SPATIAL VARIABILITY OF FOREST FLOOR THICKNESS FOR ESTIMATION OF REFINED CARBON STOCKS IN A TROPICAL MONTANE FOREST

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JEYANNY V, BALASUNDRAM SK, AHMAD-HUSNI MH & WAN-RASIDAH K. 2016. Spatial variability of forest floor thickness for estimation of refined carbon stocks in a tropical montane forest. Spatial variations of forest floor thickness in tropical montane forest influences carbon stocks estimates in forest floor and soil, microbial decomposition and soil conservation. Delineation of forest floor thickness according to decomposing layers (litter, hemic, sapric) and total forest floor will provide refined measurements of forest floor carbon stocks to improve site-specific carbon management. This study was aimed at determining spatial variability of the depths of decomposing forest floor layers in a tropical montane forest at varying topography. Sampling grids (10 m × 10 m) were established along three slope positions (summit, sideslope and toeslope) with 120 quadrants and their depths measured. Forest floor samples were georeferenced using a global positioning system. Variables were first explored using univariate statistics, including normality check, non-spatial outlier detection and data transformation. Variography and kriging analyses were used to quantify spatial variability of forest floor depths. Results showed that spatial structure of test variables differed across topographic positions. The coefficient of variation for test variables ranged from 27 to 64%. Surface maps displayed distinct spatial clustering and acceptable accuracy of interpolated values. Hemic and total forest floor were highest at the toeslope where hemic constituted approximately 80% of total forest floor. Site-specific management of forest floor carbon stocks in tropical montane forest should be based on topographic delineation.

Keywords: Detritus material, spatial variation, high altitudes, topography, management zoning

INTRODUCTION

Forest floor accumulation and its decomposition differ across elevational gradients due to variations in plant productivity and temperature. Forest floor comprises litter (fibric), hemic and sapric components. Hemic is intermediate in its degree of decomposition which lies between litter and the more decomposed sapric materials and is partly altered both physically and biochemically (Soil Survey Staff 2010). The combination of hemic and sapric is known as duff. In US forests, it has been reported that 8% of carbon stocks are contributed by duff and litter (Chojnacky et al. 2009). Segregation of forest floor components is rarely done in Malaysia and typically reported as default values especially in tropical montane forests, which boasts thick organic forest floor layers. Estimating the spatial variability of decomposing layers on heterogeneous landscapes such as toeslope, sideslope and summit will provide better assessment of carbon stocks in the forest floor and the mineral soil beneath it. It is believed that variations in carbon stocks is deeply influenced by topographic variations that control hydrological, soil processes and vegetation in forest ecosystems (Martin & Timmer 2006, Saw 2010).

Geospatial statistics are advanced tools to quantify spatial features of soil parameters and to carry out spatial interpolation. Common geostatistical procedures include classification and modelling of spatial structure, spatial interpolation to predict values at unsampled locations and optimisation of spatial sampling (Nogueira et al. 2002). Spatial patterns of soil organic carbon have been computed using geostatistics in agricultural soils (Liu et al. 2006, Law et al. 2009) and grasslands (Schloeder et al. 2001, Cerri et al. 2004). Similar studies on forest floor have focused on temperate regions (Schoning et al. 2006, Martin & Timmer 2006). Developing spatial maps for forest floor depths at varying topography will allow forest managers to strategically demarcate field management zones in order to conserve areas with significant amount of organic material and have potential to sequester carbon, protect the mineral soil (Martin et al. 2011, Jeyanny et al. 2013) and provide ample feed for carbon transformations via microbial metabolic processes (Hertel & Leuschner 2010). Forest floor materials also prevent landslides and conserve tree biodiversity within a locality of a mountainous terrain.

The objective of this work was to analyse small scale variability in forest floor depths of different layers (litter, hemic and sapric) at varying topographic positions in a tropical montane forest. This information can be used to help refine forest floor carbon stock assessment for the purpose of carbon conservation and national-level reporting.

MATERIALS AND METHODS

Study site

The study was carried out in the tropical montane forest of Sungai Kial Forest Reserve (FR), Tringkap, Cameron Highlands, Pahang (4° 31.2' N, 101° 25.9' E) with steep to very steep topography ranging from 22° to 40°. The study site was 1.2 ha and was divided into summit (22° to 40°), sideslope (31° to 34°) and toeslope (29° to 36°), measuring 0.4 ha each, which reflected the actual processes and effects of the catena on selected forest properties. Site elevation varied between 1400 and 1600 m above sea level and was classified as montane forest. The soil type in this area is Ringlet series (Typic Haplohumult) comprising clay loam texture, with mean annual rainfall of 3325 mm and mean annual temperature of 17.8 °C. Site vegetation were mainly derived from the Myrtaceae, Fagaceae and Moraceae families where tree basal area ranged from 26–28 m^2 ha^{-1}.

Data collection and carbon content

At the montane forest, 10 m × 10 m grids were laid out systematically along the transect for every slope type. Each slope position had 40 quadrants and a total of 120 quadrants were established. Sampling intervals were spaced at approximately 10 m apart. A 25 cm × 25 cm frame was placed at the middle of the quadrant and the litter depth inside the frame was measured to the nearest 1–2 mm using standard metric ruler (eight measurements for every frame). Litter was collected and stored in plastic bags. Similarly, hemic and sapric layers of the decomposing organic material depths were measured and their locations were georeferenced with a global positioning system receiver. Samples were collected in October 2012 and the total forest floor depth (combination of litter, hemic and sapric layers) was determined. Representative samples of litter, hemic and sapric were ground in a Wiley mill to pass a 1-mm mesh screen. Carbon content was determined by dry combustion method using carbon analyser. The combined average values of litter, hemic and sapric were used to determine carbon content of the total forest floor.

