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CAN WE GAIN PRECISION BY SAMPLING WITH PROBABILITIES PROPORTIONAL TO SIZE IN SURVEYING RECENT LANDSCAPE CHANGES IN THE NETHERLANDS?

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Abstract. Seventy-two squares of 100 ha were selected by stratified random sampling with probabilities proportional to size (pps) to survey landscape changes in the period 1996–2003. The area of the plots times the urbanization pressure was used as a size measure. The central question of this study is whether the sampling with probabilities proportional to size leads to gain in precision compared to equal probability sampling. On average 1.03 isolated buildings per 100 ha have been built, while 0.90 buildings per 100 ha have been removed, leading to a net change of 0.13 building per 100 ha. The area with unspoiled natural relief has been reduced by 2.3 ha per 100 ha, and the length of linear relicts by 137 m per 100 ha. On average 74 m of linear green elements have been planted per 100 ha, while 106 m have been removed, leading to a net change of −31 m per 100 ha. For the state variables 'unspoiled natural relief', ' linear relicts', 'removed linear green elements', and 'new – removed linear green elements' there is a gain in precision due to the pps-sampling. For the remaining state variables there is no gain or even a loss of precision ('new buildings', 'removed buildings', 'new – removed buildings', 'new linear green elements'). Therefore, if many state variables must be monitored or when interest is not only in the change but also in the current totals, we recommend to keep things simple, and to select plots with equal probability.

Keywords: land use change, monitoring, probability sampling, probabilities proportional to size

1. Introduction

Changes in natural, semi-natural and cultural landscapes such as changes in the acid/base status of lakes and forest soils and changes in ecological communities due to global climate change or direct human intervention, are of increasing concern. Timely information on these changes and on the current condition of the environment is crucial for making proper decisions on the management of the environment and the development of sustainable landscape systems. As a result, many networks for monitoring have been installed in the past decades all over the world. The networks focus on certain aspects of the environment such as the quality of the air, the surface water, the groundwater or the soil, the abundance of plant or animal species, biodiversity, abundance of ecologically important landscape elements such as hedgerows, *etcetera*. For instance, in the United States of America the Environmental Protection Agency (USEPA) started in the late eighties of the previous century the Environmental Monitoring and Assessment Programme (EMAP) (Messer et al. 1991). The primary objective of EMAP is to estimate, with known confidence, the current status, extent, change and trends in indicators of the condition of the Nation's ecological resources – forests, arid lands, agro-ecosystems, wetlands, lakes, streams, Great Lakes, estuaries, and near-coastal systems. The networks for these resources have a common foundation, and are tailored to the extent of the resource under study; see Larsen et al. (1994) for the selection of a sample of lakes and Herlihy et al. (2000) for sampling of streams. Examples from the Old World are the Countryside Survey of Great Britain (Barr et al. 1994) and the 3Q monitoring scheme of Norway (Dramstad et al. 2002).

This paper takes the perspective of the geomorphologist and the historical geographer studying the genesis and the present development of the landscape. For changes in these aspects of the landscape, urbanization and related spatial developments are seen as the most important driving forces. In the Netherlands geomorphologic changes are usually a result of change in land use rather than erosion (except for the southernmost region of Limburg). Due to ground works related to urbanization and agricultural adaptations, significant areas have lost their geomorphologic and historical geographical identity (Rijksinstituut voor Volksgezondheid en Milieuhygiëne and Stichting DLO 2003, 2004). These changes have a large impact on landscapes which still reflect the genesis over many centuries. The resulting landscapes are places that become detached from their (natural) history.

Both geomorphologic and historical-geographical values of the Dutch landscape have been acknowledged by the Dutch government (LNV 1992, VROM 2004). In the most recent publication, the government launched the 'National Landscapes' to ensure a sustainable development of landscapes with high values (natural and cultural). The sustainable development will be reinforced by stimulating the spatial quality and character of these landscapes. For implementation and continuation of the National Landscapes policy, instruments for monitoring will prove to be essential.

This paper presents and evaluates a new methodology for surveying changes during the recent past in both geomorphologic and historical-geographical state variables of the landscape. The methodology deals with sampling aspects, determination of change in selected sampling units, and statistical inference (estimation and testing procedures). The sampling scheme is designed to determine realized changes in the recent past, not to monitor state variables of the landscape in the future.

