comparison and evaluation we used uniform formats for data collection in all countries. Data were collected on 50 plots each in Nepal and Viet Nam and 150 plots in Mexico. The methods were assessed on the basis of two main criteria: reliability and cost.

• Reliability was measured through a statistical analysis comparing the consistency of results using the different methods.
• Cost was calculated to include time spent by personnel (organized by general staff category) and other direct costs (e.g. materials, travel, training).

Setup of field survey plots

Plots were established measuring 20 m × 20 m, and the time taken to establish each plot was recorded. For each plot, the centre point (C) (Figure 1) was determined with the aid of a hand-held GPS receiver or camera with GPS receiver, and the longitude and latitude were recorded.

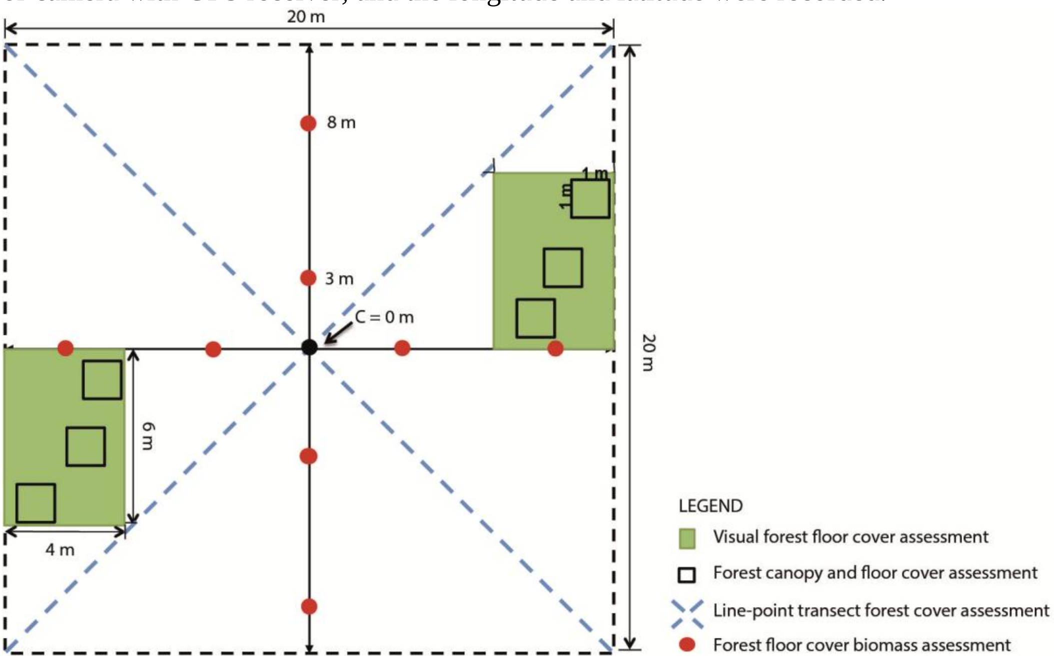

Figure 1. Layout of 20 m × 20 m plot showing sampling for all four methods

Method 1. Visual forest floor cover assessment

Two orthogonal lines were established to ensure a constant sampling area on all survey plots 10 m east and west and 10 m north and south from the centre (C). Table 2 was used for any slope distance corrections. The number of rills or gullies and any other traces of erosion such as soil pillars were immediately recorded and photographed along these two lines, before conducting any other data collection which could alter such traces. For visual assessment of floor cover, two 4 m × 6 m subplots were set up at 6 m east and west from C using a compass and a measuring tape. If this was not feasible, the subplots were located at 6 m north and south from the centre.

Visual assessment was adopted from FAJ (2011) and used to estimate the forest floor cover such as, the percentage of vegetative cover (understorey up to 80 cm tall), boulder, rock and litter cover.

Method 2. Forest canopy and floor cover assessment

Two types of data were compared in this method: very high resolution (VHR) satellite images and ground data. The method compared two variables from both data sources: canopy cover and forest floor cover. FAO trained country personnel in processing of the imagery.

Table 2 Conversion of distances for line and subplot measurements

Inclination (°)	Distance (m)			
	4.0	6.0	10.0	20.0
0-5	4.0	6.0	10.0	20.0
5-10	4.0	6.1	10.1	20.2
11-15	4.1	6.1	10.2	20.5
15-20	4.2	6.3	10.5	21.0
21-25	4.3	6.5	10.8	21.6
26-30	4.5	6.8	11.3	22.5
31-35	4.7	7.1	11.9	23.7
36-40	5.0	7.6	12.6	25.2
>40	Stop survey for your safety			

Satellite imagery

The method used VHR imagery from two satellites, QuickBird and WorldView. The products covered all sites and had the following characteristics: 0.5 m spatial resolution, 25 km^2 square zones centred on the sites, 0 percent cloud cover and four spectral bands (blue, green, red and infrared). Canopy cover was derived from this imagery.

