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Cost Considerations in Selecting Methods for Inventorying and Monitoring Carbon in Forests

A Case Study of the Noel Kempff Climate Action Project

Technical Report

Cost Considerations in Selecting Methods for Inventorying and Monitoring Carbon in Forests

A Case Study of the Noel Kempff Climate Action Project

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REPORT SUMMARY

This report presents a framework to systematically account for the main cost items and productivity parameters pertaining to different methodologies for inventorying forest carbon. The framework was applied to data from a 1997 ground survey and a 1999 dual-camera videography survey carried out at the Noel Kempff Climate Action Project in Bolivia. The framework allowed a differentiation between fixed and variable costs, which was needed to correct for the different sample sizes used in the two inventories, to identify possible economies of scale, and to determine key factors influencing the costs of long-term monitoring programs.

Background

The difficulty of estimating and monitoring carbon stocks within acceptable confidence intervals challenges the credibility of forestry-based offsets for mitigating global climate change. Many efforts have been made to study the feasibility and adequacy of alternative systems for inventorying and monitoring forest carbon. While these efforts are yielding encouraging results, insufficient attention has been given to the issue of how much it costs to inventory and monitor carbon. Answering this question is critical: inventorying and monitoring costs affect the overall cost-effectiveness of carbon offsets, an important criterion when evaluating mitigation options.

Objective

To compare the costs of ground survey and dual-camera videography methods for inventorying forest carbon, as well as to provide insights on key factors influencing the costs of long-term programs for monitoring forestry-based carbon offsets.

Approach

The project team developed a framework to systematically account for the main cost items and productivity parameters pertaining to ground survey and dual-camera videography methods for inventorying forest carbon. The team used the framework to compare the costs incurred when the two methodologies were applied to conduct inventories at the Noel Kempff Climate Action Project. They estimated potential costs of monitoring programs where multiple inventories are carried out over a certain time span in order to track changes in the stock of carbon and identified the key factors influencing costs of long-term monitoring programs

Results

Ground surveys allowed the estimation of forest carbon with a precision level of ±5% at a total cost of $350,000 and a cost of $0.003 per ton of carbon or $0.55 per hectare. These estimates compare favorably with annual costs reported for monitoring forest carbon in other regions. Total costs of the dual-camera videography experiment amounted to $35,000, but its estimates of forest carbon were not comparable in accuracy or precision to those provided by ground survey

methods. This is primarily attributable to imperfect identification of ground plots from the airplane, rather than any shortcomings of the method itself. Expressed on a per plot basis, ground surveys resulted in higher fixed and variable costs than dual-camera videography. It appears that ground survey is a more expensive than dual-camera videography at any sampling intensity. More research is needed for dual-camera videography to achieve similar levels of accuracy and precision. In addition, because estimates obtained from dual-camera videography may need to be calibrated with ground data, possible combinations of the two methods should be explored.

Cost estimates from the ground survey were used to infer "costs per ton of carbon offset" of a monitoring program where multiple inventories are carried out over an extended period. Results indicate that the costs of a 30-year monitoring program in conditions similar to the Noel Kempff project area are unlikely to exceed $0.25 per ton of offset. Three factors that will strongly influence these costs were analyzed in detail: project scale, the precision level sought at any inventory, and the accounting method chosen to track carbon gains and losses over time. Project size (measured in terms of generated offsets) is inversely related to monitoring costs (expressed on a per ton of offset basis). Costs, on the other hand, increase with precision level in a nonlinear fashion. Finally, some discounting of carbon flows should take place to ensure that projects with different carbon sequestration and emission profiles are comparable. These factors, together with the source of offsets and local conditions, should be considered in order to extrapolate results from this case study to other areas.

EPRI Perspective

Forestry management and conservation projects have the potential to generate significant and cost-effective carbon offsets for climate change mitigation, but the difficulty of accurately estimating and monitoring carbon stocks presents challenges to the use of forestry-based offsets. Traditional ground survey methods allow the estimation of baseline forest biomass and biomass changes over time within acceptable confidence intervals, but they may prove too expensive for efficient monitoring in large and inaccessible areas that may be attractive for forestry-based offset investments. EPRI and other organizations have been studying the feasibility and adequacy of alternative systems for inventorying and monitoring forest carbon. A companion report (EPRI report 1006623, forthcoming) assesses the potential of dual-camera videography and 3-D terrain reconstruction. This report provides a framework for estimating the costs of ground survey, dual-camera videography, and other approaches. It also identifies key factors influencing the costs of inventorying and monitoring programs and, thus, the overall cost-effectiveness of forestry-based carbon offsets.

Keywords

Climate change
Carbon offsets
Forestry management and conservation
Carbon monitoring and inventorying
Baselines
Sequestration

ABSTRACT

This report compares the costs of two approaches for inventorying forest carbon and monitoring carbon offsets: dual-camera videography and traditional ground survey methods. The two inventory systems have been used at the Noel Kempff Climate Action Project in Bolivia. Ground surveys allowed the estimation of forest carbon with a precision level of ±5% at a cost of $0.003 per ton of carbon or $0.55 per hectare. Analyses of ground survey data indicate that the costs of a 30-year monitoring program are unlikely to exceed $0.25 per ton of offset; this value will vary according to site-specific characteristics, project scope and scale, level of precision, and offset accounting methods. Dual-camera videography was very inexpensive relative to ground survey methods, but its carbon estimates were not comparable. More research is needed for dual-camera videography to achieve similar levels of accuracy and precision. In addition, because estimates obtained from dual-camera videography may need to be calibrated with ground data, possible combinations of the two methods should be explored.

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1
INTRODUCTION

Forestry management and conservation projects have the potential to generate significant and cost-effective carbon offsets for mitigating global climate change (Brown *et al*., 1996). Yet, the difficulty of estimating and monitoring carbon stocks within acceptable confidence intervals challenges the credibility of forestry-based offsets (Andrasko, 1997; Brown *et al*., 1997). For example, the accuracy and precision with which carbon sinks and offsets can be estimated depend on forests' spatial heterogeneity and temporal variability, both of which are known only roughly, especially in the tropics.

Because of the sizeable contribution that forest management can play in addressing the threat of climate change, many efforts have been made to study the feasibility and adequacy of alternative systems for inventorying and monitoring forest carbon (e.g., MacDicken, 1997a, 1997b; Slaymaker *et al*., 1999). While these efforts are yielding encouraging results, insufficient attention has been given to the issue of how much it costs to inventory and monitor carbon. Answering this question is critical because inventorying and monitoring costs affect the overall cost-effectiveness of forestry carbon offsets—and cost-effectiveness is an important criterion when evaluating alternative mitigation and monitoring options.

Traditional inventorying and monitoring systems have relied on data collected through ground inventories. Such systems, if properly designed and implemented, allow the estimation of baseline forest biomass and biomass changes over time within acceptable confidence intervals. However, their use may prove too expensive for efficient monitoring of carbon stocks and changes over large and inaccessible areas. For these reasons, new approaches are currently being investigated that rely upon GPS-logged aerial photography, video and three-dimensional imaging, or combined approaches.

