


Towards a European-wide sampling design for statistical monitoring of common habitats

Alterra report 2213
ISSN 1566-7197

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This publication is produced as Deliverable 3.3 of the EBONE project, commissioned by EC-FP7 programme, nr 21223 and by the Dutch Ministry of Economics, Agriculture and Innovation. Project code KB14-002-007

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Alterra Report 2213

Alterra, part of Wageningen UR
Wageningen, 2011

Abstract

D.J. Brus, M. Knotters, M.J. Metzger and D.J.J. Walvoort, 2011, *Towards a European-wide sampling design for statistical monitoring of common habitats*, Wageningen, Alterra, Alterra Report 2213

The EBONE (European Biodiversity Observation NEtwork) project includes the development of a framework for monitoring which enables Europe-wide statistically reliable, geographically referenced and comparable data collection of species and habitats of interest. We evaluated existing national programmes for monitoring of landscape features of the United Kingdom (Countryside Survey), Sweden (NILS), Spain (SISPARES), Austria (SINUS) and Denmark (Small Biotope project and NOVANA). We concluded that the Countryside Survey (United Kingdom) and NILS (Sweden) can be part of the EBONE network. We presented a design of a new, European-wide monitoring network that provides reliable information on the current status of selected properties of common habitats, and also on trends over time. Sampling units are 1 km squares. As a space–time design we propose a serially alternating design, with a periodicity of five years. We propose to select 1 km squares by probability sampling, to enable model-free, unbiased and valid estimation of target parameters and their standard errors. Valid quantification of the uncertainty of the monitoring result is important to avoid discussions on the statistical significance of estimated time trends in quality indicators and other target parameters. We propose two alternatives of spatial sampling design: (i) stratified random subsampling of the existing LUCAS sample, and (ii) stratified random sampling from geographical substrata within environmental strata. The alternative based on the LUCAS sample might have some organizational advantages. The design of the second alternative is relatively simple, which is an advantage in data processing.

Keywords: Biodiversity, stratified random sampling, environmental stratification

ISSN 1566-7197

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Alterra-report 2213
Wageningen, august 2011

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Preface

"We already have the statistics for the future: the growth percentages of pollution, overpopulation, desertification. The future is already in place."
Günther Grass

The *European Biodiversity Observation Network: a project to design and test a biodiversity observing system, integrated in time and space* (EBONE) is part of theme 6, Environment (Including Climate Change), of the seventh framework programme of the European Union. The research reported here forms a part of work package 3 of EBONE: 'Stratification and statistical analysis'.

We are very grateful to dr. Rob Jongman (Alterra, Wageningen University and Research centre) for his incessant support in all stages of the research, and his readiness to solve problems irrespective of their magnitude and source. Prof. Bob Bunce (Alterra, Wageningen University and Research centre) is gratefully acknowledged for sharing his unsurpassed expertise on ecological monitoring with us. We express our gratitude to the scientists who provided us with detailed information on the monitoring programmes they are involved in: dr. Andy Scott (Countryside Survey, United Kingdom), dr. Göran Ståhl (NILS, Sweden), dr. Marta Ortega (SISPARES, Spain), and dr. Johannes Peterseil and dr. Thomas Wrbka (SINUS, Austria).

Wageningen/Edinburgh, June 2011

Dick Brus, Martin Knotters, Marc Metzger and Dennis Walvoort

Summary

Introduction

The EBONE (European Biodiversity Observation NEtwork) project includes the development of a framework for monitoring which enables Europe-wide statistically reliable, geographically referenced and comparable data collection of species and habitats of interest. Until now data to determine the quality of the environment for the whole of the EU are not collected consistently. Besides this, the sampling intensities that are needed to obtain reliable information on status and trends need to be determined. The aim of this report is to evaluate existing national programmes for monitoring of landscape features, and to present a design of a new, European-wide monitoring network that provides reliable information on the current status of selected properties of common habitats, and also on trends over time. In Part I we evaluate the monitoring networks of the United Kingdom, Sweden, Spain, Austria and Denmark, to assess the suitability of these networks for becoming part of the European wide habitat monitoring network EBONE. In Part II we elaborate on the design of a new, European-wide monitoring network.