Image processing utilities from the Open Foris Geospatial Toolkit (OFGT) library were used to extract information from the satellite imagery. FAO's Open Foris Initiative develops, shares and supports software free and open source tools and methods for multipurpose forest assessment and monitoring (available at www.openforis.org). The working environment for the image processing tools is a Linux-based operating system (OS – a specific description can be found on the OFGT wiki). During the training sessions, participants used live USB sticks (i.e. bootable flash drives) equipped with Xubuntu 14.04 and customized with specific tools from the Geospatial Data Abstraction Library (GDAL), OFGT, the R Project for Statistical Computing, and Quantum Geographic Information Systems (QGIS).

Ground data

The ground digital photographs were taken during field trips. A 1 m × 1 m pre-prepared polyvinyl chloride (PVC) frame was placed to mark out each subplot, two subplots per plot as shown in Figure 1. The photographs were taken from directly above each frame, as vertically downwards as possible to avoid distortion. These photographs were later cropped to match the PVC frame and analysed digitally to determine the floor cover (FCP).

Three photographs per subplot were taken and referenced during the field campaigns, representing a database of at least 300 ground pictures for 50 plots, each associated with a unique ID.

The free software SamplePoint® (Booth, Cox and Berryman, 2006) was used to analyse the ground pictures (available at www.samplepoint.org). SamplePoint® provides a single-pixel sample point and the ability to view and identify the pixel context. It allows rapid measurements from image data with accuracy comparable to the most accurate field methods for ground-cover measurements. Expert use of the program requires minimal training.

Method 3. Line-point transect forest cover assessment

In line-point transect assessment the field technician tallied the vegetation or other landscape features at different points along a transect. This method used a GRS DensitometerTM, available from Geographic Resource Solutions (GRS), to measure forest cover. The densitometer readings were taken by beginning at one corner of the plot and walking from one corner to the other, stopping every step (Figure 1). The densitometer was used to determine whether the canopy reading was open sky or leaf/vegetation, and whether the ground reading was vegetation or other (e.g. bare soil, rocks, litter, moss). Along each diagonal line 30 readings were taken.

To prevent data error, it was important to adjust the densitometer to a horizontal position for each and every reading. A team of two readers and one recorder was recommended for swift data collection.

Method 4. Forest floor cover biomass assessment

Herbaceous vegetation up to 80 cm tall was cut at the base and weighed. Vegetation was measured in small areas referred to as “clip plots”. The average weight of herbaceous vegetation within the land use area was then extrapolated based on the average biomass found within the areas sampled.

The first step was to create clip plot frames which could be made of various materials and could be circular or rectangular in shape. A 50 cm × 50 cm clip plot frame made of PVC pipe was recommended. A hanging field scale was calibrated at the base camp prior to field sampling. In each 20 m × 20 m plot, eight clip plots were distributed along the two transecting 20 m lines as shown in Figure 1, at 3 m and 8 m from the centre. The clip plots were created by dropping the clip plot frame from a position parallel to the ground.

The herbaceous vegetation removed from each clip plot was placed in a subsample bag, weighed and recorded, subtracting the weight of an empty subsample bag to the results. Then the subsamples from all clip plots were combined, and 100 to 300 g of this material was placed in a sample bag for further analysis. This composite sample was weighed and recorded and the sample bag was labelled with the plot identification number and weight. The composite samples were taken to the laboratory and dried until a constant weight was reached (i.e. the dry weight). The ratio of wet weight to dry weight was calculated for these samples. This ratio was then used to estimate the total dry weight of non-woody vegetation found within the clip plots.

The same steps were repeated for the litter layer. Litter was defined as all dead organic surface material on top of the mineral soil. It includes some still-recognizable material (dead leaves, twigs, dead grasses, small branches, including dead wood with a diameter of less than 10 cm) and some unidentifiable decomposed fragments of organic material.

Results and discussions

Ranking the methods

Table 3 Analysis of variance (ANOVA) for forest floor cover in all three pilot countries (α = 0.05)

Method	Count	Mean	Variance	Connecting letter
Visual floor cover assessment	255	81.80	417.80	C
Forest canopy and floor cover assessment	255	89.02	245.06	B
Line-point transect forest cover assessment	255	91.97	154.27	A

The statistical reliability of floor cover measurements and the cost (including time) were compared to identify the best method for data collection. Analysis of variance (ANOVA), analysing the differences in group means among the forest floor cover data for all plots in all three countries, was carried out for the first three methods. Since Method 4 measured biomass only, it could not be compared with the other methods in this respect. The analysis revealed that Methods 1 to 3 were significantly different in the consistency of the data collected, as indicated by the three different connecting letters A, B and C. The forest floor cover data collected by Method 3 was the most consistent; the data sampled at various points deviated less from the mean than those collected using the other two methods, especially Method 1 (Table 3).