This report describes the carbon inventorying experience of Winrock International and Friends of Nature Foundation (FAN) at the Noel Kempff Climate Action Project in Bolivia. In 1997, Winrock, FAN, and the Museum of Natural History in Santa Cruz carried out a carbon inventory of the project area using commonly accepted forest ground survey methods. In 1999, the same area was surveyed using aerial photography. Through dual-camera videography, a three-dimensional profile of the project area was reconstructed and used to estimate the forest biomass.

The scope of this report is manifold:

1. A simple accounting framework is presented for tracking the costs of monitoring carbon in forest ecosystems.[1]

2. The framework is applied to the Noel Kempff project, where both traditional monitoring methods based on ground surveys and more recent methods based on aerial photographs and image interpretation have been used. To the extent possible, the same framework was applied to the two methodologies. The main cost elements of these methodologies are discussed, and ways to reduce costs are identified.

3. Cost estimates for these methodologies are developed and compared.

4. Cost estimates from the 1997 ground inventory are used to infer implications for future inventorying and monitoring costs under alternative scenarios. The scenarios are chosen to illustrate how inventorying and monitoring costs are influenced by (1) the level of precision desired, (2) the overall scale of the project, and (3) the accounting systems adopted to track monetary and carbon flows over time.

Appendices A, B, and C provide detailed information on cost estimates for the ground survey method and the dual-camera videography method, as well as on procedures for organizing, collecting, and compiling ground survey cost information.

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[1]This accounting framework has been integrated with the Winrock methodology to estimate optimal sample sizes (MacDicken, 1997b).

2
STUDY BACKGROUND

Study Setting

The Noel Kempff Climate Action Project in northeastern Bolivia is a 30-year, $9.6 million project cofunded by American Electric Power, PacifiCorp, BP Amoco, The Nature Conservancy, Friends of Nature Foundation, and the government of Bolivia. The project has added more than 600,000 ha to the Noel Kempff Mercado National Park, more than doubling its size. The project's overall objective is to stem climate change through forest conservation—by protecting standing forests, regenerating cut areas, and measuring how much carbon would have been lost had the forests been logged.

Carbon benefits are expected to result primarily from the cessation of logging and avoided conversion of forested lands to agriculture (Rotter and Danish 2000). Thus, the project consists of two components. Component 1 conserves carbon by shutting down logging operations, with the indemnification of timber concessions in the project area. Component 2 achieves carbon storage benefits by preventing carbon losses from conversion of forests to agriculture. These benefits begin to accrue immediately and are projected to last 30 years.

In 1997, Winrock International was contracted by The Nature Conservancy to develop a carbon inventory and monitoring plan, help conduct the baseline inventory, and calculate the potential offsets over the life of the project. The first carbon inventory was conducted in 1997. A second inventory was conducted in 1999. Projected carbon emissions due to logging and to agricultural conversion had the project not been implemented provided the baselines against which carbon offsets were estimated by Winrock.

Carbon Offset Calculation

The sources of carbon offsets are summarized below:

Averted logging (Component 1):

- Removal of commercial timber will be halted
- Damage to unharvested trees will be eliminated

Averted conversion of forested lands to agricultural uses (Component 2):

- Loss of carbon in forest biomass will be halted
- Loss of carbon from soil will be eliminated

For Component 1, carbon offsets (Net_{c1}) are measured as follows:

$$Net_{c1} = \sum_{t=0}^{30} (C_{d,t} + C_{T,t} - C_{g,t})/\delta_t \qquad [1]$$

$C_{d,t}$ are carbon emissions at time *t* caused by logging damage and on-site waste. This number is obtained by multiplying the amount of dead wood caused by logging by a decomposition factor to reflect that wood decomposes slowly. It is calculated at the concession level to reflect the fact that compartments logged long ago contain less dead wood than compartments that have been logged recently. Brown *et al*. (2000) suggests a simple way to make this time correction.

$C_{T,t}$ are carbon emissions due to the processing of the timber extracted at time *t*. Emissions arise because of off-site waste and because some of the final products are short-lived (e.g., fuel wood, paper, and paperboard). This number is obtained by multiplying the amount of timber extracted at time *t* by a transformation factor—the fraction of timber lost to off-site waste or transformed into end uses with a short lifetime (e.g., less than 5 years).

$C_{g,t}$ accounts for the impact of logging on the growth of the residual stand. If logging stimulates growth, then this number is a negative correction to the calculation of annual offsets. On the other hand, if logging induces higher mortality on the residual stand, then this number is added (not subtracted) to the calculation of annual offsets. Like $C_{d,t}$, $C_{g,t}$ is also calculated at the concession level to reflect the fact that these effects will last for multiple years, long after logging occurred.

Finally, δ_t is the discount factor $(1+r)^t$, where *r* is the discount rate. It is used here to reflect that earlier carbon sequestration may be preferable to later sequestration.

For Component 2, carbon offsets (Net_{c2}) are measured as follows:

$$Net_{c2} = \sum_{t=0}^{30} (C_{P,t} - C_{AG,t})/\delta_t, \qquad [2]$$

$C_{P,t}$ are the carbon stocks in vegetation at time *t* in the preservation area (project case), and $C_{AG,t}$ are the carbon stocks in vegetation at time *t* in areas converted to agriculture (baseline case).

Besides these direct carbon benefits, additional carbon emissions will be prevented due to reduced road construction and fuel consumption (due to the halting of the logging activities). These potential sources of carbon offsets were not included in the calculation of project benefits because, based on first-order approximations, they were insignificant compared to the project benefits of stopping logging and forest conversion.

Carbon Inventories

Ground Survey

To estimate carbon quantities, Winrock International used inventory methods and procedures based on commonly accepted forestry, soil science, and ecological survey principles and practices. The chosen inventory method was designed to provide a commercial inventory of carbon in biomass and soils at a level of precision specified by the project sponsors, in this case within ±10% of the mean with a 95% confidence level. Precision refers only to the estimate of carbon stocks in the project area, not to the quantity of offsets.

The Noel Kempff Climate Action Project area (634,286 ha) contains woody vegetation that is grouped into six general forest classes: (1) tall evergreen forest; (2) mixed liana forest; (3) liana forest; (4) tall flooded forest; (5) short flooded forest, and (6) burned forest. A stratified sampling scheme was chosen to reflect forest heterogeneity.

In the 1997 inventory, a fixed area, two-nested plot design was used to measure carbon pools in each plot for the following forest components: all trees with diameter at breast height (dbh) ≥ 5 cm, understory, fine litter, standing dead wood, and soil to 30 cm depth (MacDicken, 1997b; Brown *et al*., 2000a, Delaney *et al*., 2000). Below-ground biomass was not measured directly because of time constraints, and was instead estimated to be 25% of above-ground biomass based on a recent review of the literature by Cairns *et al*. (1997). Individual dbh values per plot were converted to biomass using single-entry biomass equations obtained from Brown (1997) or locally developed for palms and *Cecropia* sp. (Delaney *et al*., 2000). Biomass was converted to carbon using a factor of 0.5 (Brown, 1997).

