Spatial Modeling of Nature Conservation Variables useful in Forestry Planning

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ABSTRACT

A method of estimating the spatial distribution of some natural occurring characteristics important to nature conservation is described and applied to a managed forest in southern Sweden. Forest compartments were stratified by age and three different kinds of variables, namely the amount of Coarse Woody Debris (CWD), the coverage of the Forest Floor Vegetation (FFV) and the Nature Conservation Value (NCV), were measured at 289 geo-referenced circular sample plots. Spherical and exponential functions describing spatial autocorrelation were derived from semi-variograms and kriging was used to create contour maps by spatial interpolation. A majority of the investigated variables proved to be spatially autocorrelated.

For many variables the semi-variograms showed an evident nugget effect, which either could be explained by random measurement errors or, perhaps more likely, by a component of the spatial process with shorter range than the shortest sampling interval of about 30 - 40 meters. Hence, to fully explain or model Nature Conservation Variables observations at even shorter distances than this would be helpful.

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INTRODUCTION

With the introduction of the new Swedish forestry act in 1993 environmental aspects of forestry became of equal importance to traditional forest production goals (Anon. 1994). A main objective of the environmental goal is to preserve the biological diversity (biodiversity). The established strategy to achieve this is to create a combination of reserves and to apply a modified forestry management to obtain an overall increased frequency of important natural structures and processes (Liljelund et al. 1992).

Coarse woody debris (CWD) is probably one of the most important structures with infrequent occurrence in Swedish forests and it has to be restored in order to promote biodiversity (Lämås & Fries 1995). A majority (70%) of the species in the Swedish red-data list, originating from forests, is tied to dead trees and about 26% and 21% is tied to down-logs and snags respectively (Gustafsson *et al.* 1993).

Biodiversity is possible to define and measure either directly or indirectly, i.e. by the presence of certain important species or the structures (substrates) to which they are tied. Today a lot of research is focused on finding appropriate methods that directly measures biodiversity. However, for planning purposes we mainly have to rely on indirect methods (Larsson *et al.* 1999) and furthermore, we need objective methods that are unbiased and have known precision (Lämås 1996).

Ecological studies often deal with spatial data and should consequently be based on a fundamental understanding of underlying spatial relations. Many features of the landscape can be described by quantities that are continuous and gradually change with distance, e.g. elevation of ground level and nutrients in soil (Burgess & Webster 1980). If the purpose of the investigation is to reveal a true ”picture” of a spatial relation, the ”Scale” of the investigation is crucial. ”Scaling” is a concept in ecology and describes the main frame at which all relevant information is possible to reveal. A change in scale often provides different patterns, variance and overall result (Wiens et al 1989). O’Neill (1986) describes our ability to detect these patterns as a function of the extent and grain of an investigation. The extent is similar to the scale and the grain corresponds to the sample unit. For this reason, the size (grain), shape, orientation and spatial arrangement of samples are important to consider. In geostatistics these sample features are known as the ”support” of the data and normally a change in support will change the variance in variables studied (Rossi et al 1992).

In the beginning of the 60’s Matheron (1963) established the basics of what we to day refers to as geostatistics. The theory of ”regionalized variables” is a central concept, meaning a variable, taking a definite value in each point of space, and having spatial autocorrelation. The autocorrelation is often represented by the semi-variogram that describes the semi-variance as a function of the distances between points in space. The semi-variance for the argument value h is simply the expected squared difference between two variable values at distance h. The intercept on the y-axis of the variogram is often greater than zero. This is the nugget effect, which could be a consequence of high variability of the variable over distances shorter than the sampling interval. It could also indicate sampling errors. The variogram usually increases with distance and stabilizes to a value equal to the population variance, called the sill. The distance at which the sill is reached is called the range.

The kriging technique makes use of the spatial information from the semi-variogram to predict values at unrecorded locations as a weighted average of observations at known locations. One of the main advantages of kriging is that all estimates are unbiased and of minimum and known variance (Webster 1996). Since estimated errors for the predicted values are obtained it is possible to construct combined estimates with minimum variance, where, e.g., aerial photos and satellite pictures (Holmgren & Thuresson 1995) are used as another source of information. These features make kriging highly suitable for forestry planning purposes, for both the inventory and the decision phase.