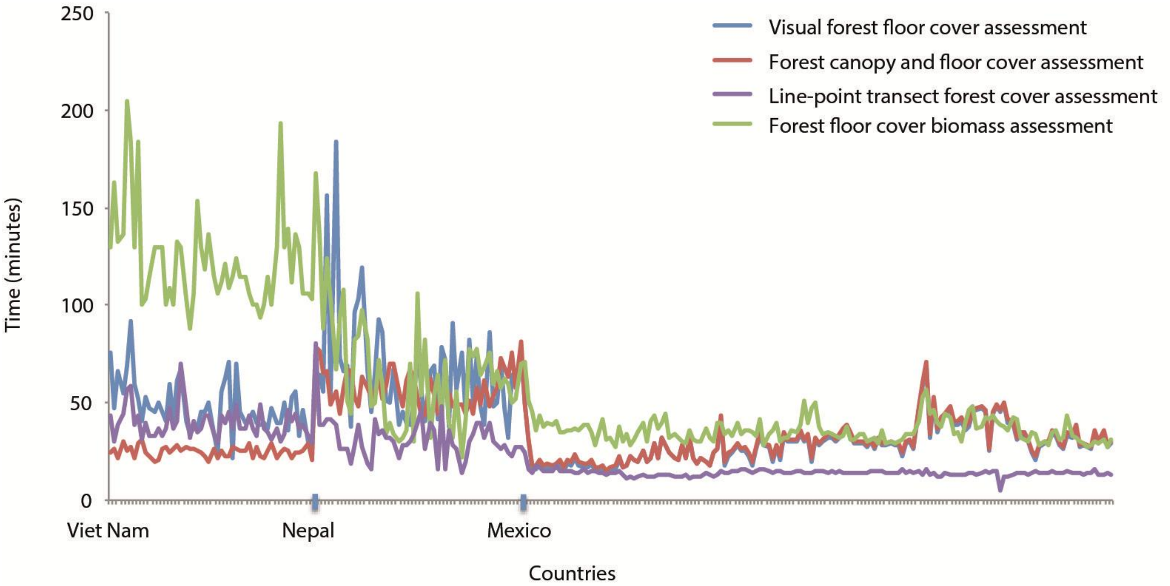

Figure 2 Data collection time for each method

Table 4 Analysis of variance (ANOVA) for data collection time among all four methods (α = 0.05)

Method	Count	Mean	Variance	Connecting letter
Visual floor cover assessment	255	40.36	485.09	A
Forest canopy and floor cover assessment	255	34.64	219.81	B
Line-point transect forest cover assessment	255	22.88	156.10	D
Forest floor cover biomass assessment	255	59.95	1 489.85	C

Information on time spent in all data collection activities was invaluable in ascertaining which of the method(s) was most cost effective and worthy of scientific application for future studies. The results (Figure 2 and Table 4) show not only that the different methods took different amounts of time, but also that the time varied among the countries. In all three countries Method 4, forest floor cover biomass assessment, required the most time and Method 3, line-point transect forest cover assessment, required the least time.

Figure 3 shows the main costs involved in collecting data for each method and travelling to the field. The running costs were highest for Method 4, forest floor cover biomass assessment, and lowest for Method 3, line-point transect forest cover assessment. The costs of travel to the field were higher than the running costs.

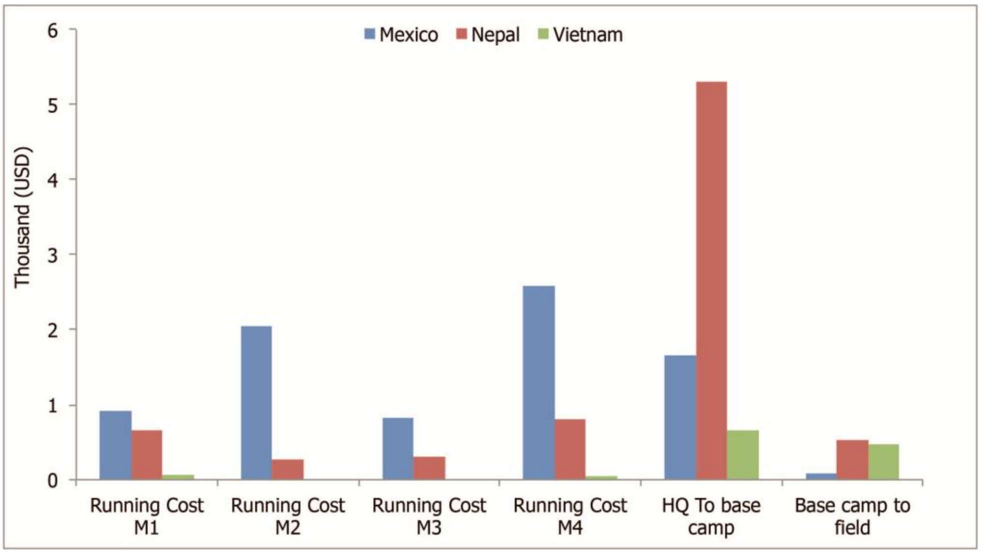

Figure 3 Partial expenses incurred during the project (M = method; HQ = headquarters)