A first attempt for a survey of recent landscape changes in the Netherlands was carried out by Dijkstra et al. (1997). In this survey 750 squares of 1 km^2 were investigated using topographical maps from different years. Although this research led to a valuable database and a first insight as to what was going on in the Dutch landscape, the method applied is not good enough for routine applications. First of all the use of topographical maps without a field check introduces errors as a result of differences in cartography throughout the years and omissions on the maps (Bakermans 1986). Secondly, the selection procedure of the 750 squares did not allow calculating valid confidence interval estimates of the changes.

Therefore a new survey sampling scheme has been developed for surveying recent changes in the landscape at a detailed level. Important characteristics of the new scheme are selection of sampling units by probability sampling (a form of random sampling) and determination of change by fieldwork. This paper describes the procedure for:

- selection of the sampling units, i.e. the sampling design;
- determination of changes in the landscape in the sampling units;
- estimation of the mean changes for the Netherlands.

Special attention was given to whether the sampling design was efficient, compared with less complex sampling designs such as stratified simple random sampling. The method by which this design-effect was assessed is described in a separate subsection. For eight landscape variables the estimated changes and the design-effects are presented. Conclusions are drawn in a final section.

2. Methods

2.1. Study area and landscape variables

The object of the survey is the Netherlands, further restricted to the rural land surface. Large water bodies such as lakes and seas, and urbanized areas fall outside the sampling domain. The rural land surface is split up into eight main landscape-types as used in policy making and spatial research (LNV 1992, VROM 2004). These landscapes reflect the combined evolution of nature and man. The eight landscape types can be aggregated into a commonly used twofold division of the Netherlands into low and high. The low western part, which is mostly below sea-level and consists of Holocene deposits, came into existence from the middle ages as man made maximum profit of natural processes to create polders. The second is the higher eastern part of the country, generally well above sea level, characterized by periglacial coversands, glacial remnants and rivers. As stated in the introduction, the Dutch landscape consists of mixed natural and cultural elements which cohesively reflect the landscape character. This is also reflected in the state variables of the landscape that have been studied, which include dominantly natural and cultural aspects. Natural aspects focus on the geomorphology (relief), cultural aspects on historical roads, waters and land reclamation structures still visible in the present landscape. For geomorphology the variable is defined as the total area of unspoiled natural relief (ha per 100 ha). The variable used to study the historical features is described as the total length of historical roads, waters and land reclamation structures (meters per 100 ha). The term 'historical' here applies to landscape elements that were already present in 1900. In addition to these two variables, also changes in land use have been recorded, for possible explanation of the changes in geomorphologic and historical features. These land use changes are surveyed by the numbers of isolated buildings in the rural area (numbers per 100 ha), and by the length of linear green elements mainly consisting of tree-rows, wooded banks, and hedgerows (meters per 100 ha). The number of buildings and linear green elements may increase or decrease in time, whereas by definition the area with unspoiled natural relief and the length of linear relicts can only decrease. To be able to distinguish between the situation where many buildings are removed and newly built (resulting in a small net change in number of buildings) and the situation with small changes in both components (no dynamics), we recorded not only the net change in the number of buildings, but both the number of new isolated buildings and the number of removed isolated buildings. For the same reason we recorded the length of disappeared linear green elements and the length of new linear green elements.

2.2. Sampling design

The sampling units are formed by the rural part of the Netherlands inside squares of 100 ha. These squares have fixed boundaries, and are used in many other surveys of natural resources, such as of birds and vegetation. Note that the support of the sampling units, i.e., the size and the geometry is not constant. For instance, for squares near the national border and with a large proportion urban area, the rural area is much smaller than 100 ha. Determination of the current and previous status of the landscape in a sampling unit is laborious and therefore expensive (see next section). With the available budget we could afford visiting 72 sampling units. These units were selected by probability sampling, i.e., by random selection such that all units in the study area have a positive and known probability of being included in the sample. The main advantage of probability sampling over convenience and purposive sampling is that population parameters such as the mean change and its precision (variance of sampling error) can be inferred with design-based estimators having desirable properties such as unbiasedness and validity of confidence intervals (Brus and De Gruijter 1997). Peterson et al. (1999) have shown that the cumulative distribution function (cdf) of secchi depth of lakes estimated from a convenience sample fell outside the confidence zone of the cdf estimated by probability sampling. In convenience sampling we must assume that the sample is representative. In this example the convenience sample clearly was not representative due to overrepresentation of large lakes with large secchi depths. In probability sampling representativeness can be guaranteed in the sense that the combination of sampling design and estimator is unbiased, i.e., if the sample selection and estimation would be repeated an infinite number of times, then the average of the estimates would be equal to the true (but unknown) value of the population parameter. An alternative to probability sampling is purposive sampling, for instance by selecting the sampling units that cover the study area the best (spatial coverage sample). For statistical inference then a stochastic model of spatial variation (like a geostatistical model) must be introduced. Englund (1990) has shown that a group of statisticians that was given the same dataset, chose a large variety of models, introducing unwanted subjectivity in the estimation procedure. Also, the quality of the estimates relies heavily on the quality of the assumed geostatistical model. In a design-based approach randomness is introduced at the sampling stage by probability sampling. No geostatistical model need to be introduced to account for the sampling error, and the sampling variance of the estimated changes can be derived from the known pairwise inclusion probabilities as determined by the sampling design. For the same reasons the US Environmental Protection Agency (EPA) based the Environmental Monitoring and Assessment Programme (EMAP) on probability sampling (Messer et al. 1991).