Geospatial data analysis

Litter, hemic, sapric and total forest floor depths were subjected to exploratory data analysis, involving descriptive statistics, normality check and non-spatial outlier detection using Statistix version 8.1. Spatial variabilities of litter, hemic, sapric and the total forest floor depths were determined. Non-normal data were transformed using appropriate functions to normalise data. Normality checks were performed using Shapiro-Wilk test. Grubbs' test was used for detecting outliers. Spatial analyses for variables were carried out using variography and interpolation techniques (Balasundram et al. 2008). Variography characterises and models the spatial variance of data using semivariogram. Semivariogram attributes (i.e. nugget, sill and effective range) were used to perform point kriging. Kriging uses modelled variance to estimate measured values between samples. In kriging, the value at an unsampled location is predicted based on neighbourhood values. Variography and kriging were computed using

GS+ 7.0 software (2004). Measured and kriged values were mapped using Surfer 8.06 software (2009). Spatial dependence of the data was computed using nugget to sill ratio according to Cambardella et al. (1994) (Table 1). Kriged values were cross-validated (Isaaks & Srivastava 1989, Law et al. 2009) to assess accuracy of the interpolated values using equations 1–3.

Firstly, interpolated mean error (ME) should be close to zero and was calculated as follows:

$$\mathrm{ME} = \frac{1}{n}\sum_{i=1}^{n}\left[\bar{z}(x_i) - z(x_i)\right] \qquad (1)$$

where n = number of sample points, $\bar{z}$ = predicted value of variable at point x_i and $z(x_i)$ = measured value of variable at point x_i. Secondly, the mean squared error (MSE) should be less than the sample variance. The MSE was given by:

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}\left[\bar{z}(x_i) - z(x_i)\right]^2 \qquad (2)$$

Thirdly, the ratio of the theoretical and calculated variance, i.e. the standardised mean squared error (SMSE), should be approximately close to 1. The SMSE was given by:

$$\mathrm{SMSE} = \frac{\frac{1}{n-1}\sum_{i=1}^{n}\left[\bar{z}(x_i) - z(x_i)\right]^2}{\sigma^2} \qquad (3)$$

where σ^2 = theoretical variance.

RESULTS AND DISCUSSION

Comparison of different components of forest floor depth according to slope types

Carbon content for litter, hemic, sapric and total forest floor were 43, 37, 37 and 43% respectively (results not shown). ANOVA revealed that litter depth was not significantly different at all three slope positions and ranged from 1.6 to 2.0 cm (Table 2). Thickness of hemic at the toeslope was significantly higher than the summit by about twofold. Hemic depth at the sideslope was the lowest between all sites. Distinctive sapric layers were absent at the sideslope. Unpaired *t*-test showed that sapric layer at the toeslope was 35% thicker compared with summit (Table 2). Total forest floor depth was significantly thicker at the toeslope, where it was threefold higher than that of the sideslope and 60% more dense than that of summit plot. This finding was similar to what was reported by Jeyanny et al. (2013) where toeslope recorded the highest litter depth (50%) among all areas. Generally, litter constituted less than 3.5 Mg C ha^{-1} stock compared with other combined decomposing layers which were five times higher (Jeyanny et al. 2014).

Hemic layer was consistently more intense at the toeslope as it comprised abundant fine root materials. Hemic may have acted as downslope barrier and a natural fine root net, accumulating downed woody and litter materials at the toeslope. High loads of downed woody debris have been reported in steep slopes (Muller 2003, Martin & Timmer 2006). Conversely, in this study, the sideslope had lower hemic depth and lacked sapric layer due to its somewhat level terrain (< 35°). The sideslope was more homogenous compared with the summit and toeslope. Level terrains usually have higher soil moisture (Martin & Timmer 2006), providing better microsite for equilibrium decomposition process that facilitates rapid turnover of carbon into soil mineral layer. The higher density of total forest floor at the toeslope was attributable to the concave slope which permits transport and deposition of forest floor fragments in the montane forest. Higher precipitation in montane forest also facilitates the downward movement of waste material through mass wasting and surface and subsurface water actions (Hugget & Cheeseman 2002).

Table 1 Classification of spatial dependence

Nugget: sill ratio	Inference
< 0.25	Strong spatial dependence
0.25–0.75	Moderate spatial dependence
> 0.75	Weak spatial dependence

Table 2 Mean thickness (cm) of litter, hemic and sapric layers and total forest floor of Sungai Kial Forest Reserve

Variable/site	Summit	Sideslope	Toeslope
Litter	1.96 a	1.62 a	2.04 a
	(0.14)	(0.15)	(0.10)
n	40	40	39
Hemic	12.31 a	7.73 b	20.65 c
	(0.79)	(0.51)	(1.22)
n	40	37	40
Sapric[†]	2.56 a	n.a.	3.46b
	(0.23)		(0.49)
n	26		34
Total forest floor	16.03 a	8.76 b	25.60 c
	(0.90)	(0.58)	(1.11)
n	40	40	39