Part I

Countryside Survey (United Kingdom)

The Countryside Survey aims to record stock and change of countryside features, including information on land cover, habitats and species. The basic spatial sampling units are squares of 1 km^2 (referred to hereafter as 1 km squares). The space–time sampling design is static-synchronous (pure panel). A core of 244 1 km squares have been surveyed in 1978, 1984, 1990, 1998 and 2007. The number of surveyed squares increased to 384, 508, 569 and approximately 620 in 1984, 1990, 1998 and 2007, respectively. The type of spatial sampling design is multi-stage (cluster) sampling, with in the first stage the selection of a systematic grid of 1200 1 km squares, and in the second stage, in 1978, equal numbers ($n = 8$) of 1 km squares were sampled from each Land Class. Variables such as vegetation and soil variables are measured exhaustively for selected plots within 1 km squares, i.e., three-stage (cluster) sampling. In 1978 and 1984 the original classification was used for stratification in the second stage. In 1990 the classification was revised, and hence new strata were constructed. The selected 1 km squares of all three surveys were next treated as stratified random samples from the revised strata. Sampling times are selected at a constant interval of six years.

Design-based estimates of total areas of attributes are obtained by first calculating arithmetic means for each stratum, and next by computing weighted summations over the strata. Proportions of land covered by an attribute in a Land Class are estimated using ratio estimators: the ratio of total attribute area to total land area estimated from the field sample squares in that Land Class. Change was estimated in two ways: (i) from observations in just the squares surveyed both times; (ii) from observations in all the squares available.

Model-based estimation of stock and change is motivated by the failure of the design-based estimation method to use all the data collected in each survey to estimate change, and the mis-match between design-based estimates, i.e., differences between stock estimates not being equal to estimates of change. This shows the flexibility of probability samples with respect to type of statistical inference: non-probability samples can be used for model-based inference only.

The Countryside Survey is a probability sample of spatial sampling units, enhancing model-free, valid estimation of stock and change. Quantification of the sampling error associated with the first sampling stage is cumbersome. As far as we know, the sampling error of the first sampling stage (selection of grid) is not accounted for. A further complication in the statistical inference is the revision of the stratification in 1990.

National Inventory of Landscapes in Sweden (NILS)

NILS aims to provide data for, and perform, analyses of biological diversity and ecological processes at the landscape scale. First, outer squares of size 5 km × 5 km are selected, with extensive remote sensing-based assessments. Second, an inner square of size 1 km^2 is positioned at the centre of each outer square, and

mapped in detail with respect to land cover and land use based on aerial photo interpretation. Third, within each km-quare, field assessments are made in circular plots and along lines. The plots and lines form a square which is centered in the 1 km square. In each square twelve circular sample plots are placed 25 m from the end of each line, and twelve linear transects, each 200 m long. Each of the twelve circular sample plots is composed of a set of concentric circular plots and small satellite sub-plots. The most important ones are (a) the 20 m radius plot where assessments of land cover and land use are made, (b) the 10 m radius plot where basic measurements of different vegetation components are made, and (c) the three small 0.28 m radius plots, at 3 m distance from the plot centre, where the vegetation is surveyed in detail.

The sample is randomly split into five panels of approximately equal size. A panel is resurveyed after five years. Each panel forms a probability sample from Sweden as a whole, i.e., it contains sampling units from all strata (a serially alternating pattern, with a periodicity of five years). A possible disadvantage of types of space–time designs in which sampling units are revisited is that disturbance and public attention may affect the observations. The spatial sampling design is systematic random sampling. Stratification into 10 strata has been done afterward. The density of the grid differs between strata. The total number of squares is 631. This total number and the allocation of these squares to the strata are based on the required power of statistical testing of hypotheses on the change of key variables. The sampling interval is five years.

Means and totals and their sampling variances are estimated after each cycle of five years, treating the sample data as being generated by a stratified simple random sampling design. The estimator of the sampling variance therefore is an approximation of the true sampling variance. The total length of linear objects is estimated by an estimator for line intersect sampling, which stems from the so called Buffon's needle, which was thrown randomly to an area. Because in NILS a systematic pattern of lines is superimposed on an area, it is implicitly assumed that the orientation of the linear objects has a uniform distribution.