Geostatistics has been heavily applied in soil science (Burgess and Webster 1980), probably due to its originators. Still, a lot of different disciplines have adopted the theoretical principles. For example, Dancy et al (1986) successfully estimated grass cover and biomass in a semi-arid rangeland and Kemp et al (1989) created region-specific hazard maps of grasshopper densities.

This article is an attempt to introduce geostatistics as a tool for an understanding of the spatial distribution of some natural occurring characteristics important to nature conservation. The result from 289 geo-referenced circular plots was evaluated with histograms, scatter-plots. Semi-variograms were constructed and kriging was used for spatial interpolation and the method was internally evaluated by means of cross-validation.

MATERIALS AND METHODS

The study area and stand data

The study area is located in southern Sweden 40 km north of Växjö (57°10' N, 14°50' E). The forest estate is owned by the county board of forestry in Kronoberg and 263 ha was inventoried east of the North-South crossing main road in early autumn 1995. The study site is slightly sloping northeast towards the lake ASA with 2.8 % non-productive (< 1 m^3 ha^{-1} yr^{-1}) peat land. The study area is representative to this region although it is intensively managed with a mean stand size of 2.6 ha. According to an objective circular plot inventory in 1995 the mean standing volume was 139 m^3 ha^{-1} and the mean site productivity 7.4 m^3 ha^{-1} yr^{-1}. In 1995, Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and broad-leaved trees (mainly *Betula pendula*) contributed 41.5, 54.0 and 4.5 % respectively to the standing volume.

The sample design

Due to the characteristics of the investigated parameters and a tradition in Sweden to keep the forest ”clean”, especially in the regeneration phase, it was presumed that older stands would contain the most information of interest to nature conservation. Therefore the set of forest compartments was divided by age into four strata, with the purpose to use shorter spacing between plots in strata with higher age. The four strata, numbered 1 to 4, are: < 10 years, 10 - 30 years, 31 - 70 years and > 70 years.

A square grid, with randomized start, was used for each stratum to position circular plot centers. When constructing a variogram it is important to obtain information at short distances. In this study this was achieved by adding two sub-plots to the grid creating ”L”- shaped clusters. The two axes (N/S and E/W) were randomly given the length of 30 and 40 meters respectively and to each cluster one of the four directions (N, E, S or W) was randomly assigned.

Figur 1. Map showing the arrangement and positions of the 289 inventoried circular plots.

A total of 289 sample plots were measured and geo-referenced using Global Positioning System (GPS) with differential correction. All plots were surveyed using the methods of the Forest Management Planning Package (FMPP) (Jonsson et al.1993). The field inventory was mainly directed towards three study areas: The ground coverage of the Forest Floor Vegetation (FFV), the amount of Coarse Woody Debris (CWD) and the Nature Conservation Values (NCV). The sample plot radius was chosen as a reasonable size with respect to inventory work and information requirements, and was 10 meters for FFV and CWD and 15 meters for NCV. The subjective data registrations were supported by measurements with caliper, hypsometer etc. All measurements were made on all tree species.

Coarse Woody Debris (CWD)

Only CWD with butt end inside the sample plot and original stem distinguishable was included in this study and a minimum diameter of 10 cm's at root was set. Three different volume estimation methods were used depending on the form of the CWD, i.e., truncated logs, full-length stems and snags. Truncated logs left from forest cutting activity was callipered at top-butt end and in the case of buttresses the diameter was callipered 40 cm further in. Diameter was callipered at breast height for all full-length stems including down logs, and volume functions (Näslund 1947) were used for volume calculation. A small amount of top logs and snags were callipered at the center of the trunk. All standing dead trees and snags were height measured with hypsometer and sometimes visually measured and calibrated by using surrounding living trees. CWD was divided into four decay classes (Ehnström & Waldén 1986). The class was determined by the most decayed condition of the log. The classes were 1) Wood hard, bark intact, 2) Wood surface soft but intact, bark falling of in to big pieces, 3) Wood soft and the outline of the trunk deformed, hard core and 4) Wood soft all through the stem. For birch the decay class was determined only by the condition of the wood, thus the bark was not considered.