A summary of carbon stocks as estimated in 1997 at the Noel Kempff project is presented in Table 2-1. The inventory allowed the estimation of carbon storage in the main pools with an overall precision level of ±5% of the mean (at 95% confidence). The error associated with the estimated mean is based only on sampling error and does not account for other types of errors, e.g., measurement, regression, analysis, or data entry errors. Work is in progress to include measurement and regression errors in future estimates (Delaney *et al*., 2000).

Table 2-1
Summary of Carbon Stocks in the Noel Kempff Climate Action Project Area, Ground Survey Inventory (Source: Delaney *et al.*, 2000)

Strata	Area	Above-Ground Woody Biomass	Palm Biomass[2]	Standing Dead Biomass	Lying Dead Biomass[3]	Above-Ground Herbaceous		Below-Ground Biomass		Total	Total Project Case
		C	C	C	C	C	Litter	C	Soils		
	ha	t C/ha									t C
Tall Evergreen	226,827	129.1	0.5	4.1	11.0	2.0	3.6	25.8	26.9	203	42,870,303
Liana	95,564	55.5	0.5	2.3	4.7	3.8	4.0	11.1	39.9	122	10,980,304
Tall Flooded	99,316	131.8	1.1	3.2	11.3	1.9	3.1	26.4	44.8	224	20,806,702
Short Flooded	49,625	111.7	0.2	3.0	9.6	2.1	2.9	22.3	55.5	207	9,652,063
Mixed Liana	159,471	89.6	1.5	4.4	7.7	2.6	4.3	17.9	24.4	152	22,150,522
Burned	3,483	56.9	0.2	1.6	4.9	0.9	4.2	11.4	36.0	116	381,040
Total	**634,286**										**106,840,934**
Statistics											
Weighted mean		106.7	0.8	3.6	9.1	2.4	3.7	21.3	33.3	181.1	
Calculated precision (error as percent of mean) = 5.3% 95% confidence interval (maximum) = 112,503,504 t C 95% confidence interval (minimum) = 101,178,364 t C											

In addition, the carbon offsets calculated for this project are under revision as more information from field measurements is collected. The assumptions used to develop the without-project scenarios or baselines are also being refined and revisited. For the averted logging component, data collection and analyses are ongoing in monitoring plots established in a nearby concession to assess the amount of immediate damage to the residual forest resulting from the logging

[2] Data are from a less-comprehensive 1999 ground inventory.

[3] Data are from a less-comprehensive 1999 ground inventory.

activity and to assess delayed damage and rates of regrowth. Further data on rates of deforestation are also being collected.

Dual-Camera Videography

In 1999, the second inventory was conducted. Videography was flown over the Noel Kempff Reserve Expansion Zone in Bolivia, covering 625 study plots that had been sampled for dbh values in a stratified distribution through the region. The majority of the sites were covered with the wide-angle video; at least 200 sites were covered on the zoom video.

Digital elevation models and 3-D mosaics were generated from the zoom video for an initial sample of 60 plots. For each site, crown areas and tree heights were measured in stereo for the 28-m-diameter plot, a 40-m-diameter plot centered on the original as much as possible, and a 1-ha outline on the video strip mosaic. Each crown diameter was multiplied by its mean height as a function of its mass. Those values were summed for each plot and correlated to the tons per hectare biomass estimates for those plots.

3
COST METHODS AND CALCULATIONS

An economic engineering approach was used to estimate the costs incurred for the 1997 and 1999 inventories. Because at the time of the inventories no specific guidelines existed to track costs, cost data were attributed to different activities ex-post. To account for inventory costs, a framework was developed that groups the main cost components into fixed and variable costs. This was done to quantify possible economies of scale.

Fixed costs, i.e., expenditures on activities that are largely independent of sample size, were reported in total US$. Variable costs, i.e., expenditures that depended primarily on the number of plots measured, were reported in US$ per plot. They were computed using daily costs ($/day) and average productivity (time required to carry out a specific activity) measured in days/plot.[4] Estimates of total costs (TC_s) were computed as the sum of fixed costs (FC_s) and variable costs (VC_s) multiplied by the number of plots inventoried:

$$TC_s = FC_s + VC_s * n \qquad [3]$$

The subscript refers to the monitoring system (ground survey, *gs*, or dual-camera videography, *dcv*), and *n* is the number of plots inventoried.

For the ground survey only, crew productivity differed by forest strata, depending on the accessibility and structural complexity. For each forest stratum *i*, $VC_{gs}^{\,i}$ was measured as follows:

$$VC_{gs}^{\,i} = \omega^i * UC \qquad [4]$$

The parameter ω^i is the level of effort required to measure a plot in forest stratum *i*, and UC is the unitary (daily) cost of personnel, equipment, and logistics effort required to carry out such measurement. Then, VC_{gs} is calculated as an average weighted by the number of plots in each stratum, as follows:

$$VC_{gs} = VC_{gs}^{\,i} n^i / \sum_i n^i. \qquad [5]$$

[4]Data collection should be organized to reflect these differences. Appendix C lists data requirements and responsibilities to facilitate and organize the data collection process. No such appendix was developed for tracking costs for dual-camera videography since this monitoring method is typically more centralized, carried out by a small number of professionals.

1997 Ground Survey Cost

The main activities pertaining to the ground survey are summarized in Table 3-1. The table highlights whether each activity has been classified as involving mainly variable or fixed costs. The third and fourth columns report some subjective indicators regarding the efficiency with which such activity has been carried out and whether significant opportunities had been identified for "learning by doing." Although very subjective, this latter indicator is included because it provides a qualitative identification of activities that could be carried out at lower costs once experience is gained and lessons have been learned.

Table 3-1
Summary of Main Activities for Ground Survey

Main Activity	Cost Category	Efficiency	Opportunity to Learn By Doing
Organizational Setup			
Secondary data collection	Fixed	Medium	Yes
Map generation and primary data collection	Fixed	Low	Yes
Sampling strategy/site selection	Fixed	Medium	Yes
Recruitment and hiring	Fixed	Medium	
Training	Fixed	Medium	Yes
Travel	Fixed	Medium	
Lodging and per diem	Fixed	High	
Overall coordination	Fixed	Medium	Yes
Other	Fixed	Medium	Yes
On-Site Plot Establishment and Measurement Costs			
Labor	Variable	Medium	Yes
Equipment	Variable	Medium	Yes
Camp maintenance (logistics) and transportation	Variable	Low	Yes
Data Analysis and Reporting			
Compilation, analysis, and documentation	Fixed	Medium	Yes

The efficiency with which most operations were conducted appears to leave ample room for improvement. Two particular activities stand out as having the greatest potential for improvement: the preparation and use of a reliable vegetation map, and running the logistics of crew support in the field. Both these issues are explored in more detail in a later section.