Probability sampling can be done in many ways (Cochran 1977). We selected sampling units by stratified-pps sampling, which will be explained now. The 35536 sampling units comprising the entire study area were partitioned into fifteen strata. The eight landscapes mentioned above were used as main strata. The landscapes Coversand, Marine clay, Lowland peat, and Peat reclamation extend over large parts of the Netherlands. These strata have been subdivided into several geographical substrata to improve the spatial coverage of the sample. This resulted in fifteen strata in total (Figure 1, Table I). Within a stratum, sampling units were selected with probabilities proportional to 'size' (pps sampling). Suppose one wants to estimate the total of a given landscape element, for instance the total length of linear green elements in the Netherlands. We expect that, on average, the total length of linear green elements in sampling units of 100 ha is larger than in smaller sampling units. If this is true, then the precision of the estimated total can be increased by selecting sampling units with probability proportional to the size of the sampling units. In our case we do not want to estimate the totals of landscape elements, but the *change* of the totals, i.e. the difference of two totals at different occasions (sampling times). Therefore, the areas have been multiplied by a factor representing urbanization-pressure (Milieu- en Natuurplanbureau 2001). We expect that this new measure of size will be more strongly correlated with the changes in the totals than the raw measure of size (area), and as a result a better ancillary variable for selecting the sampling units. In constructing a size-measure we must take care that the size-measure must always be strictly positive. The size ranges from 0.01–30.7, with a mean of 1.748 and a median of 1.060. The probability p_{hi} that in one draw a sampling unit i in stratum h is selected equals

