A New Forest Floor Corer for Rapid Sampling, Minimal Disturbance and Adequate Precision

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We describe an effective and inexpensive device for sampling forest floors. It is based on a rechargeable, battery-powered drill that drives a sharpened steel coring tube. The corer is simple to fabricate, is lightweight (3.5 kg) and can be used easily by one person to obtain intact, natural volume cores of the forest floor. It has been used extensively to obtain samples in 114 boreal forest stands of western Canada. We found that coefficients of variation were typically 30 % for forest floor organic matter and bulk density, and tended to be higher in *Pinus banksiana* stands than in *Picea glauca* and *Populus tremuloides*. Ten samples per stand gave adequate precision for a study of forest floor dynamics and autocorrelation did not appear to be a problem with five-metre sampling intervals. In addition to sampling forest floors, the corer has proven suitable for sampling moss and lichen layers and mineral soil down to about 20 cm. A similar powered system can also be used for increment boring of trees.

Keywords corer, forest floor, moss, variability, bulk density, western Canada, boreal
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1 Introduction

In upland boreal forests, there is little faunal mixing of decomposing litter with the underlying mineral soil, and consequently a distinctive organic layer soon develops. This comprises L, F and H layers (Agriculture Canada Expert Committee on Soil Survey 1987), which may or may not be distinctly delineated. For many purposes it is convenient to treat the three layers as one and refer to them as the forest floor (Kimmins 1987). The depth of the forest floor depends on many factors, including forest type, climate and stand history, and commonly ranges from 2 to 20 cm. The forest floor is important for nutrient cycling (van Cleve et al. 1983, Johnson 1995), for forest fire fuel loads (Van Wagner 1983, Forestry Canada Fire Danger Group 1992), and for its role in regulating soil temperature and moisture (Bonan and Shugart 1989). It is also important as a carbon pool, accounting for 28 % of soil carbon storage in non-peatland forests of Finland (Liski and Westman 1997) and up to one half of soil carbon in upland stands in western Canada (Huang and Schoenau 1996). Yet it is difficult to characterise because spatial variability is high (Hokkanen et al. 1995, Liski 1995). Consequently, a high number of samples is needed to achieve reasonably precise estimates for variables such as carbon density or bulk density.

The traditional method of forest floor sampling has been to extract a block, typically 30 by 30 cm square, by cutting around the perimeter of a template with a sharp knife, then lifting this block away from the mineral soil (e.g., van Cleve and Noonan 1971, Alban 1982, Quintilio et al. 1991, Paré and Bergeron 1996, Gower et al. 1997). This is time consuming and gives large quantities of forest floor material to process; as a result, small sample numbers may not capture variability efficiently. Cylindrical push-corers of smaller cross sectional area are not uncommon (e.g., Westman 1995, Zackrisson et al. 1995, Finer et al. 1997, Liski and Westman 1997), but have two important limitations for forest floor sampling. First, they compress the layer and reduce its natural volume making it difficult to obtain reasonable bulk density measurements. Second, the fibric nature of forest floor materials can cause some material to be pushed away from the cutting edge, either inward or outward, which leads to overestimates or underestimates, respectively. This problem is particularly acute with small corers, where the ratio of perimeter to cross-sectional area is high. Push-corers also tend to deflect from particularly hard material, such as roots and pieces of dead wood, resulting in a crooked core and a biased estimate of forest floor mass. Ideally, a small diameter corer should make a clean, vertical cut through the forest floor with virtually no disturbance. We have developed such a corer, which is lightweight, inexpensive to fabricate, and allows cores to be taken much faster than traditional template methods. We have used the corer over three field seasons for sampling the forest floor, as well as the moss-plus-lichen layer and shallow mineral soil, in stands dominated by *Picea glauca* (Moench) Voss, *Populus tremuloides* Michx. and *Pinus banksiana* Lamb. in western Canada. Here we describe the corer and its operation, present data on sampling variability and discuss other applications.