Mean values in columns followed by different letters are significantly different (Student–Newman–Keul test at $p \leq 0.01$), values in parentheses represent standard errors, † denotes unpaired *t*-test was performed, n = number of samples; n.a. = not available

Distribution of test variables

Descriptive statistical analysis showed that all test variables were normally distributed for all layers except for litter at all slope types (Table 2). Mean values for forest floor components could be arranged in descending order as follows:

Total forest floor > hemic > sapric > litter

Data transformation to natural log (ln) was only performed for total forest floor depth at the summit to fit a normal distribution. Litter remained non normal even after data transformation was executed. Most of the test variables in all plots were positively skewed, except for total forest floor at the sideslope (Table 2) which inclined towards the left due to negative coefficient of skewness. Sample distribution for test variables at the summit and sideslope was relatively flat around the mean due to negative kurtosis. Relatively peaked distributions were displayed for all toeslope variables and for sapric level at the summit (positive kurtosis). Coefficients of variation for summit, sideslope and toeslope ranged from 35–45, 39–61 and 27–64% respectively (Table 3).

Summary statistics reflected frequency distribution of test variables at different slopes and stipulated the probability description associated with a given value (Table 3). Positive skewness expressed asymmetric shapes about sample means (Rossi et al. 1992). Coefficient of variation values reported concurred with Penne et al. (2010) where values for litter and humic layers in the coniferous forest ranged from 26 to 40%. Litter layer had high coefficient of variation (64%) at the sideslope, and the minimum and the maximum values were 1.3 and 9.0 cm respectively (Table 3). Uneven distribution of sapric thickness also resulted in high coefficient of variation for toeslope.

Spatial structure and attributes

Semivariograms for summit, sideslope and toeslope were constructed using active lag distances of 53, 79 and 86 m respectively. Evaluated distances were manually configured for lag class intervals and they ranged from 4.5–6.9, 7.3–11.6 and 4.5–6.9 m for summit, sideslope and toeslope respectively. Generally, most of the test variables were isotropic. Most of the forest floor components could be explained using appropriate semivariogram models except for sapric at all study sites. The number of samples for sapric was below 30 for summit and correct evaluation of spatial autocorrelation would require a minimum of 30 pairs to compute a semivariogram function (Journel & Huijbregts

Table 3 Descriptive statistics for selected forest floor components thickness in Sungai Kial Forest Reserve

Site/variable depth (cm)	n[1]	Mean	Median	CV (%)	Skewness[2]	Kurtosis[2]	Normality[3]
Summit							
Litter	40	1.96	1.85	44.80	0.35	-0.53	0.01**
Hemic	40	12.31	10.85	40.59	0.74	-0.48	0.28 ns
Sapric	26	2.56	2.15	45.41	1.73	1.88	0.76 ns
Total forest floor	40	16.03	14.45	35.62	0.69	-0.41	0.04**
Sideslope							
Litter	40	1.62	1.55	60.27	0.69	-0.54	0.01**
Hemic	37	7.72	7.90	39.80	0.09	-0.23	0.58 ns
Sapric				n.a.			
Total forest floor	40	8.76	8.75	41.83	-0.38	-0.50	0.42 ns
Toeslope							
Litter	39	2.04	2.00	31.24	0.43	1.19	0.04**
Hemic	40	20.66	20.45	37.39	0.25	0.10	0.55 ns
Sapric	33	3.10	2.40	64.17	1.66	1.17	0.76 ns
Total forest floor	40	25.60	24.90	27.44	0.42	0.07	0.84 ns

[1]Non-spatial outliers were removed from data set, non-spatial outliers were detected using the extreme studentised deviate test, [2]significant if the absolute value of skewness or kurtosis is ≥ 2 times its standard error, standard error of skewness = $(6/n)^{0.5}$ while standard error of kurtosis = $(24/n)^{0.5}$, [3]estimated using the Shapiro–Wilk test if the test statistic W is significant ($p < 0.05$), thus the distribution is not normal, ns = not significant ($p > 0.05$), ** = significant ($p < 0.05$); n.a. = not available, CV = coefficient of variation

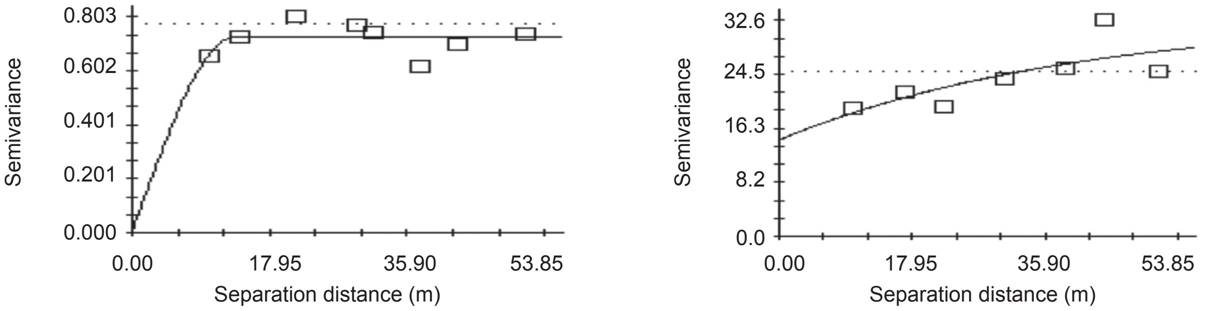
1978). Sapric was clearly absent at the sideslope and it conformed to linear isotropic model which defied prediction of spatial continuity beyond the sampled area.