Total costs for the inventory of 625 plots amounted to $350,000, giving an average cost per plot of $560 (Table 3-2) or about $0.003 per ton of carbon inventoried. Fixed costs amounted to about $112,000. Average variable costs for the 625 plots measured in the project area amounted to about $268 per plot (Table 3-2). Not all strata required the same amount of effort to be inventoried: areas with abundant lianas, for example, had unit costs up to 25% higher than more accessible areas. The details are given in Appendix A. Expressed on a per-hectare basis these costs translated into $0.55/ha, an estimate that compares favorably with annual monitoring costs reported for other regions. For example, Brown *et al*. (2000b, p. 325) report estimates of $1/ha and $5/ha in Costa Rica and India's Western Ghats, respectively.

Table 3-2
Estimated Cost of 1997 Inventory by Ground Survey

Main Cost Categories	Cost
Organizational setup	$88,730
Plot establishment and measurement	$268/plot x 625 plots = $167,500
Data analysis and reporting	$23,750
Subtotal for Main Activities	$280,000
Overhead (25% of subtotal for main activities)	$70,000
Total cost	$350,000
Total cost per plot	**$560/plot**

Because many operations will not be needed at subsequent inventories, the cost of future inventories in the Noel Kempff Climate Action Project Area is likely to be smaller. At subsequent inventories, for example, good vegetation maps will be already available, as will personnel that will not require as much training as for the first survey. It should be considered that the data collection procedures are also likely to be more efficient due to the acquired experience (e.g., individual tree data will have already been collected so that operations will run more smoothly and errors will be detected more easily). Furthermore, as local (Bolivian) counterparts acquire experience in monitoring design, implementation, and management, future overseas involvement can be contained. Finally, the inventorying of 625 plots led to an estimation of forest carbon within a finer confidence limit (±5%) than originally intended (±10%). Given the knowledge in forest variability now available, it is possible to consider a reduction in the number of plots to be measured at subsequent inventories. This reduction will lead to an even greater reduction in monitoring costs.

1999 Dual-Camera Videography Cost

The main activities involved in the collection and analysis of aerial photographs are summarized in Table 3-3.

Table 3-3
Summary of Main Activities for Dual-Camera Videography

Main Activity	Cost Category	Efficiency	Opportunity to Learn By Doing
Organizational Setup			
Planning	Fixed	High	
Preflight preparation and travel	Fixed	High	
Meetings with local representatives	Fixed	Medium	
Recruitment and hiring	Fixed	NA	
Training	Fixed	High	
Lodging and per diem	Fixed	High	
Overall coordination	Fixed	High	
Data Acquisition			
Supervision	Variable	High	
Pilot, airplane, and fuel	Fixed/Variable	High	
Materials (e.g., videotapes)	Variable	High	
Other	Variable	High	
Postflight Data Processing, Management, and Documentation			
Supervision	Variable	High	
Data interpretation	Variable	Low	Yes
Equipment and material	Variable	Medium	Yes
Other	Variable		

As in Table 3-1, subjective indicators are included for each activity regarding efficiency and opportunities for efficiency improvement. Data interpretation in particular could be made much more efficient as experience is gained.

All postflight data processing, management and documentation activities have been considered variable since, at the time this report was written, a manual crown identification and demarcation process was required. Current research is aiming at automating this process. If and when this becomes possible, the activities grouped under this heading will become primarily fixed costs. Flight activities included both fixed and variable components.

Total costs amounted to $35,000, giving an average cost per plot of $226 (Table 3-4). Fixed costs were contained to less than $8,000. The details are provided in Appendix B.

Table 3-4
Estimated Cost of 1999 Inventory by Dual-Camera Videography

Main Cost Categories	Cost
Organizational setup	$6,700
Data acquisition: flight costs	$8,337
Postflight data processing, management, and documentation*	$13,033
Subtotal for Main Activities	$28,070
Overhead (25% of subtotal for main activities)	$7,018
Total cost	$35,088
Total cost per plot	**$226/plot**

*Image processing and analysis costs were based on 60 sites. They include a technician and supervisor's time. They amounted initially to approximately $108 per site but were quickly reduced to $85 per site.

It should also be noted that these estimates do not include costs for the use of technical equipment for image processing and interpretation since these activities were cofinanced by other research organizations. Such cost activity could be considered a fixed or variable cost depending on whether equipment is acquired or rented (or, as in this case, a specialist is hired to carry out the operations).

4
COST ANALYSES

Cost Comparisons for Ground Survey and Dual-Camera Videography

The methodologies described in the previous sections need to be compared not simply in terms of their costs, but in terms of their cost-effectiveness. As discussed at length in a later section, the ideal point of comparison is “cost per ton of offset estimated with an equivalent level of precision and accuracy.”

However, the most recent estimates on the accuracy and precision of the dual-camera videography method are disappointing, and they do not reflect the potential of the method to estimate forest carbon. The poor correlation between estimates obtained from interpretation of aerial photographs and from ground surveys is attributable more to imperfect identification of plots from the air than to shortcomings of the dual-camera videography method itself (for more detail, see the companion report, *Assessing Dual-Camera Videography and 3-D Terrain Reconstruction as Tools to Estimate Carbon Sequestering in Forests*, EPRI, 2002, 1006623). In the future, devices to perfectly identify the ground plots from the air are expected to increase significantly the accuracy and precision of dual-camera videography estimates—without affecting cost significantly.

Given the lack of comparable carbon estimates, the two methodologies are compared in terms of “cost per plot inventoried.” This measure addresses the fact that the two methodologies have been used to measure two different sample sizes (625 and 60 plots for ground survey and dual-camera videography, respectively). Although this approach corrects the cost estimates for sample size, it is not a satisfactory measure of the methodologies’ relative cost-effectiveness.

Figure 4-1 provides a comparison of cost per plot for the two methodologies. Because both fixed and variable costs are higher for ground surveys, the cost of this methodology is always higher than that for dual-camera videography, regardless of sampling intensity. This measure of cost-effectiveness does decrease rapidly with sample intensity for ground surveys because fixed costs are considerable compared to variable costs. On the other hand, the cost-per-plot curve for dual-camera videography is almost flat, reflecting contained fixed costs.