NILS is based on probability sampling, which makes design-based inference feasible. However, several choices have been made that complicate the estimation of the sampling variance of the estimates. First, no unbiased estimator of the sampling variance exists for systematic random sampling exists. A further flaw is that the selection of sampling units in a given stratum is not independent from those in another stratum. This dependence of stratum-estimates must be accounted for in the estimation procedures. We would have preferred to select grid samples independently from the strata. This also increases the flexibility of adapting the (expected) sample sizes to the strata by adapting the spacing of the grid. A final comment is the non-random selection of transects and circular plots within 1 km squares. Due to this, model assumptions are required in order to quantify the sampling variance.

SISPARES (Spain)

The aim of the SISPARES monitoring programme is to study the evolution of landscape on the Spanish Iberian peninsula and Balearic islands, and the human impact on landscape. The 209 spatial sampling units are 4 km $\times$ 4 km squares. Aerial photographs were available from the years 1956, 1984 and 1998. Estimates for 1956 and 1984 are based on aerial photographs only. In 1998, photo-interpretations were validated by field visits. Sampling units were selected by stratified random sampling. Strata are biogeoclimatic land classes. The 209 sampling units were selected from 215 strata (one per stratum, six strata were not sampled). The size of the spatial units used in the biogeoclimatic classification was 2 km $\times$ 2 km, whereas the sampling units are 4 km $\times$ 4 km squares. Only pure sampling units were selected, i.e., sampling units that belong as a whole to one stratum. Besides a threshold was used for the areal proportion urban (build-up). Squares with an areal proportion exceeding this threshold were deleted from the sampling frame.

We conclude that SISPARES cannot be treated as a probability sample, as large parts of the rural landscape of Spain have a zero probability of being included in the sample. We recommend not to include SISPARES in the European-wide EBONE monitoring network. The most important reason for this is that a very large part of the Spanish landscape was excluded from the sampling frame. Besides, only one sampling unit is selected per stratum, whereas for unbiased estimation of the sampling variance of estimates at least two sampling units per stratum are required.

SINUS: monitoring of Austrian landscapes

The aim of the project 'Spatial INdices for land Use Sustainability (SINUS)' is to develop reliable, operational, and spatially explicit indicators of practical use in long-term monitoring and assessment of ecological sustainability of Austrian cultural landscapes. This differs from the aim of estimating spatial means of these indicators or temporal changes therein. The sampling universe is restricted to cultural landscapes. Mainly forested areas, for instance, were not part of the sampling universe. A two-stage sampling procedure was applied. In the first stage, a total number of 182 5 km × 5 km squares were selected using a stratified random sampling procedure to guarantee representation of the whole variety of Austrian agricultural landscapes in the sample. The stratification was based on geomorphological features (such as altitudinal level and exposition), historical land-use pattern and preliminary coarse landscape types. The number of strata is 41. In the second stage a 1 km × 1 km square was selected *purposively* within the randomly selected 5 km × 5 km square. The spatial sampling unit is a square landscape plot of 1 km × 1 km, corresponding with the Austrian national grid. Field work took place during two periods in the years 1996 and 1997. As far as we know the survey was not repeated yet.

Some parts of the forested landscapes and larger wilderness areas, like the nival belt of the Alps, were excluded from the survey. For EBONE, these areas form part of the target population and therefore additional sampling plots must be selected. This also explains the purposive selection of a 1 km square from the 5 km × 5 km squares. This complicates the quantification of the sampling error in estimated spatial means of indicators and changes therein seriously.

The Small Biotope project and NOVANA in Denmark

An important goal of the Small Biotope project (started in 1981) to influence policy and decision-makers, by changing the focus of conservation interests to incorporate dispersed fragments of semi-natural vegetation. The Small Biotope project is continued as part of the NOVANA programme, to monitor structural landscape development in arable land with special emphasis on the trend with regard to small biotopes. Sampling units are squares of 4 km^2. The sites selected for the Small Biotope project were observed in 1981, 1986, 1991 and 1996. As far as we know the same 32 sites were observed in all four years, i.e. a static-synchronous pattern. Extensive and intensive monitoring stations are distinguished. The highest sampling frequency of NOVANA will be annual, due to economic constraints on the monitoring. As a result, variables that need more frequent measurements to be interpretable will not be included in the monitoring programme. As long as we have no detailed information on how the sites of the NOVANA programme are selected we cannot evaluate its suitability for incorporation in EBONE. The emphasis of the Small Biotopes project and NOVANA is on small biotopes. EBONE is not concerned only with trends in small biotopes, but in all biotopes.