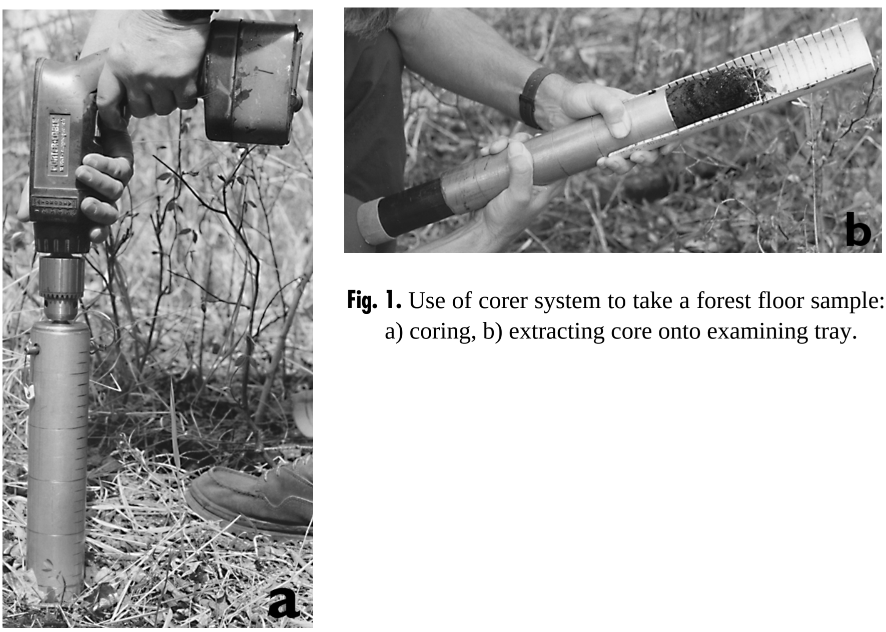

Fig. 1. Use of corer system to take a forest floor sample: a) coring, b) extracting core onto examining tray.

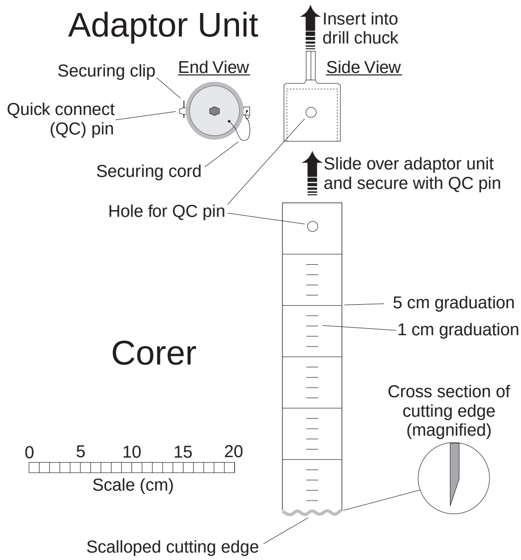

Fig. 2. Corer and adaptor unit.

2 Description and Operation

2.1 Design and Construction

The corer system consists of a sharpened length of steel water pipe driven by a battery-powered rotary drill through an adaptor unit (Fig. 1). This system has become feasible with the recent wide availability of powerful drills driven by rechargeable batteries. Details of the corer and adaptor are shown in Fig. 2. The tubular corer is made from standard, mild steel water pipe. We used two-inch pipe (55.9 mm OD, 52.6 mm ID). The exact diameter is not critical, but larger diameter pipe would require more torque, and battery life may be limiting. A pipe length of 30 cm was suitable for our purposes but it could be shorter or longer depending on the application. Two holes at the upper end take a quick-connect pin that couples the corer to the adaptor. The machined adaptor unit (Fig. 2) comprises a 9.6 mm hexagonal shaft, which is clamped in the drill chuck, a cylinder whose outer diameter is such that it fits flush within the corer pipe, and a quick-connect pin that goes transversely though the cylinder. The motive force is provided by a standard, industrial-quality drill, which should have a 12 mm (1/2-inch) chuck. Because torque and battery life are critical, we would recommend that the drill have a torque rating of at least 34 N-m (300 inch-pounds), low-reduction gearing providing speeds of 350 rpm or less, and a battery of at least 12 volts. For most field applications, one or two spare rechargeable batteries will be required.