The advantages and disadvantages of each method (FAO, 2015b) were compared during an international workshop attended by the pilot countries. The participants noted that Method 3, line-point transect forest cover assessment, was the easiest to perform in the field whereas Method 4, Forest floor cover biomass assessment, was tedious. They also mentioned that Method 1, Visual forest floor cover assessment, needed experienced personnel to judge the percent cover because the method is not mechanical.

Based on the above statistical results and the discussion during the workshop, it was concluded that Method 3, the line-point transect method, was the best among the four methods tested in the field. However, as this method was not capturing erosion evidences, it was adjusted to include them. In addition to recording the canopy and ground cover, this method also recorded the presence of soil pillars, the number of rills and gullies present along the lines and their width and depth together with the general slope of the sampling site. The resultant "line-point transect forest cover and erosion assessment" method (FAO, 2015c) is recommended for gathering data that can serve as a proxy indicator for the soil and water protective function of forest.

Conclusions/outlook

This study tested four methods for collecting data on the soil and water protective function of forests. The line-point transect forest cover assessment method proved to be the most accurate, least expensive and easiest to apply among the four methods tested. This method is scientifically accurate and records forest canopy and floor cover by using the GRS DensitometerTM, an instrument which is small, light, easy to carry and comparatively cost efficient.

Therefore, after extensive discussion with the country coordinators of the field study, based on the data results, the line-point transect forest cover assessment method was adjusted to incorporate erosion evidence. The resulting line-point transect forest cover and erosion assessment method is recommended for use in developing countries to enhance data collection and reporting on forest protective function for FRA and national inventories.

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References

Booth D.T., Cox, S.e. & Berryman, R.D, 2006. Point sampling digital imagery with 'SamplePoint'. *Environmental Monitoring and Assessment*, 123: 97–108.

Booth, Cox, S.e. and Berryman, R.D, 2006. SamplePoint®, available at www.samplepoint.org [accessed 10.03.2015].

FAO, 2008. Forests and water, *FAO Forestry Paper 155*. Rome.

FAO, 2010. Global Forest Resources Assessment 2010 – Main report. Rome.

FAO, 2012. FRA terms and definitions, *Forest Resources Assessment Working Paper 180*. Available at: www.fao.org/docrep/017/ap862e/ap862e00.pdf [accessed 10.03.2015].

FAO, Open Foris Geospatial Toolkit (OFGT) library, available at www.openforis.org [accessed 10.03.2015].

FAO, 2015a, n.d. Harmonized World Soil Database, Version 1.2. Rome. Available at: http://www.fao.org/soils-portal/en/ [accessed 10.03.2015].

FAO, 2015b. Testing field method for assessing the forest protective function for soil and water, *Forest Resources Assessment Working Paper 185*. Available at: http://www.fao.org/forestry/fra/88988/en/ or http://www.fao.org/forestry/42707-0fac19370cbfa3f0ffbd50857fc6591ae.pdf [accessed 10.03.2015].

FAO, 2015c. Field guide for rapid assessment of forest protective function for soil and water. Rome. Available at: http://www.fao.org/forestry/fra/88988/en/ or http://www.fao.org/forestry/42705-09aa51f8e88decbf94687b3dfd30aa051.pdf [accessed 10.03.2015].

Forest Agency of Japan (FAJ), 2011. *Manual for baseline survey of forest ecosystem diversity.* Tokyo.

IPCC, 2003. Annex A, Glossary. In: *Good practice guidance for land use, land-use change and forestry*. Hayama, Kanagawa, Japan, Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme.

Neary, D.G., Ice, G.G. & Jackson, C.R., 2009. Linkages between forest soils and water quality and quantity. *Forest Ecology and Management*, 258: 2269–2281.

Robards, T.a, berbach, M.W., Cafferata, P.H. & Valentine, b.e. 2000. A comparison of techniques for measuring canopy in watercourse and lake protection zones. California Forestry Note No. 115. Sacramento, California, USA, State of California, Department of Forestry and Fire Protection.

Society of American Foresters, 1998. *The dictionary of forestry*, ed. J.A. Helms. CABI Publishing.

Suchar, V.a. & Crookston, N.l., 2010. Understorey cover and biomass indices predictions for forest ecosystems of the northwestern United States. *Ecological Indicators*, 10: 602–609.