Part II

Basic design choices in space–time sampling

The target area is defined as all 27 EU countries, supplemented by Norway and Switzerland, above the mean low tide line. Sweden and the United Kingdom are excluded from the sampling frame. These two countries do belong to the target area, but a monitoring network need not be designed for these two countries, as statistically sound nation-wide monitoring networks have already been implemented here.

Sampling units are 1 km squares. For the selected 1 km squares a map of the habitats is constructed on the basis of aerial photographs and fieldwork using the BioHab mapping procedure. Reporting units are the entire target area and twelve environmental zones. It is expected that the total number of observed 1 km squares will be too small to obtain reliable estimates for the separate environmental strata (EnS, subdivisions of the environmental zones), as well as for the countries (except large countries). For the latter purpose the monitoring data of the EBONE sample can be combined with national data in order to obtain more reliable estimates of status and trend of habitat properties at the national level.

As a space–time design we propose a serially alternating design, because simulation experiments have shown that this design is relatively efficient for estimating a linear temporal trend of spatial means (totals) (Brus and de Gruijter, 2011). Further, we propose a periodicity of five years. A static-synchronous design (pure panel), in which every sampling time the same sample of 1 km squares is observed, is less attractive for reasons of efficiency and for organizational reasons.

We propose to select 1 km squares by probability sampling. This enables model-free, unbiased and valid estimation of target parameters and their standard errors. Valid quantification of the uncertainty of the monitoring result is important to avoid discussions on the statistical significance of estimated time trends in quality indicators and other target parameters.

The total number of 1 km squares in the EBONE sample was set at 10,000 (2,000 per year). This number is not based on a thorough statistical analysis of the minimum number of 1 km squares given a requirement on the quality of the monitoring result. The number of 1 km squares per EnS *per year* was computed by multiplying the total number per year (2,000) by the relative areas of the EnS, i.e. the areas of the EnS outside the United Kingdom (UK) and Sweden (SE), divided by total area of target area outside UK and SE (proportional allocation).

Spatial design

We focus on two types of spatial sampling design: (i) stratified random subsampling of LUCAS sample, and (ii) stratified random sampling from geographical substrata within EnS. In both types of sampling design environmental strata (EnS) are used as strata. In total there are 84 environmental strata, four of which are outside the target area and two entirely fall in the United Kingdom and Sweden. This leaves 78 environmental strata to be sampled.

Stratified random subsampling of LUCAS sample

LUCAS (Land Use/Cover Area frame statistical Survey) was launched by Eurostat in 2001, in close collaboration with the Directorate General for Agriculture of the EU, and with support of the Joint Research Centre in ISPRA. For operational and financial reasons it can be attractive to locate the EBONE sampling units at (a subset of) the LUCAS sampling points.

The LUCAS sample (as selected in 2006) is a two-phase sample. In the first phase a square grid is randomly selected with a spacing of 2 km (LUCAS master sample) from EU25. Points located on small islands such as Baleares, Azores, Canary Islands, Cyprus, Malta, and Greek islands (except Creta) were excluded from the sample. Also points above 1200 m altitude (according to a digital terrain model) were discarded. The nodes of the grid were classified into seven land use/cover classes by means of photo-interpretation. The nodes of the 2 km grid with similar land use/cover served as a stratum in subsequent subsampling (second phase).

The number of points in the LUCAS sample located in our study area, outside the United Kingdom and Sweden, equals 200 850. This is far too many for the EBONE sample, and therefore this LUCAS sample must be subsampled, leading to a three-phase sample. We subsampled the LUCAS sample by stratified random sampling, using the environmental strata (EnS) as strata.

For design-based estimation of the means and totals at a given year the inclusion probabilities of the selected 1 km squares are needed. These inclusion probabilities are the product of the inclusion probabilities at the three phases.

Stratified random sampling from compact geographical substrata within EnS

With this sampling design the 78 environmental strata (EnS) served as the main strata. These EnS were further subdivided into compact geographical substrata, taking care of a good spatial coverage of the 1 km squares observed in a given year within an EnS by using the k-means algorithm. Within each geostratum five or ten 1 km squares are selected by simple random sampling. The order of selection of the 1 km squares is registered. The set of km-squares of the same order are sampled in the same year. If from each geostratum ten 1 km squares are selected, we have each year two 1 km squares in each geostratum. This has important advantages for estimating the sampling variance of the estimates. The size (area) of the geostrata within a given EnS is not constant. The differences in size (area) of the geostrata must be accounted for in the statistical estimation of target parameters.