Forest Floor Vegetation (FFV)

The ground cover of the forest floor vegetation was measured for every sample plot and the plot-radius was checked by IR- and tape measurement. A smaller number of sample plots was sampled twice for calibration purposes. To assure high quality data, first a subjective partition of the plots into four sections was made and each section was carefully measured. Finally the measurements from the four sections were added. The ground coverage of each species of interest and covering more than 0.5 m^2 was visually estimated with respect to vegetation density. The vegetation classes used were those according to Hägglund & Lundmark (1987).

Nature Conservation Value (NCV)

Different characteristics of the forest may indicate areas likely to contain endangered species. A wide range of these characteristics is listed in Appendix 1 and is partly defined by subjective criteria with respect to the specific geographic location of this study. For each plot each of these characteristics was given the value of one and the values were added to bring a total NCV value for the plot. Objects that are tree dependent, e.g., tinder fungus (*Fomes fomentarius*), were counted even outside the plot if the substrate that the fungus benefits on was originated from the plot.

Geostatistical approach

The first step in the statistical analyses was to evaluate the degree of spatial dependence for every variable of interest. Empirical semi-variograms were estimated according to the expression

$$\hat{\gamma}(h) = \frac{1}{2m(h)} \sum_{i=1}^{m(h)} \left\{ z(x_i) - z(x_i + h) \right\}^2$$

where h is the distance (lag), $m(h)$ is the number of paired comparisons at distance h and $z(x_i)$ is the value at position x_i. For each value of h, all pairs of points with a distance close to h were included to obtain at least about 35 to 40 pairs in the sum above.

Two different parametric models were found appropriate to fit the empirical variograms in this study, the spherical model and the exponential model, given by the equations

$$\gamma_{(h)} = c\left\{\frac{2h}{3a} - \frac{1}{2}\left(\frac{h}{a}\right)^3\right\} \quad \text{for} \quad h < a$$

$$= c \quad \text{for} \quad h \geq a$$

and

$$\gamma_{(h)} = c\left\{1 - \exp(-h/r)\right\}$$

respectively. Here a is the range, h is the distance and c is the variance. The nugget effect, usually denoted c_0, was added to the two equations as a constant (Webster 1996) when fitting.

The second step was to create contour maps with ordinary punctual kriging, using the information of the model, the range and the nugget. The contour map pixel size was chosen to be approximately the same size as the inventoried plots, i.e. 18 * 18 m or 26 * 26 m (Fig. 3, 4, 6 and 7.).

To determine the efficiency of the kriging method a cross-validation technique was chosen (Höck et al. 1993). The true sampled value was temporarily discarded and estimated through kriging by using the remaining sample. This was done, one by one, for all 289 measured plots. Estimated and measured values were compared and evaluated by linear regression.

RESULTS

It was not possible to detect any spatial non-zero autocorrelation in strata 1 and 2. This is partly a consequence of the stratification, producing too few pair-wise comparisons in these strata. Only strata 4 contained a sufficient number of pairs and an aggregation of strata was made for this reason. Therefore strata 1 and 2 are combined with strata 3 and 4 in most results. Strata 4 produced similar semi-variograms as strata 3 and 4 aggregated and therefore these strata are never separated in the results.

The assumption that older stands should contain more information seems to be correct since the mean values for all the nature conservation variables, with no exception, were higher for strata 3-4 than strata 1-4.

The resulting semi-variograms are presented for all variables and the result is summarized in table 1, 2 and 3.

”Nature Conservation Value” (NCV)

Tab. 1. Data from semi-variance analysis of the ”Nature Conservation Value” variable.