The last two components of the system are a light-weight core extractor and an examining tray (Fig. 1b). The core extractor is a piece of ABS water pipe cut slightly longer than the corer and sealed at each end with plastic end caps. The pipe diameter should be chosen so that the end cap fits snugly into the steel corer pipe. In the North American system, a 4.4 cm (1 3/4-inch) ABS pipe works well with the two-inch corer. An examining tray is made from white polyvinyl chloride pipe of the same internal diameter and length as the corer. It is cut in half vertically, making one “half” slightly larger than the other. The longitudinal edges of the larger half are then flared out by heating and bending the plastic so that the soil core is securely held in the examining tray while the high sides prevent accidental loss of material. To aid in measuring layer depths, we suggest drawing lines around the inner circumference at 1-cm intervals.

A critical aspect of the system is a sharp corer. Sharpening can be done with the drill and a rotary sanding disc, which is how the edge is kept sharp in the field, but a belt sander (or grinder) is quicker and easier for the initial shaping of the edge. Sand first with coarse grit (#50) and work up to fine grit (#120). The angle of the edge should be 25–30 degrees and the edge must be scalloped. A peak-trough depth of 1–2 mm with a cycle interval (peak-peak distance) of 2 cm worked well. At this stage, it is also useful to scribe horizontal lines on the outside of the pipe to indicate the depth of coring (Fig. 2).

Apart from the adaptor, which must be machined, the system can be put together by anyone with a modicum of mechanical skill. Our system, including the drill, two rechargeable batteries, construction materials and machine shop charges, cost less than US$500.

2.2 Operation

To take soil cores, clamp the adaptor firmly in the drill chuck, clip the corer onto the adaptor, and hold the corer vertically over the sampling point (a 2-D level glued to the top of the drill can be helpful for keeping the corer vertical). Select the low-speed gear, engage the motor and slowly lower the corer, letting it cut through the moss and lichen layer (if present), through the L, F and H layers and into mineral soil. Only a slight weight is required on the cutting edge, therefore support the weight of the drill while coring; too much pressure may compress the sample, particularly moss, which will prevent proper bulk density measurements. Core a few centimetres into the mineral soil to create a base for the forest floor sample. Stop the drill and lift the corer out. Keeping the corer upright, disconnect it from the adaptor, put the top of the corer onto the base of the examining tray, insert the core extractor into the bottom of the corer and gently push the core out of the corer and onto the examining tray (Fig. 1b). At this point, the layers can be identified, any extraneous material removed, depths of layers measured, and layers described as necessary. The required layers are then separated, usually with a sharp knife, and transferred to plastic bags for later laboratory analysis.

2.3 Practical Aspects

Weighing only 3.5 kg, the complete corer system is easy to carry and can be operated by one person. It takes only a few seconds to drill a core and a few more seconds to extract it into the examining tray. The longest process is examination, separation of layers, description, and bagging of samples. Field time can be reduced by returning the cores to the laboratory intact, but for our purposes, we found that field examination of the cores was preferable. It avoided any chance of samples being disturbed in transport, examination was easier in daylight, and we could relate the core to site conditions and resolve any queries that arose.

Battery life, and hence the number of rechargeable batteries required, will depend on the depth of forest floor, depth cored into mineral soil and texture of the mineral soil. In particular, penetration of clay mineral soil requires full power, which can rapidly drain the battery. At one extreme, we found that coring through deep *Populus tremuloides* forest floors and 15 cm into underlying clay could drain a battery in as few as 10 cores. At the other extreme, one battery was sufficient for 30–40 cores in *Pinus banksiana* forests where there were thin forest floors over sandy mineral soil.