Spatial means at a given year for the entire EU and for the twelve environmental zones and their sampling variances are estimated by design-based inference, weighting for the relative sizes of the geostrata. With one 1 km square per geostratum the spatial variance cannot be estimated. In this case the 'collapsed strata method' can be used to obtain an approximate estimate of the sampling variance.

The change of the spatial mean between two years can be estimated by the difference in the estimated spatial means at the two years. The sampling variance of this estimated difference can be estimated by the sum of the sampling variances of the two estimated means minus the sampling covariance.

We define the linear temporal trend as a linear combination of the spatial means. With this definition the temporal trend is a population parameter, not a model parameter. Defined as a population parameter, the linear trend and its sampling variance can be estimated by design-based inference.

Computation of required number of 1 km squares

An important advantage of statistical methods for survey is that the precision of the survey results (estimates) can be quantified. If we are able to make a guess at these spatial variances prior to sampling, then we can compute in advance the number of sample locations required to achieve a given minimum quality of the estimated target parameter. We use three quality constraints: (i) on the sampling variance or (ii) on the coefficient of variation, and (iii) on the probability of an absolute or relative error of a given size. Computations of the required number of 1 km squares for estimating spatial *means* at a given year, and of changes of totals or means between two years are entirely analogous.

The simplest situations are for simple random sampling (SI) and stratified simple random sampling (STSI) when the quality constraint is formulated in terms of the sampling variance or standard deviation of the estimated mean or total. For STSI, prior estimates of the spatial variances within strata can be used to compute the optimal allocation, i.e. the numbers of sample locations per stratum that result in the minimum sampling variance of the estimated total, given the total sample size.

Conclusions and recommendations

We conclude that the Countryside Survey (United Kingdom) and NILS (Sweden) can be part of the EBONE network. For the remaining part of the target area we recommend the development of a Europe-wide monitoring programme, based on probability sampling to make model-free, valid estimation of status and trends feasible. This is crucial given the aim of EBONE to develop a framework for monitoring which enables Europe-wide statistically reliable, geographically referenced and comparable data collection of species and habitats of interest. Given this aim we recommend that unremitting attention should be paid to a conscientious sampling design, now and in future.

1 Introduction

1.1 Background and problem definition

In 2008 the EBONE (European Biodiversity Observation NEtwork) project started. The objective of EBONE is to develop and implement a terrestrial biodiversity observation network that is transmissible, cost effective and provides added value to the currently independent data sources of *in situ* data and Earth Observation (EO). The EBONE project includes the development of a framework for monitoring which enables Europe-wide statistically reliable, geographically referenced and comparable data collection of species and habitats of interest. These data should form the basis for EU-conservation policy. To improve the effectiveness of EU environmental protection policy the effects of different protection regimes should be identified. This is complicated, however, because the current national monitoring networks differ strongly per EU country. Therefore it is essential to collect comparable information for all EU countries. Until now data to determine the quality of the environment for the whole of the EU are not collected consistently. Besides this, the sampling intensities that are needed to obtain reliable information on status and trends need to be determined.

1.2 Aim and scope

The aim of this report is to evaluate existing national programmes for monitoring of landscape features, and to present a design of a new, European-wide monitoring network that provides reliable information on the current status of selected properties of the habitats, and also on trends over time.

In this report we will elaborate on sampling designs for statistical monitoring of habitats in Europe. The monitoring designs reported here focus on monitoring of the size (spatial extent) and quality indicators of common, widespread habitats. For rare habitats more tailored monitoring designs are required, entailing, amongst others, targeted selection of sampling units (km squares). Monitoring these rare habitats is partly covered already by the monitoring networks in the Natura 2000 sites.

1.3 Outline

Several countries in Europe already have a network for monitoring landscape features. In Part I of this report we will evaluate the monitoring networks of the United Kingdom, Sweden, Spain, Austria and Denmark, to assess the suitability of these networks for becoming part of the European wide habitat monitoring network EBONE. In Part II we will elaborate on the design of a new, European-wide monitoring network. The report ends in Chapter 13 with general conclusions and recommendations.