Variable	$\sqrt{\text{nugget}}$	Range (m)	$\sqrt{\text{variance}}$	Mean	Value > 0 (n)
Conservation-Value, strata 1-4	1.33	129	2.26	2.41	221
Conservation-Value, strata 3-4	1.10	122	2.23	2.73	165
Conservation-Value, strata 4	1.13	114	2.34	3.57	89

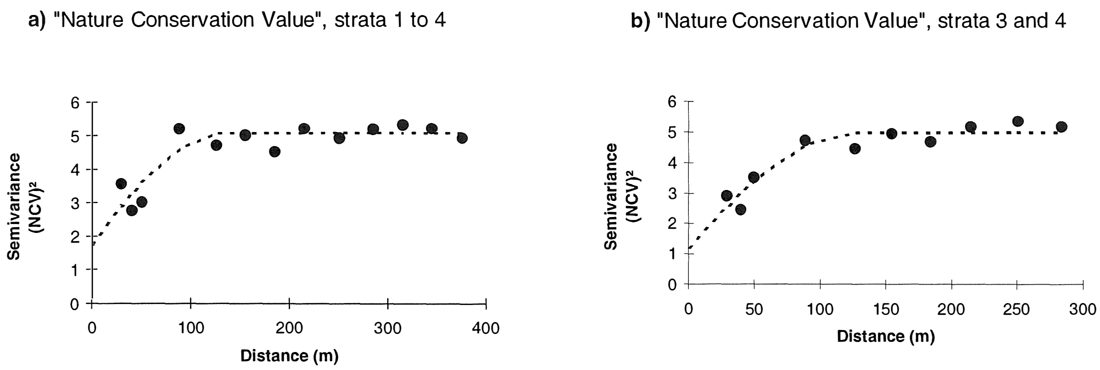

Fig. 2. Semi-variograms displaying spatial autocorrelation of "Nature Conservation Value" variable for a) strata 1 to 4, and b) strata 3 and 4. The dotted line represents the fitted theoretical model (spherical).

Fig. 3. Kriging estimates of the "Nature Conservation value" variable, the value ranging from 0 (white) to 10 (black). Strata 3 and 4.

Fig. 4. Standard errors of the "Nature Conservation value" prediction. Values ranging from 0 (white) to 3.11 (black). Strata 3 and 4.

The result from the cross-validation suggests that the kriging estimator of the NCV variable provides a better prediction when only strata 3 and 4 is included than when all four are so. The correlation between estimated and observed values is higher for strata 3-4 ($R^2 = 0.34$) than 1-4 ($R^2 = 0.26$) and this is also the overall highest correlation among all NCV and CWD variables in this study.

Coarse Woody Debris (CWD)

In order to reveal any spatial correlation between sample plots a thorough analysis of the CWD data was carried out. Deciduous trees only comprised a very small volume of the total CWD and did not show any autocorrelation. For some variables it was difficult to determine the most appropriate model for fitting the empirical variogram. This was especially true for CWD variables of Norway spruce (*Picea abies*), strata 3-4, which produced smooth but flat semi-variograms. The models chosen for the CWD variables are presented in table 2.

Tab. 2. Results from the semi-variance analysis of "Coarse woody debris" variables. Variables for which no result is reported did not display any autocorrelation.

Variable	$\sqrt{\text{nugget}}$	Range	$\sqrt{\text{variance}}$	Mean	Value > 0 (n)	Model
Total CWD (m^3), strata 1-4	0.256	161	0.435	0.264	206	Spher.
Total CWD (m^3), strata 3-4	0.213	108	0.340	0.298	152	Spher.
Pine, CWD (m^3), strata 1-4	0.010	80	0.279	0.084	96	Spher.
Pine, CWD (m^3), strata 3-4	0.010	79	0.307	0.087	71	Spher.
Spruce, CWD (m^3), strata 1-4	0.229	205	0.340	0.152	138	Spher.
Spruce, CWD (m^3), strata 3-4	0.255	179	0.364	0.186	106	Expo.
Total truncated CWD (m^3), strata 1-4	-	-	-	-	114	
Pine, truncated CWD (m^3), strata 1-4	-	-	-	-	51	
Spruce, truncated CWD (m^3), strata 1-4	-	-	-	-	61	
Total snags CWD (m^3), strata 1-4 and 3-4	-	-	-	-	76 and 64	
Pine, snags CWD (m^3), strata 1-4	0.090	202	0.112	0.023	28	Spher.
Pine, snags CWD (m^3), strata 3-4	0.065	185	0.126	0.026	24	Spher.
Spruce, snags CWD (m^3), strata 1-4 and 3-4	-	-	-	-	44 and 38	
Total logs CWD (m^3), strata 1-4	0.010	163	0.330	0.116	133	Spher.
Total logs CWD (m^3), strata 3-4	0.010	142	0.340	0.133	105	Spher.
Pine, logs CWD (m^3), strata 1-4	0.010	151	0.225	0.033	42	Spher.
Pine, logs CWD (m^3), strata 3-4	0.010	168	0.289	0.037	34	Spher.
Spruce, logs CWD (m^3), strata 1-4	0.085	209	0.242	0.071	89	Spher.
Spruce, logs CWD (m^3), strata 3-4	0.089	196	0.232	0.088	73	Expo.
Tot snags and logs CWD (m^3), strata 1-4	0.192	160	0.396	0.195	164	Spher.
Tot snags and logs CWD (m^3), strata 3-4	0.255	179	0.412	0.234	128	Spher.
Pine, snags and logs CWD (m^3), strata 1-4	0.010	186	0.276	0.056	62	Spher.
Pine, snags and logs CWD (m^3), strata 3-4	0.010	163	0.313	0.063	51	Spher.
Spruce, snags and logs CWD (m^3), strata 1-4	0.218	179	0.312	0.122	110	Spher.
Spruce, snags and logs CWD (m^3), strata 3-4	0.255	173	0.342	0.157	90	Expo.
Decay classes CWD, strata 1-4	-	-	-	-	206	
Decay classes CWD, strata 3-4	-	-	-	-	152	