$$p_{hi} = \frac{z_{hi}}{\sum_{j=1}^{N_h} z_{hj}}, \tag{1}$$

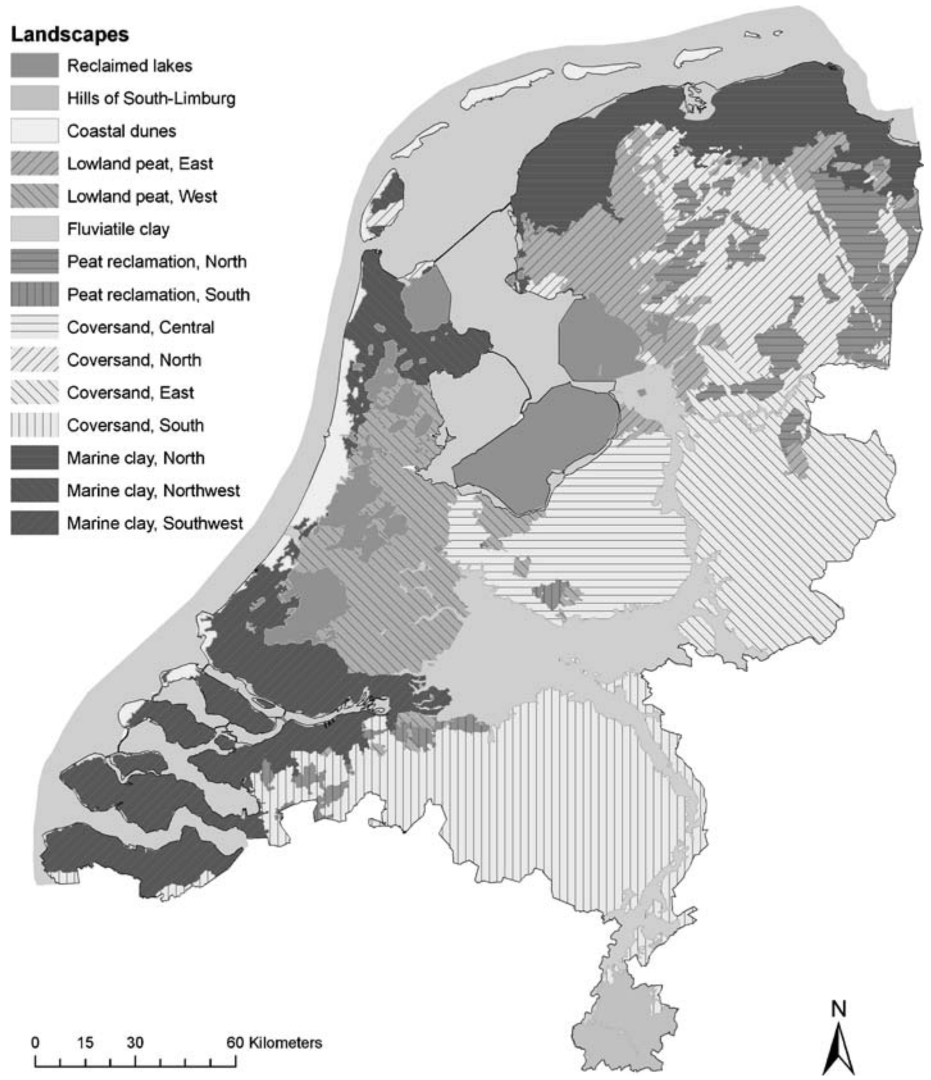

Figure 1. Stratification of the study area.

where z_{hi} is the size of sampling unit i in stratum h and N_h is the total number of sampling units in stratum h. After a sampling unit has been selected, it is replaced, so that in subsequent draws we have the same selection probabilities. This implies that a sampling unit can be selected more than once. This replacement is for statistical convenience only. The number of draws per stratum was roughly proportional to the rural area of a stratum with a minimum of two (Table I). Figure 2 shows the locations of the 72 selected sampling units.

TABLE I
Properties of strata

Stratum	# Sampling units	Area (ha)	# Draws
Hills of South-Limburg	596	45381	3
Coversand, North	2726	258318	7
Coversand, Central	2315	208581	5
Coversand, East	3524	330098	6
Coversand, South	4918	436390	8
Peat reclamation, North	1644	152867	3
Peat reclamation, South	324	27269	2
Fluviatile clay	3335	294524	6
Marine clay, North	2678	251630	5
Marine clay, Northwest	929	81687	2
Marine clay, Southwest	4275	369840	7
Lowland peat, West	2499	210449	5
Lowland peat, East	2118	201681	4
Reclaimed lakes	2826	258215	7
Coastal dunes	829	66134	2

2.3. Statistical inference

The sample data were used to estimate the target quantity

$$t(d) \equiv \frac{T(d)}{A} \equiv \frac{1}{A}\sum_{i=1}^{N}\left(y_{2,i} - y_{1,i}\right) \equiv \frac{1}{A}\sum_{i=1}^{N} d_i, \tag{2}$$

where $T(d)$ is the total difference (difference of totals) of the target variable on the two occasions in the study area, A is the total area of the study area (1 unit of area = 100 ha), N is the total number of sampling units in the Netherlands, $y_{2,i}$ is the current value of the state variable in sampling unit i, and $y_{1,i}$ is the value of the state variable on the first occasion in sampling unit i. A 'total' is the total number of point-objects of a given type, the total length of linear elements, or a total area occupied by two-dimensional elements. Division of these totals of differences by the area A, leads to a total difference per unit of area (100 ha). The total difference per unit of area, Eq. (2), was estimated by estimating the total for the study area (numerator of Eq. 2) and dividing it by the known area:

$$\hat{t}(d) = \frac{\hat{T}(d)}{A}. \tag{3}$$

Hereafter $\hat{t}(d)$ and $\hat{T}(d)$ will be shortened to $\hat{t}$ and $\hat{T}$, respectively. The total difference was estimated by the sum of the estimated totals per stratum,

$$\hat{T} = \sum_{h=1}^{L}\hat{T}_h, \tag{4}$$

Figure 2. Location of 72 selected sampling units.

where L is the number of strata. The total for a stratum was estimated by the Hansen-Hurwitz estimator (Thompson 2002, p. 51)

$$\hat{T}_h = \frac{1}{n_h} \sum_{i=1}^{n_h} \frac{d_{hi}}{p_{hi}}, \tag{5}$$

where n_h is the number of draws in stratum h.