Part I

Evaluation of existing national networks

2 Introduction

Several member states of the European Union developed monitoring programmes to collect information on status and trends in ecological variables at a landscape scale. Examples are the Countryside Survey in the United Kingdom, NILS in Sweden, SISPARES in Spain, SINUS in Austria, and Small Biotopes/NOVANA in Denmark. In Chapters 3 to 7 we will evaluate the sampling design of these national monitoring programmes, in order to assess the suitability of these networks for becoming part of the European-wide biodiversity monitoring network EBONE. The evaluation is restricted to the sampling theoretical aspects of the monitoring networks. Questions to be answered are for instance:

- Does the aim of the national monitoring scheme correspond with the aim of EBONE?
- What are the sampling units (size, shape), and how are these sampling units selected? Of special interest is whether the sampling units are selected by probability sampling or not.
- Are the sampling units subsampled, e.g. for collecting soil data at point locations and vegetation data of quadrats, and if so how are these sites selected?
- How are the data statistically processed, i.e. how are stocks and changes estimated and/or tested?
- Is the quality of the monitoring result (for instance, the sampling variance of estimated totals or areal proportions) quantified, and if so how?

This analysis is mainly based on publications (journal papers and reports) on the national monitoring networks. Part I ends in Chapter 8 with concluding remarks.

3 Countryside Survey (United Kingdom)

Our evaluation is based on the following publications:

- Barr, C.J., R.G.H. Bunce, R.T. Clarke, R.M. Fuller, M.T. Furse, M.K. Gillespie, G.B. Groom, C.J. Hallam, M. Hornung, D.C. Howard and M.J. Ness, 1990. *Countryside survey 1990. Main Report*. Institute of Freshwater Ecology, Institute of Terrestrial Ecology (nowadays Centre for Ecology and Hydrology).
- Howard, D.C., C.J. Barr and W.A. Scott, 1998. The validity of using Countryside Survey sample data from Great Britain to estimate land cover in Scotland. *Journal of Environmental Management* **52**(2): 131-146.
- Howard, D.C., J.W. Watkins, R.T. Clarke, C.L. Barnett and G.J. Stark, 2003. Estimating the extent and change in Broad Habitats in Great Britain. *Journal of Environmental Management* **67**(3): 219-227.
- Firbank, L.G., C.J. Barr, R.G.H. Bunce, M.T. Furse, R. Haines-Young, M. Hornung, D.C. Howard, J. Sheail, A. Sier and S.M. Smart, 2003. Assessing stock and change in land cover and biodiversity in GB: an introduction to Countryside Survey 2000. *Journal of Environmental Management* **67**(3): 207-218.
- Haines-Young, R., C.J. Barr, L.G. Firbank, M. Furse, D.C. Howard, G. McGowan, S. Petit, S.M. Smart and J.W. Watkins, 2003. Changing landscapes, habitats and vegetation diversity across Great Britain. *Journal of Environmental Management* **67**(3): 267-281.
- Petit, S., R.C. Stuart, M.K. Gillespie and C.J. Barr, 2003. Field boundaries in Great Britain: stock and change between 1984, 1990 and 1998. *Journal of Environmental Management* **67**(3): 229-238.
- Scott, W.A., 2008. *CS Technical Report No.4/07, Statistical Report*. Centre for Ecology and Hydrology.

3.1 Aim

The Countryside Survey is the monitoring project to record stock and change of countryside features, including information on land cover, habitats and species, in the United Kingdom.

3.2 Sampling design

3.2.1 Spatial sampling units

The basic spatial sampling units are squares of 1 km^2 (shortly referred to hereafter as 1 km squares). For collecting data on soil and vegetation these 1 km squares are subsampled. 1 km squares with more than 90% sea and squares with more than 75% built-up area or urban land were excluded from the sampling frame.

3.2.2 Type of space–time design

The first survey was carried out in 1978 with 256 selected 1 km squares. In the Countryside Survey of 1984, 1990, 1998 and 2007 the same 1 km squares were resurveyed whenever possible. This is done to obtain the most reliable (precise) estimates of change. Such a space–time design is referred to as a static-synchronous design (de Gruijter et al., 2006) or a pure panel. A core of 244 squares have been surveyed in all five surveys (see hereafter), and the number of surveyed squares increased to 384, 508, 569 and approximately 620 in 1984, 1990, 1998 and 2007, respectively.