Litter depth for summit fitted a spherical model and had a nugget to sill ratio of less than 0.001, implying strong spatial dependence according to Cambardella et al. (1994) (Figure 1a). Both hemic and total forest floor at the summit were best explained by exponential models, where spatial dependence was strong and moderate respectively (Figures 1b and c). Effective range portrays the distance beyond which covariance function is equal to 0 and will no longer demonstrate spatial correlation (Rossi et al. 1992, Balasundram et al. 2008). Effective range values for litter, hemic and total forest floor were 13.6, 39.9 and 24.9 m respectively at the summit. Sampling distance (10 m × 10 m) was shorter than the effective range and complied within required assumptions.

Exponential model was more suitable for litter at the sideslope (Figure 2a). Similar to summit, both hemic and total forest floor fitted spherical models (Figures 2b and c). All three models demonstrated very strong spatial dependence of 0.22, 0.02 and 0.06 for litter, hemic and total forest floor respectively. Spatial dependence implied that total variation in litter, hemic and total forest floor could be explained geostatistically by 99.7, 99.9 and 99.9% respectively. The effective range for sideslope for all test variables ranged between 110 and 210 m, slightly longer than the effective range for summit.

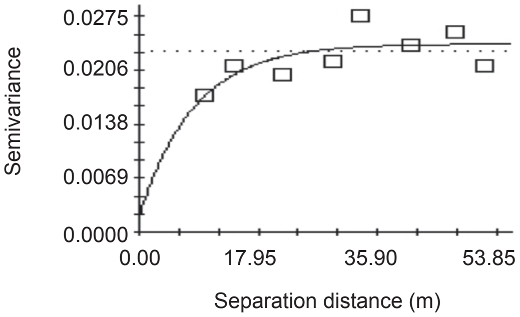
At the toeslope, litter depth fitted an exponential model, where spatial dependence was strong (i.e. 0.10) and effective range was rather short (6.4 m) (Figure 3a). Hemic and total forest floor best fitted spherical semivariogram models and displayed comparable strong spatial dependence. Effective range values for hemic and total forest floor ranged from 83 to 133 m (Figures 3b and c).

Lag class interval specifies the size of interval applied uniformly across the active lag distance (Gamma Design Software 2004). Most of the chosen lag class intervals were shorter than the sampling distance (10 m) in order to portray smaller semivariogram values (y-axis) which were closer together and were more likely to be spatially continuous (Rossi et al. 1992). Shorter effective range for test variables was encountered in summit and longer ones in sideslope and



(a) Litter depth (cm)
Model: spherical, spatial dependence: strong,
nugget: 0.001, sill: 0.73, effective range: 13.6 m

(b) Hemic depth (cm)
Model: exponential, spatial dependence: moderate,
nugget: 14.56, sill: 33.06, effective range: 39.9 m



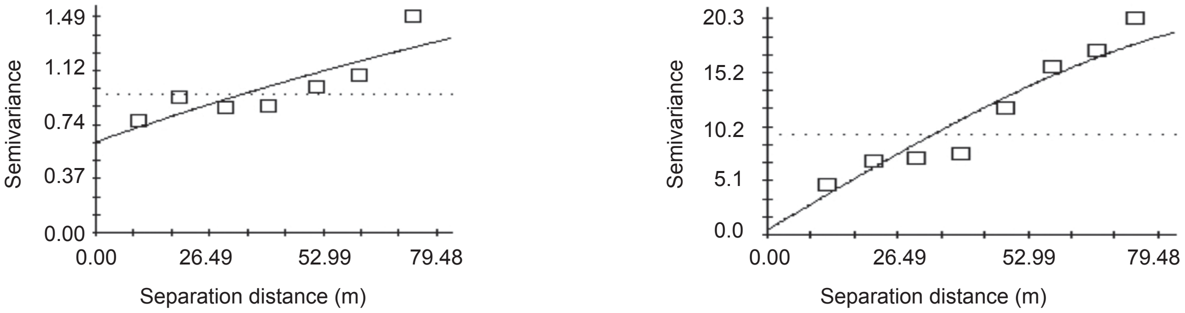
(c) Total forest floor depth (cm)
Model: exponential, spatial dependence: strong,
nugget: 0.002, sill: 0.02, effective range: 24.9 m

Figure 1 Spatial structure and attributes of litter, hemic and total forest floor depths at the summit of Sungai Kial Forest Reserve

toeslope (Figures 1–3). For example, longer effective range in the sideslope for hemic (111 m) showed that the 10-m sampling interval was not necessary and can be increased approximately to 111 m (i.e. 100 m). On the contrary, summit and toeslope required more intense sampling distances due to heterogeneity. Thus, the use of effective range is very important in making preliminary recommendation on spatial scale of test variables and planning of suitable sampling intervals for development of spatial maps. This will also lessen initial inputs in sampling such as manpower, time and expenditure which lead to cost savings. Effective range for detecting fine spatial scale in forest floor can range from 4 to 12.5 m in temperate forests (Douglas fir, Scots pine and Norway spruce) (Samonil et al. 2008). The authors recommended 20–40 and 40–80 m effective ranges for hemic and sapric components respectively. Optimal sampling interval for total forest floor depth across slopes ranged from 33 to 60 m when the 0.25 threshold recommended by Mulla and McBratney (1999) was administered. Spatial dependence was fairly strong for most of the test variables in the montane forest and this observation concurs with Samonil et al. (2008).