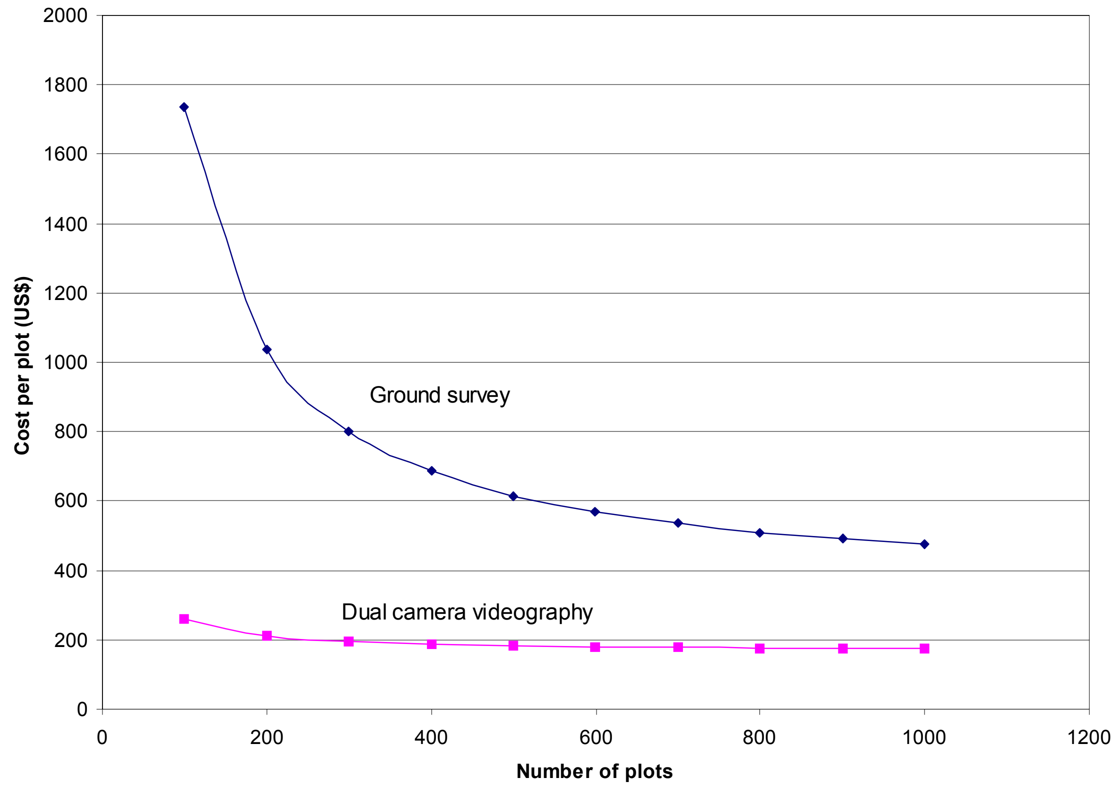

Figure 4-1
Comparison of Cost Per Plot for Ground Survey and Dual-Camera Videography

Effects of Project Scope on Offset Monitoring Costs

Previous sections reviewed the costs of inventorying a forest area using two different methodologies. Although interesting as such, these estimates could also be used to infer the costs of a monitoring program where multiple inventories are carried out over a certain time span in order to track changes in the stock of carbon. This is a speculative exercise since it relies on future parameters (e.g., cost and frequency of future inventories) that are presently uncertain. Nonetheless, it provides estimates on the cost of a full monitoring program and points at factors that are likely to influence these costs.

This section details the results of an effort to infer the costs of a carbon monitoring program on the basis of the cost estimates derived from the 1997 ground inventory, as well as to assess the cost implications of some characteristics related to project scope: project scale (in terms of amount of offsets), the precision level sought, and the accounting of carbon flows. For example, it is obvious that monitoring costs expressed on a per-ton-of-offset basis will decrease with the amount of offsets generated by the project, other things being equal. This is because many costly operations still need to be carried out, whether a large or a small amount of offsets is generated. The precision level is also important because higher levels of precision require a more intensive inventory. Finally, carbon offset projects involve costs and benefits that occur over long periods of time. How one decides to sum carbon offsets that occur over time strongly influences the cost per ton of carbon.

Several simplifying assumptions were made in using the cost estimates from the 1997 ground inventory to estimate the cost of future monitoring events. For example, similar operations were envisioned (e.g., re-measurement of plots within and outside project area) at certain time intervals. It is possible—indeed likely—that the timing and intensity of future monitoring events will be revised based on the experience gained and lessons learned. Such future revisions will likely lead to different cost estimates from the ones presented below. Although the actual values may change, the main conclusions regarding the relationship between project scope and inventorying and monitoring costs will remain valid. As such, the general lessons derived from this analysis can be extended to other inventorying methodologies.

The important influences of project scale and precision level on costs are exemplified in Figure 4-2, which uses the sample size calculator developed by Winrock (MacDicken, 1997b), the cost structure shown in Table 3-2, and the project life span of 30 years. To obtain Figure 4-2, it was assumed that annual offsets are constant and that at the end of the 30^{th} year, they sum up to 5, 15, or 30 million tons. There are eight monitoring events that occur at year 1, 3, and 5 and every 5 years thereafter, according to the specifications provided at the inception of the project (Delaney *et al*., 2000). Because subsequent inventories benefit from acquired experience and rely on investments made for the first inventory (e.g., vegetation maps, organizational infrastructure; see also the Discussion section), it is assumed that costs at subsequent inventories are half the cost of the first inventory (Table 3-2). Total cost and carbon values are summed without any discounting (i.e. a dollar has the same value whether spent today or 10 years from now.)

Project scale. In this example, the cost per ton of carbon is six times higher for a project that generates only 5 million tons of offsets versus one that generates 30 million tons.

Precision level. For a project that generates 5 million tons of offsets (upper curve), the marginal cost of increasing the precision level up to 10% is fairly low: The total difference in achieving a 10% level as opposed to a 30% precision level is only about $24,000. To attain a precision level of 10%, about 80 plots are required (based on the variance estimated from 625 plots). This number drops to 36 plots for a precision level of 15% and to 14 plots if the precision level is 20%.

Attaining precision levels higher than 10% increases the cost significantly because of additional plot requirements: Increasing the precision level from 10% to 5% would raise total costs by almost $120,000. Pushing this to a precision of 2.5% (results not shown) would increase total costs by an additional $260,000.

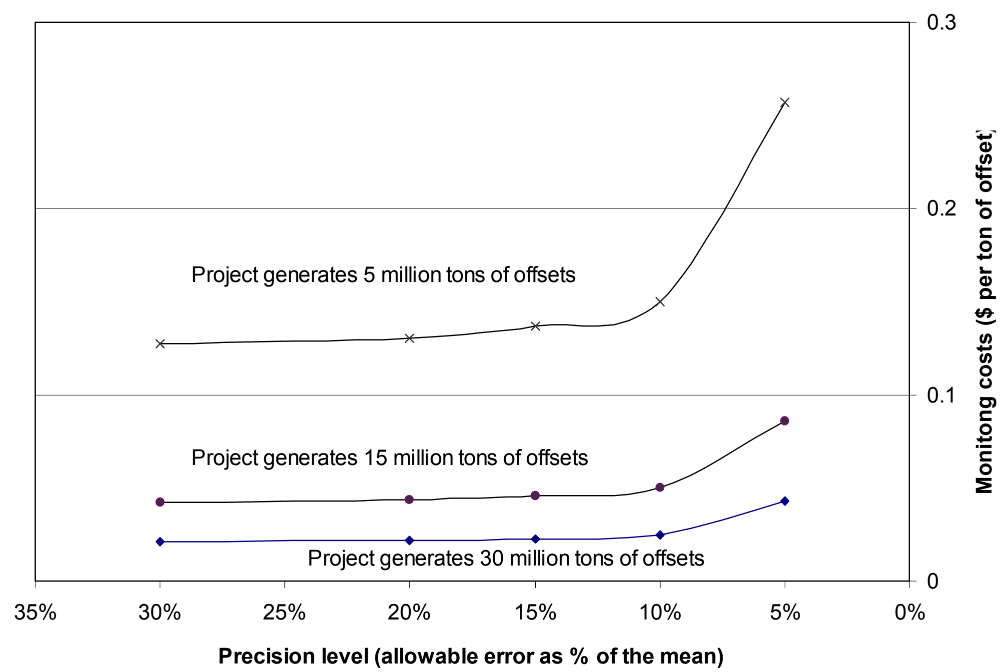

Figure 4-2
Monitoring Costs and Total Offsets for a 30-Year Period, Calculated From Eight Inventories Using Ground Surveys

Thus, aiming at a precision level of 5% almost doubles the cost of inventorying and monitoring versus a precision level of 10%. Project developers need to be careful in selecting an appropriate level because the cost of achieving high precision may represent a significant percentage of the total price for the offset, particularly if the purchase price is low.