3.2.3 Type of spatial sampling design

The type of spatial sampling design is multi-stage (cluster) sampling:

1. In the first stage a systematic grid of 1200 1 km squares was selected, spread throughout the United Kingdom.

2. In the second stage, in 1978, equal numbers ($n = 8$) of 1 km squares were sampled from each Land Class irrespective of their estimated relative areas in the United Kingdom. This is a stratified random sampling with Land Classes as strata. The allocation of the sampling units to the strata is non-proportional, since equal numbers were selected from each Land Class. In 1984, 1990, 1998 and 2007 most of these 1 km squares were resurveyed. The sample was extended with new 1 km squares in 1984 (135 1 km squares, four per stratum), 1990 (122 1 km squares), 1998 (68 1 km squares) and 2007 (60 1 km squares). The 122 1 km squares added in 1990 were allocated such that the sample sizes are proportional to Land Class surface areas, as near as possible. Most of the 1 km squares which were surveyed in a particular year for the first time were revisited in the next surveys.

3. Several variables such as vegetation and soil variables are not measured exhaustively within 1 km squares but for selected plots within 1 km squares. For these variables the type of design is three-stage (cluster) sampling. We do not have information on the sampling design of this third stage.

In 1978 and 1984 the original ITE classification was used for stratification in the second stage. In 1990 the classification was revised, which enabled to classify all 240,000 1 km squares in the United Kingdom. Hence new strata were constructed. The selected 1 km squares of all three surveys were next treated as stratified random samples from the revised strata.

3.2.4 Selection of sampling times

Sampling times are selected at a constant interval of six years. We did not find information on the sampling period within a year. For variables showing seasonal fluctuations, such as groundwater levels, soil attributes *et cetera*, this is an important aspect of sampling in time.

3.3 Statistical inference

3.3.1 Estimation of total areas of attributes

First, arithmetic means for each stratum are calculated (Barr et al., 1990, A3.15). Next, 'The total area of an attribute in the whole population and its sampling variance are estimated by weighted summations over the strata, as detailed in Appendix 3a.' (Barr et al., 1990, p. 164, A3.20). Confidence limits of means (and totals) per stratum are computed by first log-transforming the variables, computing the confidence limits on the log-scale, and then backtransforming these confidence limits. This results in asymmetric confidence intervals.

3.3.2 Estimation of proportions of land covered by an attribute in a Land Class

Proportions are estimated using ratio estimators: the ratio of total attribute area to total land area estimated from the field sample squares in that Land Class (Barr et al., 1990, p. 167, A3.39). The total land area in a Land Class is estimated as the total area (including sea) in the Land Class minus the total area of sea in that Land Class, as determined from the 1 : 250,000 topographical map, multiplied by a ratio B. The ratio B is estimated by computing field survey estimates of sea area (determined from 10,000 topographical maps) and determinations based on the 1 : 250,000 map.

3.3.3 Estimation of changes

Change was estimated in two ways:

1. From observations in just the squares surveyed both times.

2. From observations in all the squares available.

Ad 1. First the change in cover in each individual square is calculated. Next, the Land Class and total population change is estimated as for total stock in any one survey (that is, weighted summations of stratum means or totals over the strata). This means that the mean or total of differences is estimated.
Ad 2. The estimate is simply the difference between the two population totals based on all available squares. This is the difference of means or totals.

Barr et al. (1990, p. 165, A3.27) state that 'If the sample units change so much from survey to survey that there is on average no correlation between the value (amount of land cover) of Y in successive years on the same sample unit (1 km square), then no gain in precision is obtained by resampling the same squares rather than taking a completely new random sample'.

3.3.4 Model-based estimation

Scott (2008) proposed model-based estimation of stock and change. This model-based estimation is motivated by the failure of the design-based estimation method to use all the data collected in each survey to estimate change, and the mis-match between design-based estimates, i.e., differences between stock estimates not being equal to estimates of change. This shows the flexibility of probability samples with respect to type of statistical inference. Probability samples can be used both in design-based and in model-based inference. Non-probability samples can be used for model-based inference only.