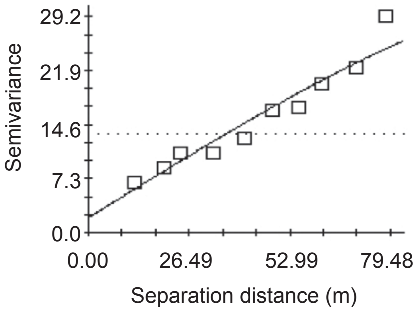
Spatial variability

All variables except sapric at all slope levels exhibited spatial clustering of test values. Cross validation of all three variables showed that interpolation accuracy criteria were satisfied (Table 4). The best estimator should have mean error closer to 0. Mean square error was less than sample variance. Generally, the sum of mean squared error values was closer to 1 (Table 4).



(a) Litter depth (cm)
Model: exponential, spatial dependence: strong,
nugget: 0.623, sill: 2.83, effective range: 210.9 m

(b) Hemic depth (cm)
Model: spherical, spatial dependence: strong,
nugget: 0.45, sill: 20.89, effective range: 111.7 m



(c) Total forest floor depth (cm)
Model: spherical, spatial dependence: strong, nugget: 2.0,
sill: 35.0, effective range: 154.9 m

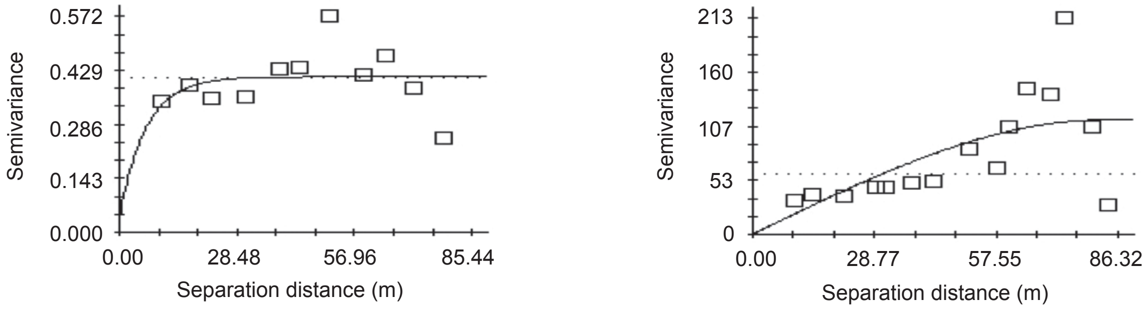
Figure 2 Spatial structure and attributes of litter, hemic and total forest floor depths at the sideslope, Sungai Kial Forest Reserve

Litter depths were higher in the south-western region of the summit and levelled off towards the south-eastern region (Figure 4a). Hemic values plunged to shallow depths in the west-east transect and increased slightly in the south-eastern and the north-western areas. Total forest floor was erratic at the summit, illustrating peaks in the east (Figures 4b and c).

Litter distribution at the sideslope was markedly high (> 2 cm) in the north-eastern area and slowly levelled off towards the east (Figure 5a). Hemic and total forest floor were more profound in the north-eastern and the south-eastern regions of the forest. Both variables were less than 5 cm in the north-western section with no definitive peak values (Figures 5b and c).

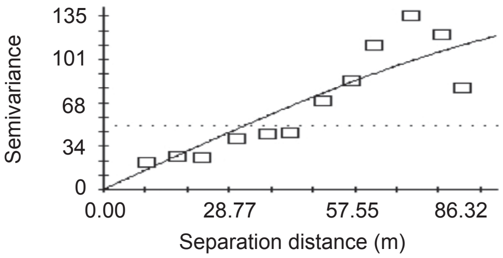
Litter depths ranged from 0.6 to 3.4 cm at the toeslope but pockets of high peaks were encountered in the north and west (Figure 6a). Conversely, clustered peaks of hemic values were seen in the north-eastern to the south-western transects where values were way above 10.5 cm. The extent of total forest floor was mostly high at all toeslope areas and thickness increased in the south-western region (Figures 6b and c).

Generally, different components of forest floor consistently exhibited dissimilarities between each other and in varying slopes. This was also true for carbon contents of the decomposing layers which ranged from 37 to 43%. Total forest floor thickness varied from 1 to 26 cm in this study compared with 6 to 15 cm reported by Penne et al. (2010). This further proved that it was necessary to quantify the spatial variability according to various decomposition stages and at topographic positions to provide better assessment of forest floor carbon stocks in montane forests. Spatial



(a) Litter depth (cm)
Model: exponential, spatial dependence: strong,
nugget: 0.04, sill: 0.41, effective range: 6.4 m

(b) Hemic depth (cm)
Model: spherical, spatial dependence: strong,
nugget: 0.1, sill: 113.1, effective range: 83.1 m



(c) Total forest floor depth (cm)
Model: spherical, spatial dependence: strong,
nugget: 0.1, sill: 139.50, effective range: 133.3 m

Figure 3 Spatial structure and attributes of litter, hemic and total forest floor depths at the toeslope, Sungai Kial Forest Reserve