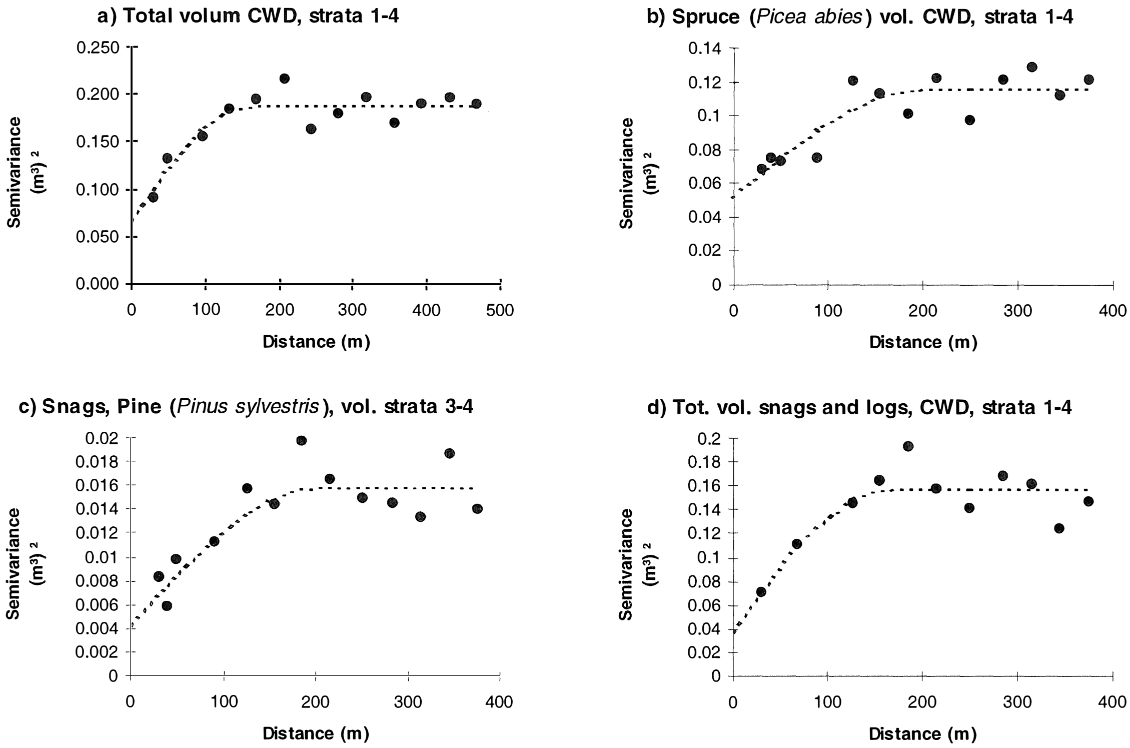

Fig. 5. Semi-variograms displaying spatial autocorrelation of "Coarse Woody Debris" variables. The dotted line represents the fitted theoretical model (spherical).