It is important that the corer be kept sharp. In normal use, we found it necessary to sharpen the edge every 20–30 cores. As noted above, this can be done with the drill and a rotary sanding disc, or with a sharpening stone for a light touch-up. When sharp, the corer slices cleanly through virtually all forest floor materials, including roots up to 2 cm thick. It is possible to cut through thicker roots, but the battery drain becomes excessive. The corer is not suitable for stony soils or for soils where bedrock is close to the surface as the cutting edge is easily dulled; if in doubt, it is wise to probe the soil with a thin metal rod to determine stoniness or depth to bedrock.

2.4 Other Applications

We have also used the corer system for three other applications. First, the corer has been effective in obtaining shallow mineral soil samples (down to about 20 cm) for determination of bulk density, organic matter content and water holding capacity. In the western Canadian boreal forest stands that we have sampled, we have noticed that fine roots are concentrated in the forest floor and shallow mineral soil, an observation confirmed by Steele et al. (1997). This suggests that the corer would be ideal for investigations of nutrient cycling in these areas, because nutrient release from decomposition and nutrient uptake by roots is occurring in the soil layers that are easily sampled by the corer. The second application was for preliminary evaluations of soil characteristics. The corer is much faster than digging a soil pit and provides a larger and cleaner core than the common 22 mm soil probe. When the core is laid in the examining tray, layers and horizons are clearly visible as are other characteristics such as soil colour, mottles, fire scars, and fine roots. The third application is taking increment cores from trees, albeit with a standard increment borer tube instead of the two-inch water pipe and an appropriate adaptor. The concept is similar to a previously described borer powered by a chainsaw motor (Hall and Bloomberg 1984), but the battery-powered drill is much lighter, is easier to operate, has no exhaust fumes and virtually no fire risk. We found it provided adequate power for trees in our region where increment cores are seldom longer than 25 cm. Apart from the advantage of speed, this "powered borer" enables cores to be taken at ground level, which is important for reducing uncertainty when trees are being aged.

3 Sampling Considerations

3.1 Methods

We used the corer to determine stand level values of forest floor organic matter and bulk density, as well as moss-plus-lichen layer biomass and bulk density. These means were used for a forest floor dynamics study (Nalder and Wein Submitted). Here our objective is to present stand level variability data. We sampled 114 upland stands across the western Canadian boreal forest. Stands were dominated by *Picea glauca, Populus tremuloides* or *Pinus banksiana*. In each stand, we took 10 cores at five-metre intervals along a randomly-oriented sampling transect. Cores were taken vertically through moss/lichen and the forest floor and 15–20 cm into mineral soil. When cores could not be taken at the designated spot because of logs, large roots or rocks, the corer was moved 50 cm further along the transect. The depth of each layer was recorded. We routinely checked for compression of the sample by comparing the length of the core in the examining tray against the depth cored. The moss-plus-lichen layer was removed at the top of the litter layer, which was essentially at the base of the photosynthesising tissue. As we were interested in forest floor accumulations since the last stand-replacing fire, the base of the forest floor layer was defined by the midpoint of the fire scar or at the mineral soil surface if no fire scar was discernible. Forest floor samples were airdried, woody matter was chopped into small fragments, the sample was ground until suitably homogenous, and a subsample of approximately 5 g was taken. This subsample was oven-dried to constant weight at 75 °C, then ashed at 450 °C for 16 hours to determine organic matter content and percent organic matter. Bulk density was calculated as oven-dry mass divided by volume (cross sectional area of corer by depth of forest floor). Cores containing unusually large accumulations of organic matter, such as rotten logs or squirrel middens, were flagged for separate analysis. Biomass of moss-plus-lichen layer samples was determined by oven-drying to constant weight at 75 °C and bulk density was calculated as for the forest floor.