The sampling variance of the estimated stratum total can be estimated by

$$\hat{v}(\hat{T}_h) = \frac{1}{n_h\,(n_h - 1)} \sum_{i=1}^{n_h} \left(\frac{d_{hi}}{p_{hi}} - \hat{T}_h \right)^2 = \frac{\hat{s}_h^2(\breve{d})}{n_h}, \tag{6}$$

where $\hat{s}_h^2(\breve{d})$ is the estimated spatial (population) variance in stratum h of a new variable $\breve{d}$, defined as d/p, i.e., the differences divided (expanded) by their draw-by-draw selection probabilities. The sampling variance of the estimated total for the study area as a whole can be estimated by

$$\hat{v}(\hat{T}) = \sum_{h=1}^{L} \hat{v}(\hat{T}_h), \tag{7}$$

Finally, because the area A is known, the sampling variance of the estimated total difference per unit of area can simply be estimated by

$$\hat{v}(\hat{t}) = \frac{1}{A^2} \hat{v}(\hat{T}). \tag{8}$$

In the above estimators the known area A of the rural land is used to estimate the difference per 100 ha. The alternative is to estimate this area from the pps-sample, and to divide the estimated total by the estimated area. So both the nominator and the denominator of a ratio are estimated. The Hansen-Hurwitz estimator of the rural area in a stratum is (compare Eq. 5)

$$\hat{A}_h = \frac{1}{n_h} \sum_{i=1}^{n_h} \frac{a_{hi}}{p_{hi}}, \tag{9}$$

where a_{hi} is the area of the sampling unit selected in the ith draw from stratum h. The estimated total for the study area is divided by the sum of estimated stratum areas:

$$\hat{t}_{gr} = \frac{\hat{T}}{\hat{A}} = \frac{\hat{T}}{\sum_{h=1}^{L} \hat{A}_h}. \tag{10}$$

This estimator is named the group ratio-estimator. The rationale for the ratio-estimator is that if we have selected a sample with a small estimated total, the area also might be underestimated. Dividing the estimated total by the estimated area may thus increase the precision of the estimated total per unit of area. The variance of the group ratio estimator is approximated by replacing the variable d_i (Eq. 6) by the residual e_i:

$$e_i = d_i - \hat{t}_{gr} \cdot a_i, \qquad (11)$$

where a_i is the area of sampling unit i. Cochran (1977, p. 32) shows that the variance of the group ratio estimator can then be approximated by the variance of the estimated mean of e divided by the squared mean area of the sampling units:

$$\hat{v}(\hat{t}_{gr}) = \frac{\hat{v}\left\{\hat{t}(e)\right\}}{(\bar{a})^2}. \qquad (12)$$

The variance in the nominator is estimated by Eqs (6) and (7).

2.4. Determination of change for selected sampling units

This study focuses on recent changes in the Dutch landscape, therefore the time span 1996–2003 was chosen. Some relevant data sets were available for this period: detailed aerial photographs with a 1 × 1 m resolution, and topographical maps dating from 1996 and 2003. These two data sets have proven to be essential for determining changes in land use. For geomorphology the 'Actuele Hoogtebestand Nederland' has been used, a laser altimetry based data set containing detailed elevation for each 5 × 5 m grid. This Digital Elevation Model (DEM) enabled the production of a reference map for 1996 using the existing geomorphologic maps of the Netherlands (Koomen et al. 2004) which was mainly mapped in the pre 1996 era. Changes between 1996 and 2003 were first studied using topographical maps and aerial photographs and finally checked in the field. For the historical-geographical landscape features a new 1996 reference was produced using topographical maps from 1900 in combination with those for 1996. Here too, changes between 1996 and 2003 were initially recorded from topographical maps and aerial photographs and then thoroughly checked in the field. Field work proved to be an important additional phase to check changes recorded from data sets, to clarify recordings that were doubtful and to record recent changes that were not visible on the topographical maps and aerial photographs. This resulted in a data set for all 72 sampling units, where changes in the variables as described above are ready to be used as input for the statistical analysis.