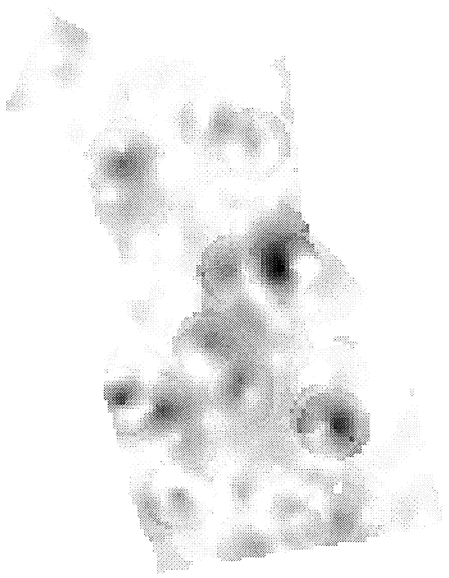

Fig. 6. Kriging estimates of the total volume of CWD (m^3). Values ranging from 0 m^3 ha^{-1} (white) to 3.32 m^3 ha^{-1} (black). Strata 1- 4.

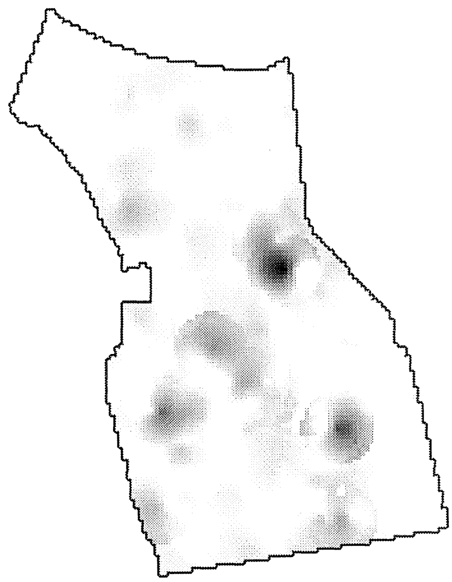

Fig. 7. Kriging estimates of the total volume of CWD of down-logs. Values ranging from 0 m^3 ha^{-1} (white) to 3.25 m^3 ha^{-1} (black). Strata 1- 4.

Forest Floor Vegetation (FFV)

The same kind of analyses as above was also made for FFV and the results are summarized in table 3 and figure 8.

Tab. 3. Results from the semi-variance analysis of the "Forest Floor Vegetation" variables. Variables for which no result is reported did not display any autocorrelation.

Variable	$\sqrt{\text{nugget}}$	Range (m)	$\sqrt{\text{variance}}$	Mean	Data > 0 (n)
Sphagnum sp. – Polytrichum sp. (m^2), strata 1-4	3.16	152	49	27.9	94
Sphagnum sp. – Polytrichum sp. (m^2), strata 3-4	24.7	246	86.3	38.5	72
Tall herb (m^2)	-	-	-	-	35
Short herb (m^2)	-	-	-	-	35
Vaccinium myrtillus (m^2), strata 1-4	9.4	118	49	28.4	204
Vaccinium myrtillus (m^2), strata 3-4	9.8	101	53.6	38.5	165

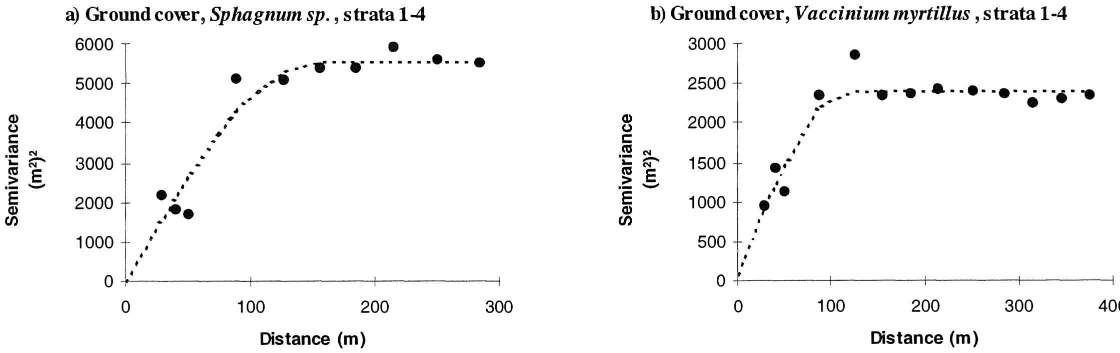

Fig. 8. Semi-variograms displaying spatial autocorrelation of "Forest Floor Vegetation" variables. The dotted line represents the fitted theoretical model (spherical).