3.2 Results and Discussion

3.2.1 Precision

Coefficients of variation (CV) were high for all variables (Table 1). This was particularly so for moss-plus-lichen biomass, where CV's were close to 80 %, mainly because many cores had no moss or lichen, i.e., moss or lichen cover tended to be patchy. For forest floor variables, CV's were on average about 30 % (Table 1). Values for *Pinus banksiana* were generally much higher than the other two species, and values for organic matter and bulk density were higher than those for depth and percent organic matter. The variability in percent organic matter was surprisingly high, and is likely due to the unavoidable inclusion of small amounts of mineral soil with each forest floor sample. Similar CV's for forest floor variables have been reported elsewhere. In *Pinus sylvestris*, there is a CV of 27 % for C density (kg m^{-2}) of the FH layer (Liski 1995) and 32 % for H layer thickness (Finer et al. 1997). Across a range of forest types in the northern United States, Grigal et al. (1991) report a CV of 30 % for percent organic matter. The latter study noted that variability was correlated with means, which is also evident in our data (Fig. 3). The linear relationship between standard deviations and means for each species indicates that CV's remain fairly constant over a wide range of means.

Table 1. Mean coefficients of variation for within-stand variation for several variables (mean CV ± standard deviation of CV, number of stands in parentheses).

Variable	*Picea glauca*	*Pinus banksiana*	*Populus tremuloides*
Forest floor			
Organic matter (kg m^{-2})	34%±13% (23)	38%±14% (42)	29%± 9% (49)
Bulk density (Mg m^{-3})	32%±11% (17)	53%±29% (36)	32%±12% (47)
Percent organic matter	21%± 7% (23)	37%±17% (42)	21%± 8% (49)
Depth (cm)	30%±15% (17)	44%±14% (36)	22%± 7% (48)
Moss-plus-lichen			
Biomass (kg m^{-2})	75%±51% (23)	81%±40% (37)	NA[1)]
Bulk density (Mg m^{-3})	42%±17% (17)	45%±15% (33)	NA[1)]

[1)] No moss-plus-lichen data are given for *P. tremuloides* because occurrence of moss or lichen was rare in these stands

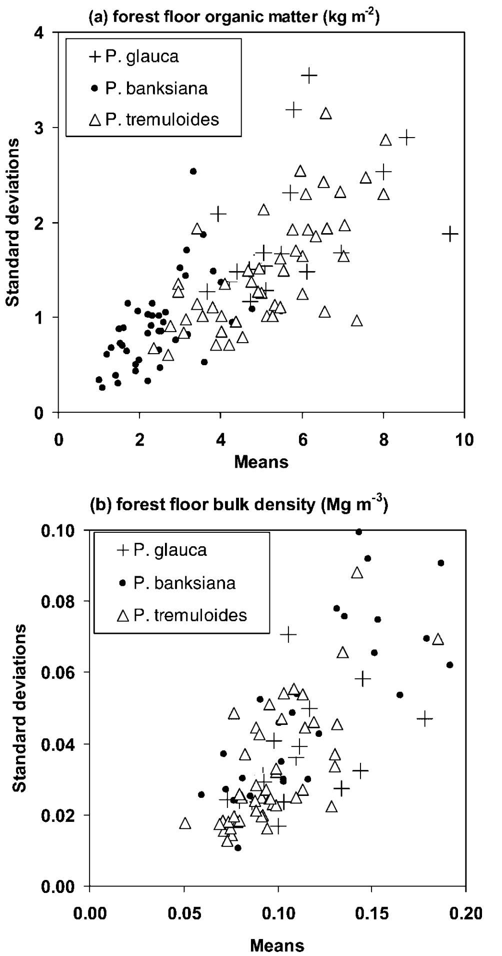

Fig. 3. Linear relationships between means and standard deviations: a) forest floor organic matter, b) forest floor bulk density.

Data in Table 1 will tend to be conservative because unusually deep forest floor cores, particularly those through rotten logs, were excluded from this analysis. Considering forest floor organic matter as an example, inclusion of the excluded cores increases CV's to 37, 47 and 34 % for *Picea glauca*, *Pinus banksiana* and *Populus tremuloides*, respectively. Depending on the purpose of the study, it may or may not be desirable to treat these cores separately; for our dynamics study, it enabled separation of components whose dynamics were quite different (Nalder and Wein Submitted).