2.5. The design effect

We compared the variance of the estimated means obtained with the applied stratified pps-sampling design with the variance that we would have obtained with the following sampling designs:

- simple random sampling, i.e., independent selection with equal probabilities (SI);
- stratified simple random sampling, i.e., simple random sampling within strata (STSI).

The sampling variance for these non-executed sampling designs was approximated by the bootstrap technique (Särndal et al. 1992, p. 442). In this technique an artificial population is created by replication of the selected sampling units. Each sampling unit is replicated $1/\pi_{hi}$ (rounded to nearest integer) times, where π_{hi} is the probability that sampling unit i in stratum h is included in the sample. This inclusion probability can be derived from the draw-by-draw selection probabilities as follows (Särndal et al. 1992, p. 51):

$$\pi_{hi} = 1 - (1 - p_{hi})^{n_h} . \tag{13}$$

The d-values of the replicates equal that of the parent sampling unit. The sampling variance for stratified simple random sampling can now be approximated by

$$\hat{v}_{STSI}(\hat{T}) = \sum_{h=1}^{L} N_h^2 \frac{\hat{s}_h^2(d)}{n_h}, \tag{14}$$

where $\hat{s}_h^2(d)$ is the estimated spatial (population) variance of the d-values in stratum h. This spatial variance is simply estimated by the variance between all replicates in stratum h. The sampling variance of the estimated totals per unit area (100 ha) can then be obtained with Eq. (8). The sampling variance for simple random sampling (with replacement) can be approximated by

$$\hat{v}_{SI}(\hat{T}) = N^2 \frac{\hat{s}^2(d)}{n}, \tag{15}$$

where $\hat{s}^2(d)$ is the estimated spatial variance of the d-values in the study area as a whole.

We also calculated the sampling variances for STSI and SI by the method described by Cochran (1977, p. 136). For more details on this method in the context of spatial surveys we refer to Brus (1994).

3. Results and Discussion

3.1. Estimated changes

Table II shows several sample statistics, besides the estimated differences per 100 ha for the eight state variables. The number of sampling units with zero total differences constitutes a large proportion of the total sample size, and varies from 23

TABLE II

Statistics of stratified pps-sample ($n = 72$), and estimated changes per 100 ha in eight state variables of the landscape. Within parentheses: estimated standard error. *: differs significantly from 0 ($\alpha = 0.05$). ^{1}: numbers per 100 ha; ^{2}: ha per 100 ha; ^{3}: m per 100 ha;

State variables	# zeros	Min	Max	Sample mean	Skewness	Estimated change	
						Known area	Ratio estimate
New buildings[1]	36	0	7	1.21	1.7	1.03* (0.27)	1.23* (0.30)
Removed buildings[1]	55	0	25	1.13	5.0	0.90* (0.41)	1.08* (0.45)
New – removed buildings[1]	33	−25	7	0.083	−4.3	0.13 (0.25)	0.15 (0.29)
Unspoiled natural relief[2]	23	−49.1	0	−4.2	−3.1	−2.3* (0.58)	−2.8* (0.72)
Linear relicts[3]	57	−7556	0	−231	−6.5	−137* (54)	−164* (58)
New linear green elements[3]	46	0	1992	99	4.7	74* (26)	89* (32)
Removed linear green elements[3]	35	0	4723	190	5.9	106* (26)	126* (31)
New – removed linear green elements[3]	24	−4723	1938	−91	−4.3	−31 (32)	−37 (35)

(unspoiled natural relief) to 57 (linear relicts). For all eight state variables the sample distribution is skewed.

On average 1.03 buildings per 100 ha have been built in the period 1996–2003, while on average 0.90 buildings per 100 ha have been removed. Both changes differ significantly from 0 ($\alpha = 0.05$, one-sided test). The estimated net change in buildings is 0.13 building per 100 ha (1 building per 769 ha). The group ratio estimator leads to a slightly larger net change, 0.15 building per ha. This is because the area is underestimated by the sample, 26686 units versus 31931 units of 100 ha. These estimated net changes do differ not significantly from 0 ($\alpha = 0.05$, two-sided test).

The area with unspoiled natural relief has been reduced in the period 1996–2003 by 2.3 ha per 100 ha. The linear relicts have been reduced in this period by 137 m per 100 ha. Estimated by the group ratio estimator, these two reductions are 2.8 ha per 100 ha and 164 m per 100 ha, respectively. Both reductions differ significantly from zero ($\alpha = 0.05$, one-sided test).