Accounting of carbon flows. Three approaches are mentioned in the literature to sum carbon offsets over time: (1) flow summation, also known as the stock change method; (2) averaging; and (3) discounting (Hourcade *et al*., 1996; Brown *et al*., 2000b). *Flow summation* measures the total tons of carbon sequestered (in net terms) over the lifetime of a project by simply summing up the annual offsets, regardless of when they occur. *Average carbon storage* is the cumulative change in the amount of carbon stored on site averaged over the project cycle. *Discounting* attaches a higher weight to early carbon benefits, similar to what one would do with monetary benefits.

Although previous carbon sequestration studies have used flow summation as the preferred method (for a review see pp. 345-356 in Hourcade *et al*., 1996), many analysts now tend to use discounting to ensure comparability between projects with different time profiles for costs and benefits (Boscolo *et al*., 1998). The issue is mentioned here because the accounting method chosen influences the indicator of interest in this discussion: the cost to monitor a ton of carbon offset.

To illustrate this, three scenarios were compared in this study: (1) neither costs nor offsets are discounted, (2) only monetary costs are discounted, and (3) both monetary costs and offsets are discounted with the same rate (10%). (When average carbon storage is divided by the mean annual costs, the averaging method yields results equivalent to Scenario 1.) These scenarios are based on a project that generates a total of 15 million tons of carbon; cost estimates were developed based on the same assumptions and data used to construct Figure 4-2.

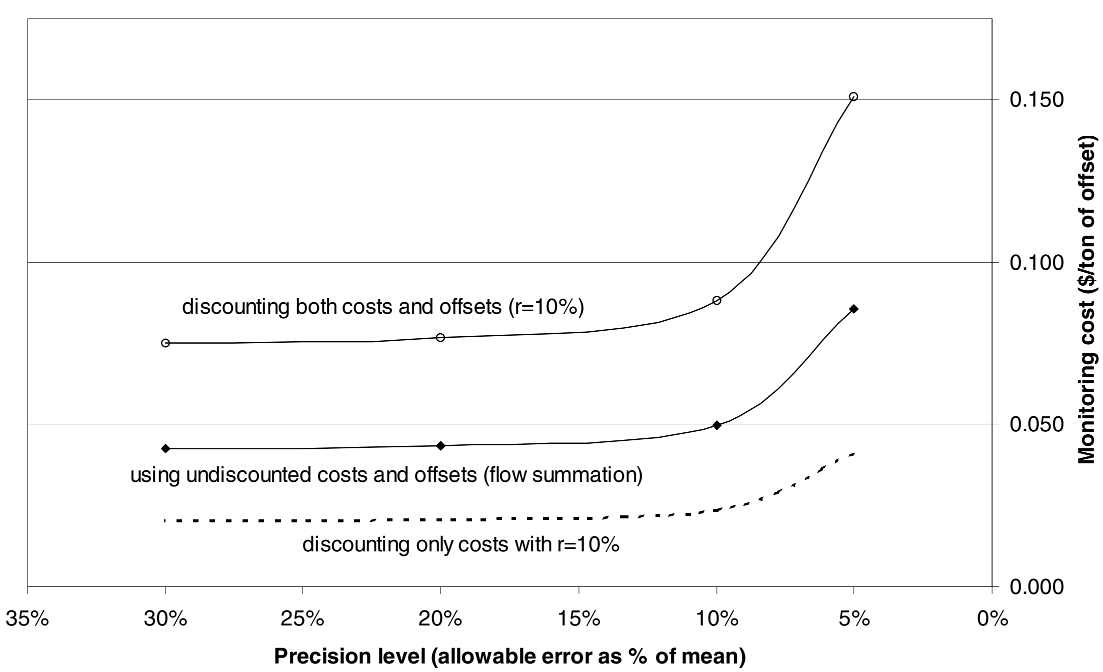

Figure 4-3
Costs of Monitoring Carbon for a Project That Generates 15 Million Tons of Offsets, With and Without Discounting

Results are illustrated in Figure 4-3. Discounting neither costs nor offsets (Scenario 1) yields a summary indicator that is twice as high the one of Scenario 2, but is lower than the one obtained by discounting both costs and offsets (Scenario 3).

Because different projects may have different cost profiles and carbon emission avoidance or sequestration profiles, summary statistics such as “dollars spent per ton of carbon monitored” offers meaningful information on cost-effectiveness across projects only if both project costs and net carbon benefits are discounted. This is equivalent to treating carbon offsets like any other commodity.

To conclude, project scope—including scale, level of precision, and accounting for carbon flows—is likely to influence inventorying and monitoring costs significantly. For a project that generates 5 to 15 million tons of offsets, in conditions similar to those for the Noel Kempff Climate Action Project and on the basis of the assumptions described above, the cost of inventorying and monitoring carbon offsets is expected to be below $0.10-$0.25/ton of offset (see Figure 4-2).

5
DISCUSSION

The purpose of the study was to develop an accounting framework to systematically document the cost of inventorying and monitoring carbon in forest ecosystems using different methodologies. The technologies considered were ground surveys and dual-camera videography. This information produced cost estimates for the inventorying of individual plots. Therefore, cost estimates were expressed in dollars (US$) per plot.

Ultimately, however, one would want to compare the two methods in terms of the costs to achieve similar levels of accuracy and precision.[5] For example, to estimate biomass using dual-camera videography, a tree's basal area is inferred from the size of the tree's crown. However, the relationship between basal area and crown size is not perfectly linear. Furthermore, tree crowns of different shapes are approximated by circles during image processing. This approximation process may introduce additional errors. It is therefore likely that the error associated with biomass estimation based on interpretation of aerial photographs is larger (and, thus, the measurement precision is lower) than the error obtained using data collected from the field. If the two methods are equally accurate (they produce the same estimated mean biomass), dual-camera videography will require more measurements (plots) to achieve the same confidence level attainable with ground measurements.

However, if dual-camera videography is also associated with a positive systematic error,[6] increasing the sample size provides no correction. In this case, estimations based on image interpretations need to be calibrated with the measurements obtained with an accurate method. As such, the most cost-effective option may be a combination of the two methods, e.g., use of ground surveys to calibrate estimates obtained with dual-camera videography.