What are the implications of these high CV's for sampling intensity? For our dynamics study, 10 samples per stand proved adequate to detect the hypothesised effects of age, species and climate on forest floor accumulation (Nalder and Wein Submitted). In Finland, Liski (1995) recommends 8–10 samples per stand for studying organic layer and mineral soil dynamics. As illustrated by Fig. 4, however, the number of samples is very sensitive to the desired relative standard error (RSE), defined as the standard error of the mean ($S_{\bar{x}}$) as a percentage of the mean. This may vary considerably depending on the objectives of the study. At one extreme, 100 samples (RSE = 3 % with a CV of 30 %), would probably be insufficient for detecting year-to-year changes in forest floor C pools because long-term accumulation rates are generally less than 1 % per year (Nalder and Wein Submitted). At the other extreme, RSE's of 20 % have been suggested as adequate for wildfire fuel load studies (Brown

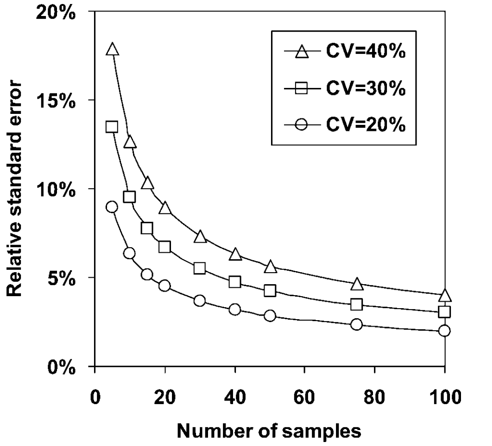

Fig. 4. Relationship between relative standard error (RSE) and number of samples (N) for a range of coefficients of variation (CV) assuming a normal distribution (RSE = CV / √N * 100 %).

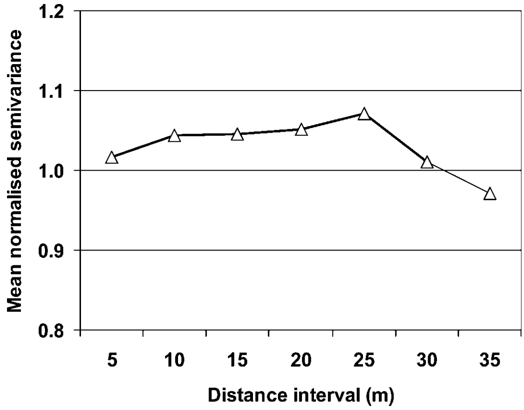

Fig. 5. Semi-variogram showing spatial variability along sampling transect, averaged across 114 stands.

1974, Van Wagner 1982) so that three samples per stand may suffice. This assumes normally-distributed data, which was not true for any variable based on the Lilliefors test at 5 % significance level (SPSS Inc. 1993). Rather, all variables except percent organic matter were log-normally distributed. As shown by Grigal et al. (1991), fewer samples are required for the same precision under the log-normal assumption.

It may be possible to reduce variability by sampling with a larger cross-sectional area, such as the traditional 30-cm square template. Certainly the integrating effect of 900 cm^2 has an intuitive appeal compared with the 22 cm^2 of the corer presented here. From our observations, however, forest floor variability is small over a scale of centimetres compared with a scale of meters. In support of this, organic layer accumulation is greater under canopies or close to tree stems (Hokkanen et al. 1995, Liski 1995) which in most stands provides a patterning on the scale of meters. Consequently, we doubt that a larger cross-sectional area would have a significant impact on sampling variability. If so, then the sampling efficiency (defined as $1/(n * t)$, where n is the number of samples required and t is the time taken for each sample) will be much lower for large template methods.