DISCUSSION

The statistical theory of the variogram is fairly simple and there are lots of papers written on the subject in many different disciplines Nevertheless it is a comprehensive work to model the proper variogram that corresponds to the most accurate description of the data observed. This is especially true when the aim is to investigate variables that exhibit short ranges with few lag classes represented in data within the given range. In general, the theoretical model may be fitted visually or estimated statistically within a class of functions, either by the method of least squares or a weighed version of it. The final choice of model is to some extent subjective, based on non-statistical knowledge and the uncertainty caused by this increases with irregular and erratic data.

What is the connection between knowledge or "reality" and the variogram? The nugget effect may, as stated earlier, arise from a lack of information in distances less than the shortest sampling interval. A true variogram that increases fast close to $h = 0$ could appear to have a nugget effect if appropriate data is missing. For some of the variables studied it is likely to assume that the spatial process contains a component with short range, where the range falls short of the sampling interval. The variance (sill) of this component then explains why a nugget effect seems to exist when the process is observed at distances equal to the sampling interval. Evident cases here are vegetation variables like *Vaccinium myrtilllus* (Fig. 8b) and especially *Sphagnum sp*. (Fig.8a), but can also be seen in the NCV variable (Fig.2a).

A complicated reality demands a more complex theoretical model and construction of such a model requires a detailed study of the investigated variable. If the spatial relationship is restricted to areas with either “all or nothing” the benefits from the theory of the “regionalized variable” is somewhat limited.

For some of the variables it has been impossible to fit a model (Tab. 2 and 3). There are mainly two reasons behind this. First, it may not exist any spatial (non-zero) autocorrelation, which is likely to be the main reason for the non-autocorrelated CWD variables in tab.2. Secondly, the occurrence of one’s (or zero’s) of some binary valued variables was too low and scattered, which is the case for Short and Tall herbs (Tab. 3). Snags from *Picea abies* did not display any autocorrelation but snags from *Pinus sylvestris* did. If this is a result that truly describes a difference in spatial distribution of snags for the two species or just reflects the specific conditions unique for the investigated area remains to be revealed.

The sample design is difficult to optimize when the investigated variables display different characteristics in space and to some extent in time. In this study, stratification was performed with respect to age of the forest. Vegetation variables are probably better classified using geological maps and with interpretation of color infrared (CIR) aerial photos (Ihse 1993). Natural structures important from the aspect of nature conservation, including CWD, are possible to detect using CIR aerial photos (Lämås & Fries 1995). However, in a forest with management oriented towards highest timber production these natural structures are rare and the aim is not necessarily to find objects with true nature conservation values but to find objects with high potential to future development. (Angelstam & Andersson 1997)

Exclusion of strata 1 and 2 in general decreased the nugget effect and increased the multiple coefficient of determination (R^2) for all CWD- and NCV variables, as shown by the cross validation.

Addition of the extra samples from strata 1 and 2 facilitated the smoothing of the variogram when combined with the values in strata 3 and 4. The reason is that the addition of samples covered more of the overall forest variability. The drawback is that the addition of almost uncorrelated observations increased the semi-variance in lag-classes within the given range and thus provided changed and less steeply sloping semi-variance curves.

An important factor to consider when constructing the sample design on small forest estates concerns the number of pairs in the estimation of the empirical variogram. It is necessary to ensure a minimum number in each lag class to avoid large random errors. In this study the minimum was 35 to 40 pairs and this figure was not always attained in single strata. This was especially the case when an (unreported) anisotropy analyze was carried out, with the purpose to check whether the autocorrelation was the same for different directions or not.