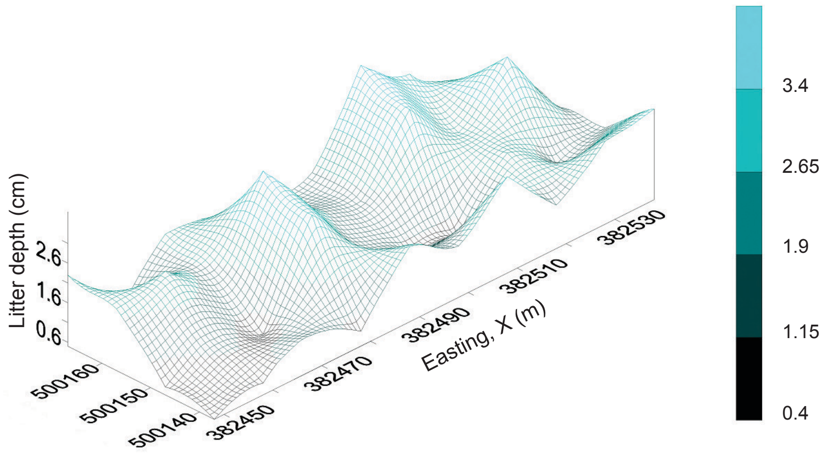
Table 4 Cross-validation statistics of kriged values at Sungai Kial Forest Reserve

Site	Variable	Model	Sample variance	ME	MSE	SMSE
Summit	Litter	S	0.78	0.03	0.76	1.00
	Hemic	E	25.02	-0.24	24.25	1.00
	Total forest floor	E	0.02	-0.01	0.02	0.96
Sideslope	Litter	E	0.95	-0.01	0.86	0.93
	Hemic	S	9.45	0.01	4.58	0.57
	Total forest floor	S	13.45	0.01	6.79	0.52
Toeslope	Litter	E	0.40	0.04	0.38	0.95
	Hemic	S	59.74	0.01	43.93	0.75
	Total forest floor	S	49.30	-0.02	28.11	0.58

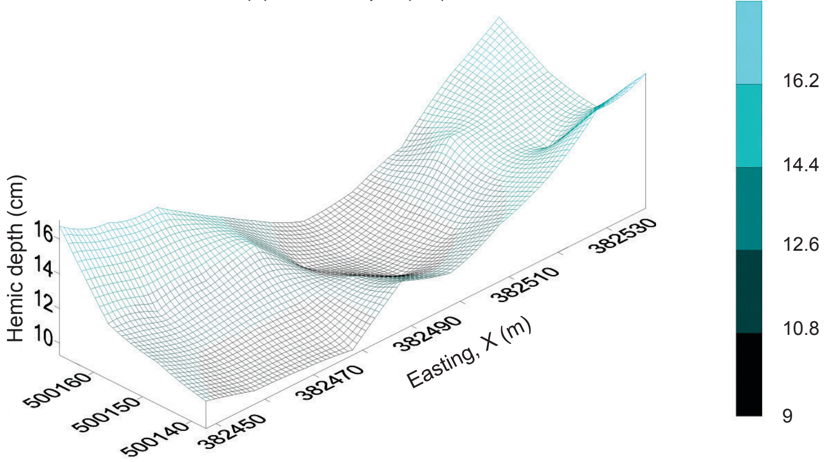
S = spherical, E = exponential; ME = mean error, MSE = mean squared error and SMSE = sum of mean squared error

variability of forest floor depth in tropical montane forest was closely related to topographic positions as well as processes involved in debris accumulation and mobilisation, and production and decomposition of organic material.

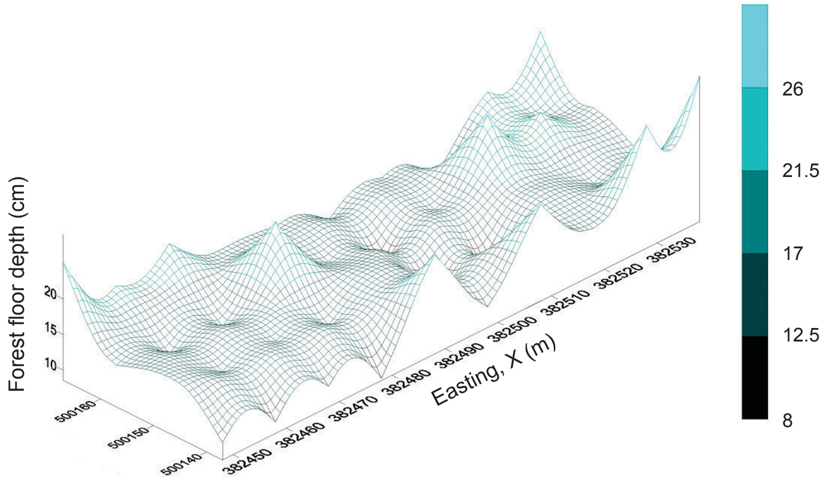
Heavy accumulation of forest floor, especially hemic at the toeslope was the result of gravitational forces that influence soil, water and forest floor fragment transportation (Martin & Timmer 2006). This was confirmed in a previous



(a) Litter depth (cm)