3.2.2 Spatial Autocorrelation

Spatial autocorrelation may lead to bias in estimates, particularly if sampling intervals are small compared with the scale of variation. We tested for spatial autocorrelation with two methods, using forest floor organic matter as an indicator variable. First, we calculated autocorrelation coefficients for lags ranging from 1 to 8 and tested for significance at the 5 % level using the Box-Ljung statistic (SPSS Inc. 1993). Of the 114 stands sampled, only seven showed evidence of autocorrelation, defined as having more than one significant lag interval. Three other stands had one significant lag interval, but given the large number of tests performed, this is to be expected by chance alone. Among the seven stands, there was no apparent pattern. Two were *Picea glauca*, two were *Pinus banksiana*, three were *Populus tremuloides*, and they spanned a wide range of ages and stem density, suggesting that the apparent autocorrelation was due to chance. The second method was a semivariogram analysis, a technique commonly used in geostatistics (Kitanidis 1997). For each stand, we calculated semi-variances for lags from 5 to 35 m at five-metre intervals. Because there were insufficient points in each stand to develop a stable variogram, we normalised semi-variances by expressing them as a fraction of the stand mean, then averaged the normalised semi-variances across all stands.

Again there was little evidence of spatial autocorrelation: the composite semi-variogram indicates variability is fairly constant with distance (Fig. 5). This is consistent with two studies in *Pinus sylvestris* stands. In one, there was no clear spatial dependence over intervals of 5–50 m (Hokkanen et al. 1995), and in the other, spatial dependence occurred mainly at distances less than 5 meters (Liski 1995). We conclude that spatial autocorrelation was not a concern with the 5 m sampling intervals used in this study.

3.2.3 Other Variability

Spatial variability is just one component of variation leading to the high CV's in Table 1. Here we consider three other sources, corer bias, layer separation error and core compression. Corer bias may occur for two reasons. First the corer never makes a perfect vertical cross section through sampled layers; as noted previously, the cutting edge may push some material aside, or capture some material that is outside the cross sectional area, or be diverted by hard objects. We cannot quantify this effect, but qualitatively we judge it to be insignificant given the clean cut made by our corer. Second, not all chosen points along the transect can be cored because of obstructions, particularly large logs representing the boles of fallen trees. This may bias estimates if forest floor characteristics are different at these points. To illustrate, large logs obstructed 112 of the 1252 sampling points in this study. Because logs tend to screen the underlying ground from litterfall, it is likely that the forest floor is thinner under logs. Assuming a 50 % reduction, our estimates of mean forest floor organic matter would overestimate actual values by about 5 %. Clearly, there is a potential for significant bias.

The second potential source of error occurs because identification and separation of layers is never precise; layers often inter-grade and estimation of a layer boundary has an element of subjectivity. We found that assigning a layer boundary to the nearest 0.5 cm was as precise as was warranted, even with the good quality cores produced by our corer. This imprecision can represent a significant source of error, particularly in thin layers. Next to spatial variability, we would judge this to be the next largest component of variability, and it probably accounts for the higher CV's in *Pinus banksiana* (Table 1).

The third potential source of error is core compression which affects bulk density. Significant compression can occur, particularly with the moss-lichen layer, if the corer is not sharp or if the drill is pushed down while coring. However, with a sharp corer and the proper coring technique, we were not able to measure any core compression, so we doubt that this would be a significant source of variation.

4 Conclusion

We have described an effective device for sampling forest floors, which is also useful for other layers. It is easy to fabricate, inexpensive, allows cores to be taken rapidly by one person, and gives undisturbed, natural-volume cores when coring through materials as varied as moss, lichen, litter, ferment, humus and mineral soil. Sampling CV's for forest floor organic matter and bulk density were typically 30 % or higher. We attribute most of this variation to spatial variability although the lack of precision in identifying layer boundaries undoubtedly forms a significant component, particularly for thin layers. The impact of logs is not insignificant and needs to be considered. It is clear that high precision is not feasible in forest floor sampling. For a study of forest floor dynamics, 10 samples per stand gave adequate precision and we think this would be sufficient for many studies. Obtaining more precise estimates would soon become very expensive in sampling effort. Our data support our choice of five-metre sampling intervals as adequate to avoid spatial autocorrelation.

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