In the period 1996–2003, on average 74 m of linear green elements have been planted per 100 ha, while on average 106 m have been removed per 100 ha, leading to a net change of -31 m per 100 ha. As estimated by the group ratio estimator the net change in linear green elements equals -38 m per 100 ha. Similar to the net changes in number of buildings, these estimated net changes do not differ significantly from zero ($\alpha = 0.05$, two-sided test).

3.2. Design effect

For the state variables 'unspoiled natural relief', 'linear relicts', 'removed linear green elements', and 'new – removed linear green elements' there is a gain in precision due to the pps-sampling (compare standard errors in Tables II and III). For the remaining state variables the gain is negative, or of doubtful significance. From Eq. (6) we can see that the variance of the estimated stratum total is zero if

TABLE III

Standard errors for stratified simple random sampling (STSI) and simple random sampling (SI) approximated by the bootstrap technique. Within parentheses: estimated by method of Cochran (1977)

State variable	STSI	SI
New buildings	0.21 (0.22)	0.24 (0.23)
Removed buildings	0.47 (0.38)	0.38 (0.35)
New – removed buildings	0.50 (0.35)	0.35 (0.31)
Unspoiled natural relief	1.1 (0.89)	1.0 (0.84)
Linear relicts	85 (74)	82 (73)
New linear green elements	33 (34)	35 (31)
Removed linear green elements	42 (40)	47 (42)
New – removed linear green elements	49 (48)	55 (49)

the differences are exactly proportional to the draw-by-draw selection probabilities, i.e. when $d_{hi} = cp_{hi}$. The selection probabilities p_{hi} on their turn are proportional to the size-measures z_{hi} (Eq. 1), so the variance is zero if

$$d_{hi} = \frac{c}{\sum_{i=1}^{N_h} z_{hi}} z_{hi} = c' z_{hi}. \tag{16}$$

So, in a scatter plot of the d_{hi}-values against the z_{hi}-values the points at best lie on a line through the origin. Note that the proportionality constants may differ between the strata. Figure 3 shows the scatter plots for the state variables 'new buildings', 'unspoiled natural relief' and 'linear relicts'. For the latter two variables, sampling units with zero change mainly have small sizes too, and the larger the size, the larger the change on average. For the state variable 'new buildings' there is no such proportionality. It is known from sampling theory that if the assumed proportionality is not valid, pps-sampling will lead to larger standard errors than equal probability sampling within strata. To illustrate this we calculated the standard error of the estimated area (Eq. 9) for the STpps and STSI design. These standard errors need not be estimated but can be calculated without error, because the area of the sampling units is exhaustively known. For STpps this standard error is 5083 areal units, for STSI 942 areal units. The area is not proportional to the size measure (area times a measure for urbanization pressure), which explains the large standard error for STpps.

4. Conclusions

1. Probability sampling according to a well-defined sampling design is advantageous because the estimated changes are unbiased, for moderate to large sample sizes valid confidence interval estimates of the changes can be obtained, and the estimated changes can be tested statistically against zero-change or target levels.
2. For most state variables sampling with probabilities proportional to size performed reasonably well. For some of these variables there is no gain in precision compared to simple random sampling (equal probabilities).
3. Sampling with probabilities proportional to size is beneficial only if the size-measure is more-or-less proportional to the (change in the) state variable of interest. In general, for monitoring studies one has many state variables. If there are doubts on the proportionality for some of the state variables, then we advise to keep things simple and to refrain from pps-sampling. This is because for these state variables pps-sampling may lead to worse results (less precise estimates of change and of its standard error compared to simple random sampling). Moreover, if one wants to estimate the current totals (stocks) besides