There is a sample design problem to balance a wide grid and more satellite plots that improves variogram construction against a tighter grid and fewer satellite plots that results in higher accuracy of the kriging predictions. The final arrangement of plots is also dependent on the size of the total area to be studied. When dealing with rare objects and, in addition to that, objects that exhibit short ranges it is important to both increase the number of lag classes within the range and to shorten the distance between plots in the grid. In this study there is a maximum of four, often three, lag classes in the range of 100 meter and at least one extra lag class in the range of 70-90 meter would have been desirable.

As a conclusive remark it is justified to say that many naturally occurring structures important to nature conservation, especially CWD, is spatially continuous and this holds true even for the intensively managed forest studied. Notably is also that truncated CWD appeared in 39 % of the plots but did not show any autocorrelation.

Further investigations concerning spatial continuity would comprise virgin forests or at least forests free from sharp stand borders and with naturally occurring structures and processes important to nature conservation.

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Appendix 1.

CHARACTERISTICS for the NCV variable

The fulfilment of each of the following criteria has contributed by 1 to the NCV variable.

1. Considerable diameter spread of main tree species. Trees represented in each cutting class.
2. Deviating number of trees with coarse diameter. Number of trees >= 3 with diameter >= 40 cm.
3. Over aged trees. Trees > 127 years old. 1,5 * 85 years (Average length of prod. cycle for this particular forest-estate).
4. Natural thinning. Characterised by dense stands with standing dead/dying trees.
5. Open forest. Sparsely covered stands. Demands large gaps, > 50 % of total area.
6. Solitaire trees. One or more free-standing trees without shading surroundings.
7. Many trees with distinct sockets.
8. Standing dead trees/snags.
9. Many standing dead trees/snags. Objects > 2.
10. Standing dead trees/snags. Exposed to sun.
11. Dying or recently dead trees. Down-logs, snags and standing trees.
12. Down-logs.
13. Many down-logs. Objects > 2.
14. Down-logs. Coarse diameter > 30 cm.
15. Down-logs. Coarse diameter > 30 cm. Exposed to sun.
16. Down-logs in different decomposition stages.
17. Polypores. Growing on tree stems.
18. Bryophytes growing on stems of deciduous trees.

19. Hanging lichens. “Beard-like” lichens, e.g. *Usnea sp*.

20. Bryophytes growing on vertical “wall” of stone. Stone wall higher than 2 meter.

21. Berry bushes, e.g. Dog-rose (*Rosa canina*), Blackthorn (*Prunus spinosa*), Alpine currant (*Ribes alpinum*)

22. Field layer rich in species.

23. Fire traces. Remnants left from fire.

24. Uprooted Trees. Root system and soil exposed.

25. Flat rocks/rocks revealed.

26. Stony soil. Ground characterized by boulders.

27. Damp/wet soil.

28. Topsoil with moving water. Water table emerging.

29. Spring.

30. Brook/stream.

31. Adjoining wetland/lake.

32. Coarse Pine (*Pinus sylvestris*). Diameter > 35 cm.

33. Aspen (*Populus tremula*) / Sallow (*Salix caprea*). Diameter > 10 cm.

34. Common black alder (*Alnus glutinosa*) / Bird-cherry (*Prunus padus*) / Rowan-tree (*Sorbus aucuparia*). Diameter > 10 cm.

35. Deciduous trees. Diameter > 30 cm.

36. Coarse hardwood trees. Diameter > 40 cm. Mainly Ash (*Fraxinus exccelsior*), Oak (*Quercus robur*), Maple (*Acer platanoides*) and Elm (*Ulmus glabra*).

37. Coarse Norway spruce (*Picea abies*). Diameter > 45 cm.

38. “Bouquet” growing trees. Mainly Hazel (*Corylus avellana*).

39. Mixed tree species. Deciduous trees > 30 % of total tree volume.

Serien Arbetsrapporter utges i första hand för institutionens eget behov av viss dokumentation. Rapporterna är indelade i följande grupper: Riksskogstaxeringen, Planering och inventering, Biometri, Fjärranalys, Kompendier och undervisningsmaterial, Examensarbeten samt internationellt. Författarna svarar själva för rapporternas vetenskapliga innehåll.

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