In considering these options, one will want to account for the contribution that each additional measurement makes in terms of increased precision. One should also account for the fixed cost of adopting a method. It is possible, for example, that it would cost less to achieve a certain level of precision by measuring more plots using a single method (e.g., ground survey) than using the two methods together. It may still be cost-effective to use a single method if the systematic error associated with its use is known and predictable, e.g., when it remains stable across different forest strata or over time. In this case, short-term costs for calibration need to be balanced with

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[5] *Systematic error* is the difference between the mean of the measured value and the true value. *Random error* is the difference between the measured value and its mean. *Accuracy* reflects the agreement between the estimated value and the true value. *Precision* reflects the confidence with which the true value is believed to be within a certain distance from the estimated value.

[6] Due, for example, to the fact that much understory vegetation (trees with dbh < 7 cm) is not visible from aerial photographs.

savings in the long term. In sum, comparing the desirability of alternative methodologies requires the consideration of their accuracy and precision, as well as of the costs associated with their use. Without these considerations, cost comparisons alone may be misleading.

Additional factors influence the cost of inventorying and monitoring carbon in forest ecosystems and point to the appropriateness of one or another methodology. These factors are described below.

Source of carbon variations. The elements of the carbon pool that are to be measured should be considered in choosing a method. It makes a difference whether the main objective of monitoring is to track variations resulting from biomass decay and/or build-up (e.g., during and following disturbances) or from broad changes in land uses (e.g., reforestation practices, abandonment of agricultural land to natural secondary regeneration, deforestation, etc.). Methods based on aerial photographs are likely to be more cost-effective in tracking broad changes in land use over time than a system based on permanent plots. Conversely, ground surveys may be the only way to track flows in soil and litter.

Local conditions. Deciding which method to employ may vary upon the specific circumstances. Important factors to consider include the cost of labor, equipment, transportation, and logistics for each of the different methods available. For example, ground surveys may be preferable to aerial photo interpretations in areas where local costs are low or where bringing in outside technology is very expensive—or in relatively homogeneous and easily accessible areas. On the other hand, for large, heterogeneous, inaccessible forests, methods that use aerial methods might be preferable. Site-specific risks and hazards may also influence the choice of technology. For example, where security concerns are high, aerial techniques may be preferable even if they are more expensive for a given level of precision and accuracy.

6
CONCLUSION

As noted in Section 1, acquired inventorying and monitoring experience strongly influences the cost of future events. Indeed, planning and implementation experience has been gained through the 1997 and the 1999 inventories. For example, the logistical efforts of supplying field crews in a remote, forested area were considerable, and many lessons were learned during the baseline inventory in 1997 about how to conduct such a large-scale inventory. This inventory highlighted the importance of having a detailed logistical supply plan in place before the inventory starts, and then of executing the plan efficiently to help minimize overall costs.

Investing in an accurate vegetation map, which is essential for stratifying a target population, can also result in significant savings. Proper stratification of the target population allows an efficient distribution of sample plots, as well as reduces the chance of oversampling—which can be costly in large, remote areas such as the Noel Kempff project area. Finally, good data management is critical for any carbon inventory. Clear lines of responsibility for moving data from the field to the office should be identified, and the flow of data should be continuously monitored to ensure that data are handled correctly or are not lost. This saves time and money in the field and during the data analysis and report writing process. However, the extent to which the lessons learned during the Noel Kempff pilot project will lower the cost of inventorying, monitoring, and evaluating carbon offsets is unknown.

The credibility of forest-based carbon offset projects depends to a great extent on the ability of project participants to demonstrate the accuracy and validity of the offsets that are claimed. The Noel Kempff Climate Action Project participants have devoted a great deal of resources to the field inventory to ensure that the final carbon offset calculations will be transparent and verifiable and will stand up to the scrutiny of the scientific community.

Data from this case study can also be used to acquire general lessons. The cost of inventorying and monitoring carbon is influenced by the total amount of offsets generated by the project: The greater the number of carbon offsets, the lower the per unit costs. Unit costs also increase as the level of precision increases. Based on this analysis for the Noel Kempff Climate Action Project, monitoring costs are anticipated to be below $0.25/ton of offset, a small fraction of the overall costs to generate carbon offsets (see Houcade *et al*., 1996). The actual cost will depend on the amount of verified offsets, the frequency and costs of future monitoring events, and on how costs and offsets are discounted over time.

While ground surveys have traditionally been used to estimate forest biomass and may remain the preferred method, new methods are being developed (e.g., dual-camera videography or radar technologies) that may prove more cost-effective than ground surveys. Methods based on remote sensing might also be preferable to capture patterns and rates of land-use change in projects that obtain carbon benefits from halting deforestation. Results from the dual-camera videography experiment conducted in 1999 at the Noel Kempff project site suggest that this technology could greatly reduce the costs of inventorying forest carbon. Yet, because the two methods still attain quite different levels of accuracy and precision, using a combination of field surveys and remote sensing technologies is a strategy that deserves further scrutiny.

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A
COST ESTIMATES FOR GROUND SURVEYS (IN US$)

Organizational Setup

		Local			Expatriate		
	Units	Unit Cost	Number	Total Cost	Unit Cost	Number	Total Cost
Secondary Data Collection							
Personnel	Man-days	80	114	9,120	250	50	12,500
Materials		5,000		5,000	5,000		5,000
Map Generation and Primary Data Collection							
Personnel	Man-days	10	10	100	250	10	2,500
Materials		1,000		1,000	1,000		1,000
Sampling Strategy/Site Selection							
Technician	Man-days	80	10	800	150	10	1,500
Supervisor	Man-days	80	10	800	250	10	2,500
Assistant	Man-days	50	5	250	50	5	250
Recruitment and Hiring	Man-days	80	5	400	250	5	1,250
Training	Man-days	80	15	1,200	250	15	3,750
Travel	Man-trips	250	8	2,000	1,000	8	8,000
Lodging and Per Diem	Man-days	40	50	2,000	80	117	9,360
Other		8,450		8,450	10,000		10,000
Subtotal				***$31,120***			***$57,610***

On-Site Plot Establishment and Measurement Costs

Daily Cost Per Crew

	Units	Unit Cost	Number	Total Daily Cost
Labor—Supervision	Man-days	140	2	280
Labor—Crew	Man-days	100	3	300
Equipment (rental rate)[1]	$/day	253	1	253
Camp Maintenance (logistics)	$/day	50	1	50

Crew Productivity (crew-days per plot measured)

	Forest Strata					
	6T1	6L2	6H4	6F3	6M5	6Q6
Days to Reach Camp[2]	0.017	0.017	0.017	0.017	0.017	0.017
Days to Reach Average Plot[3]	0.215	0.230	0.215	0.215	0.250	0.215
Days to Measure Average Plot	0.045	0.100	0.045	0.045	0.045	0.045
Total (crew-days per plot)	0.277	0.347	0.277	0.277	0.312	0.277

Cost Per Plot Measured ($/plot)

Personnel	160.47	201.07	160.47	160.47	180.77	160.47
Equipment	70.00	87.71	70.00	70.00	78.85	70.00
Logistics	13.83	17.33	13.83	13.83	15.58	13.83
Total ($/plot)	244.30	306.11	244.30	244.30	275.20	244.30
					Weighted average =	**268.03**

Subtotal for 625 plots = $167,518

(1) Could be disaggregated in more detailed analyses.
(2) Takes 1 day to reach camp, where approximately 60 plots are measured.
(3) Estimates based on a 10-hour workday; about 2 hr/day were added to account for the time needed to clear the area separating plots (average 100 m).