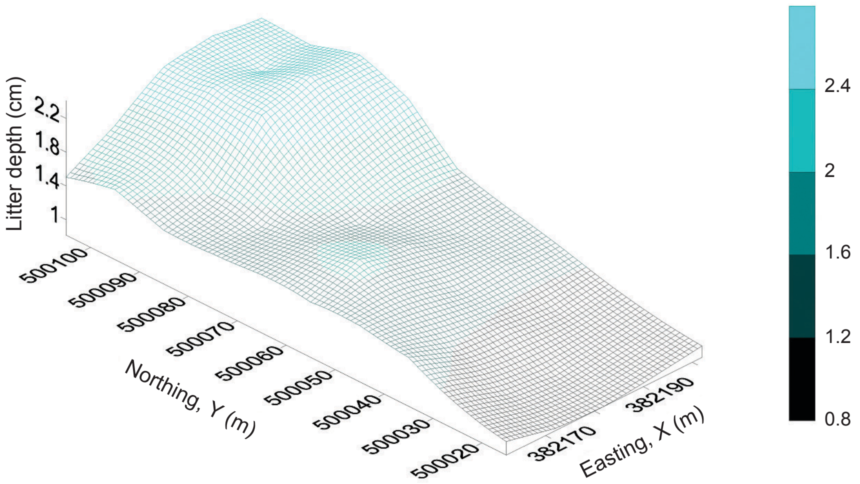


(b) Hemic depth (cm)

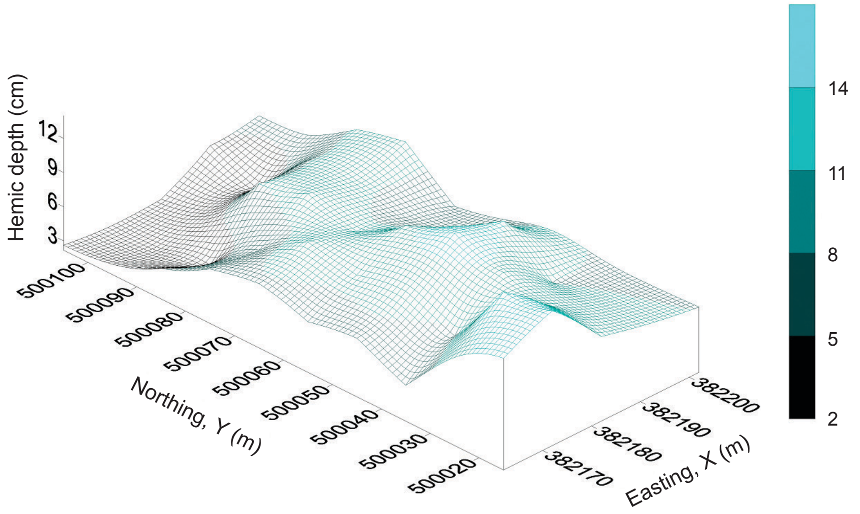


(c) Total forest floor depth (cm)

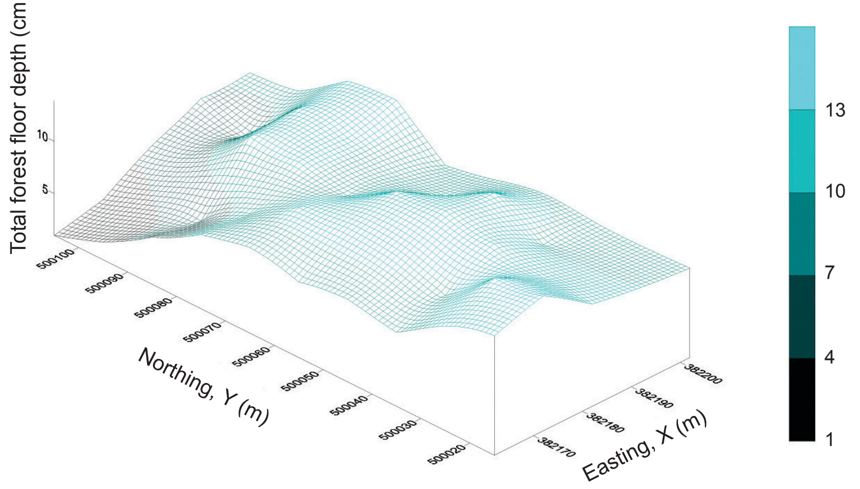
Figure 4 Spatial variability of litter, hemic and total forest floor at the summit of Sungai Kial Forest Reserve



(a) Litter depth (cm)

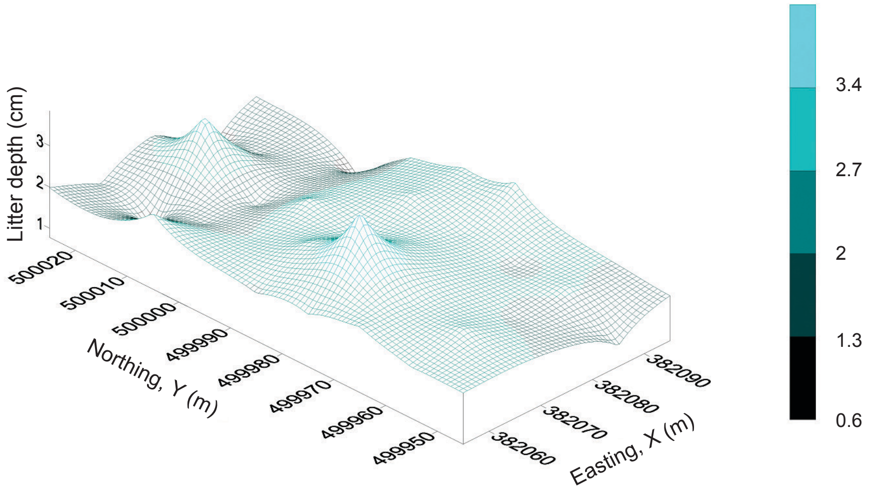


(b) Hemic depth (cm)