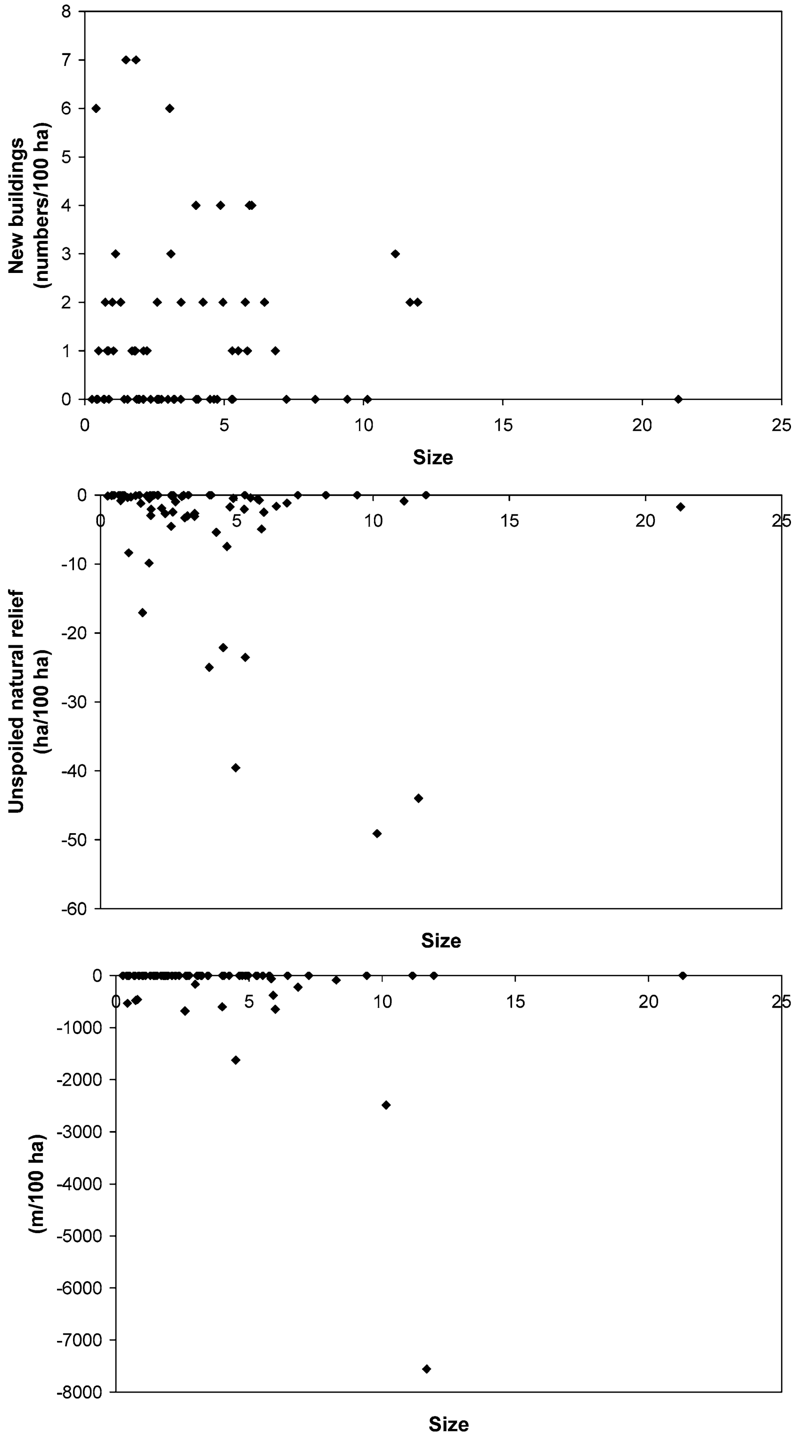

Figure 3. Scatter plots of change of three state variables against size for 72 selected sampling units.

the changes in these totals, finding an appropriate size-measure that leads to increased precision for both the current totals and the changes in these totals of all state variables, will become even more difficult.

4. The sample size of 72 units is too small to be almost sure that the net changes in buildings and green linear elements differ from 0. In this study the sample size is kept rather small because a labor-intensive and therefore expensive method was used to determine the changes for the selected sampling units. An interesting alternative is to look for cheaper but less precise methods for determination of the change, so that the sample size can be increased with the same budget.
5. Pps-sampling is a method that selects preferentially sampling units with considerable expected changes. Sampling units with expected zero changes will be under-represented, and that is what we aim at. An alternative, much simpler way of selecting sampling units with zero and small changes with small probabilities is stratification, using the expected change as a stratification variable. The efficiency of pps-sampling and size-stratified sampling must be compared in future studies in situations where the assumption of proportionality is violated.
6. If we still have a large proportion of sampling units with zero changes, then we could try more precise estimators of the total change. Pennington (1983) describes such estimators, but these estimators cannot be used applied as simply to pps-samples.

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