Data Analysis and Reporting

Compilation, Analysis, and Documentation

	Units	Unit Cost	Number	Total Cost
Personnel	Man-days	250	75	18,750
Other		5,000		5,000
Subtotal				***23,750***

Total Costs

	Cost
Activities Subtotal	*280,000*
Overhead (25% of activities subtotal)	*70,000*
Total (based on 625 plots)	***$350,000***

B

COST ESTIMATES FOR DUAL-CAMERA VIDEOGRAPHY (IN US$)

Organizational Setup

	Units	Unit Cost	Number	Total Cost
Planning (e.g., preparatory meetings)	Man-days	400	4	1,600
flight Planning, Testing, and Preparation	Man-days	400	7	2,800
flight Travel and Excess Luggage @$500				1,300
Meetings With Local Representatives		400	1	400
Recruitment and Hiring	Man-days	300	0	0
Training	Man-days	300	0	0
Lodging and Per Diem	Man-days	130	0	0
Overall Coordination	Man-days	400	0	0
Other		600		600
Subtotal				***$6,700***

Data Acquisition

	Units	Unit Cost	Number	Total Cost
Consultant—Salary	Man-days	400	5	2,000
Consultant—Per Diem	Man-days	100	5	500
Airplane and Fuel—Travel to site	Plane-hrs	229	5	1,145
›lane and Fuel—Data collection	Plane-hrs	229	18	4,122
Pilot—Travel to site and data collection	Man-days	65	5	325
Videotapes		12.25	20	245
Subtotal				***$8,337***

Postflight Data Processing and Management

	Units	Unit Cost	Number	Total Cost
Personnel	Man-days	400	6	2,400
Personnel: Interpretation[1]	Man-days	200	52	10,333
Equipment: daily rental rate		70	0	0
Other		300	0	300
Subtotal				***$13,033***

(1) Approximately 3 plots can be interpreted in a day's work.

Total Costs

	Cost
Activities Subtotal	28,070
Overhead (25% of subtotal)	7,018
Total (based on 60 plots)	***$35,088***

C
ORGANIZING DATA COLLECTION AND COMPILATION FOR GROUND SURVEYS

In order to judge the relative cost-effectiveness of the different methodologies and to assess the most effective combination of methods to achieve a satisfactory carbon measurement, the following information is required:

- Costs disaggregated by activity, so that their variable and fixed components can be calculated;
- Costs disaggregated by forest stratum; and
- Shape and determinants of the total cost function for all relevant technologies.

Since cost data collection pertains to different activities, it needs to be coordinated at different levels. For simplicity, and to organize thoughts, a potential structure to collect cost data for ground measurements is presented below. It includes three levels of organizational and operational effort.

Level 1: Main Office—Organizational Setup

This office is required to monitor all the costs that pertain to the overall **organizational setup**. Key activities are as follows.

Identification and acquisition of information. This information (e.g., vegetation maps, human settlement maps, infrastructure and land use data) is necessary in order to obtain a correct stratified sample. If adequate information is not available, it may be necessary to generate it ex-novo. For example, vegetation maps may be generated from satellite imagery or from aerial photos. Either circumstance will require personnel and material costs. If new maps have to be generated, adequate equipment is also needed. To monitor costs, needed information includes the following:

- Labor requirements (e.g., number of days per worker, by type of worker) and wage rates (in $/day).
  - Example: site mapping, consultants, 30 days, $150/day
- Other benefits and labor expenses
- Equipment and materials
  - Example: site vegetation map, Ministry of Agriculture, 1996, provided at no cost

  - Example: digital elevation map, 1993, $600 for data and software, 20% of computer time, $3000 computer
  - Example: map of trails and logging roads, developed in house, 1995, $900
- Travel and related expenses (if technical expertise is required from outside)

Sampling strategy development. Once adequate information has been collected (either from existing sources or from newly generated maps), personnel trained in sampling design will work on identifying an appropriate sampling strategy (sample size, site selection, etc.) and coordinate the process of plot establishment. (This process may not be necessary if aerial technologies can adequately monitor biomass flows without permanent plots.)

- Example: sample selection, technician, 45 days, $100/day

Staffing. Finally, field crews and support staff will be recruited, hired, and trained for the activities they will carry out in the field.

- Example: hiring and management of field crews, 50% of manager's time, pay rate
- Example: training seminar personnel, food transportation etc., $455

The main office must also make estimates for the use of field office equipment and personnel time. This would include telephones, computers, copiers, secretaries, managers, vehicles, etc. Many of these types of "hidden" expenses are commonly ignored or underestimated. If such calculations are too cumbersome (primarily for infrastructure and for other multipurpose facilities) to be dealt with independently, an alternative is to evaluate a fair "overhead" rate that could range between 5 and 20% of the total monitoring costs.

In addition, the main office is responsible for coordinating data collection and verifying the consistency and quality of the data collected at the lower levels (see below). The field office will thus compile all of the information collected in the field and input the data into the accounting framework included here. A data collection sheet should be set up at each level to organize the collection of such data. Finally, activities related to data analysis and reporting are also likely to be carried out at this level.

Level 2: Field supervision—Crew Costs

Field supervisors will record the costs of those activities that they manage or coordinate in the field. Such activities may include the following:

- Paying salaries for field crews and office staff (both in the field and in preparation)
  - Labor requirements (e.g., number of days per worker)
  - Wage rates (in $/day)
  - Other benefits and labor expenses
- Rental, maintenance, and replacement of equipment

- All expenses associated with logistical issues (e.g., camp maintenance, cooking, contingencies, etc.)
- Overseeing the accuracy and completeness of the data collected by the field crews
- Compiling and organizing the field data
- Any other significant expense and contingency

These costs must then correspond to one or more of the items described in the field-crew time-allocation sheets.

Level 3: Field Crews—Crew Productivity

Data need to be collected to monitor the costs associated with measuring plots in different forest strata. Field crews will therefore need to carefully monitor their time both in preparation and in the field. Line items would include the following:

- Travel time to the site where camp is established, e.g., “November 17, one truck to carry Crews 3 and 4 from Area A to Area B. Six hours. Total cost: $24”
- Travel time to Area A (this should correspond to the various strata)
- Time required to make measurements of one plot in Area A
- Travel time from one plot to the next in Area A
- Travel time from Area A to Area B
- Unproductive time and reasons

If field crews are authorized to handle discretionary expenses, then these expenses should also be included at this level.

Target:

Least Cost Options for Meeting Greenhouse Gas Reduction

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