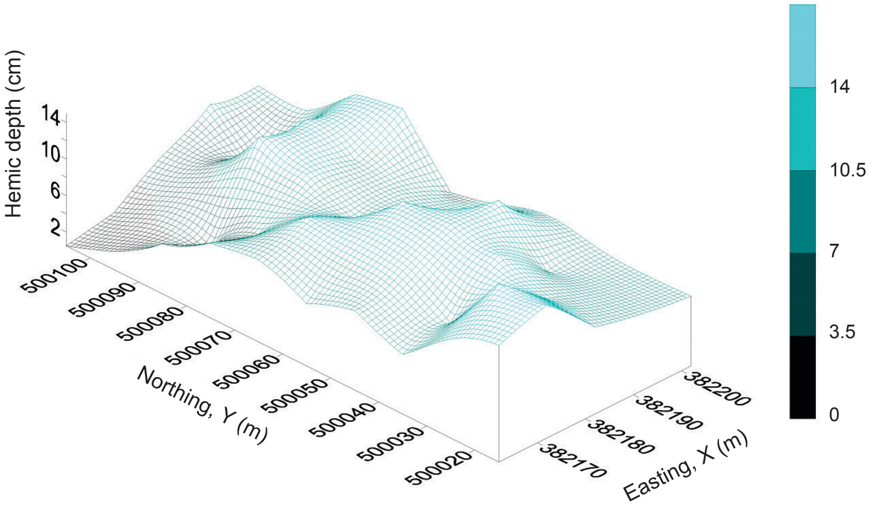


(c) Total forest floor depth (cm)

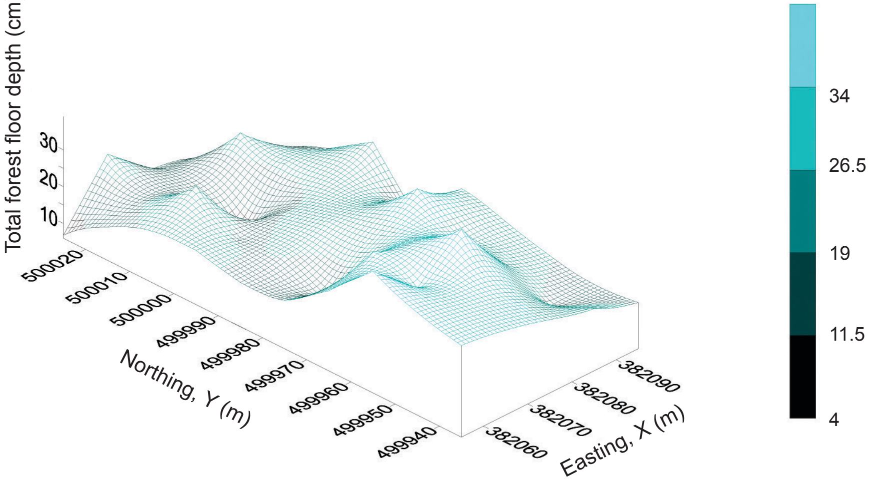
Figure 5 Spatial variability of litter, hemic and total forest floor at the sideslope of Sungai Kial Forest Reserve



(a) Litter depth (cm)



(b) Hemic depth (cm)



(c) Total forest floor depth (cm)

Figure 6 Spatial variability of litter, hemic and total forest floor at the toeslope of Sungai Kial Forest Reserve study where the highest forest floor accumulation was at the toeslope and soil carbon stocks reported were 98 and 126 Mg C ha^{-1} for summit and toeslope respectively (Jeyanny et al. 2013). Litter was randomly distributed and exhibited lower effective range for summit and toeslope, confirming its high variability in the montane forest. Production of litter was governed by various tree species and tree population density for primary litter components (Gourbiere & Debouzie 1995) and more complex mechanisms (time, soil moisture, temperature) for secondary components such as sapric and hemic. Tree basal area was more uniform compared with species variation at all slope positions. Thus, biodiversity of tree species and dynamic variables that influence decomposition process may have had more prominent role in determining forest floor thickness and carbon contents, which need to be addressed for refined stocks estimates.

CONCLUSIONS

Litter, hemic and total forest floor depth fractions confirmed spatial variations according to topography. Hemic and total forest floor were highest at the toeslope where hemic constituted approximately 80% of total forest floor. Spatial structure of test variables varied across and within the catena. Most variables exhibited strong spatial dependence with the exception of hemic layer at the summit which exhibited moderate spatial dependence. The effective range for most test variables showed moderate values except for litter depth which revealed shorter range for summit and toeslope. Shorter effective range implied that spacing of samples should be closer, and longer effective range suggested that the distance between sampling can be increased, leading to cost savings especially at the sideslope. The majority of surface maps of the test variables showed distinct spatial clustering and displayed acceptable accuracy of interpolated values, suggesting that litter depths, hemic and total forest floor depths along elevational gradients could be estimated reliably via geospatial analysis. Carbon contents of the forest floor were also markedly different in the various layers. Thus, topographic delineation is one prerequisite that needs to be considered for various purposes, including assessment of carbon stocks for national carbon accounting and establishment of conservation and erosion control strategies, especially in tropical montane forests. Future research should quantify spatial variability of forest floor carbon stocks to compliment soil carbon stocks values.

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