3.4 Evaluation

The Countryside Survey is a probability sample of spatial sampling units, enhancing model-free, valid estimation of stock and change. The first sampling stage (the square grid of 1 km squares) was built in for practical reasons, as due to computational limitations in the multivariate clustering software TWINSPAN. An additional advantage of this first sampling stage is that strong spatial clustering of sampling units (1 km squares) is avoided: no adjacent 1 km squares can be selected. This will in general have a positive effect on the precision of the estimates. However, quantification of the sampling error associated with the first sampling stage is cumbersome. An unbiased estimator of the sampling variance for systematic random sampling does not exist (Cochran, 1977). As far as we know, the sampling error of the first sampling stage (selection of grid) is not accounted for.

A further complication in the statistical inference is the revision of the stratification in 1990. The inclusion probabilities of the sampling units selected in 1978 and 1984 are determined by the original stratification, and in statistical estimation these inclusion probabilities should be used. However, in estimation the samples of the 1978 and 1984 sampling round are also treated as stratified random samples from the revised classification (Barr et al., 1990, A3.8), i.e., the inclusion probabilities are derived from the new stratification, whereas evidently these inclusion probabilities are determined by the original stratification. This is a practical solution.

In model-based estimation of stock and change as proposed by Scott (2008) the means for a given Land Class in a given sampling round are model parameters, whereas in design-based estimation these are defined as population parameters. Estimation errors of these two types of parameters generally differ. For instance, in exhaustive sampling, i.e., if all 1 km squares of a given Land Class were sampled in a given sampling round, the estimation error (sampling error) of the mean defined as a population parameter is zero, whereas the error in the model mean is larger than zero. Also, the spatial residuals are assumed independent. Indeed, the 1 km squares within a Land Class are selected independently, which makes the observations design-independent (p-independent). However, model-independence is different from design-independence (de Gruijter and ter Braak, 1990; Brus and de Gruijter, 1997). The consequences of confusing design- and model-independence for quantification of the estimation error must be explored.

4 National Inventory of Landscapes in Sweden (NILS)

Our evaluation is based on the following publication:

- Ståhl, G., A. Allard, P.-A. Esseen, A. Glimskär, A. Ringvall, J. Svensson, S. Sundquist, P. Christensen, A.G. Torell, M. Högström, K. Lagerqvist, L. Marklund, B. Nilsson and O. Inghe, 2011. National Inventory of Landscapes in Sweden (NILS)–scope, design, and experiences from establishing a multiscale biodiversity monitoring system. *Environmental Monitoring and Assessment* **173**: 579-595.

4.1 Aim

The main objective of NILS is to provide data for, and perform, analyses of biological diversity and ecological processes at the landscape scale. Different environmental conditions that can have direct or indirect effects on biological diversity are included. More specifically, the programme provides data for national and international policy purposes, and provides an infrastructure for other monitoring programmes and research projects.

4.2 Sampling design

4.2.1 Spatial sampling units

The following sampling units can be distinguished (see Figure 4.1):

1. An outer square of size 5 km × 5 km, with extensive remote sensing-based assessments.
2. An inner square of size 1 km × 1 km (hereafter termed the 1 km square) at the centre of each outer square, mapped in detail with respect to land cover and land use based on aerial photo interpretation.
3. Within each km-quare, field assessments are made in circular plots and along lines. The plots and lines form a square which is centered in the 1 km square. In each square twelve circular sample plots are placed 25 m from the end of each line, and twelve linear transects, each 200 m long. Thus, lines and sample plots are placed in a 750 m × 750 m square inside the 1 km square, leaving 125 m on each side to the borders of the 1 km square.
4. Each of the twelve circular sample plots is composed of a set of concentric circular plots and small satellite sub-plots. The most important ones are (a) the 20 m radius plot where assessments of land cover and land use are made, (b) the 10 m radius plot where basic measurements of different vegetation components are made, and (c) the three small 0.28 m radius plots, at 3 m distance from the plot centre, where the vegetation is surveyed in detail.

4.2.2 Type of space–time design

The sample is randomly split into five panels of approximately equal size. A panel is resurveyed after five years. Each panel forms a probability sample from Sweden as a whole, i.e., it contains sampling units from all strata (see hereafter). De Gruijter et al. (2006) refer to this type of space–time design as a serially alternating pattern, with a periodicity of five years. Since the sampling units are revisited each five years, disturbance and public attention may affect the observations. This might be a disadvantage of this type of space–time design and all other types of space–time designs in which sampling units are revisited.

4.2.3 Type of spatial sampling design

Sampling units are selected by systematic random sampling. Stratification has been applied afterward (Figure 4.1). The total number of strata is 10. The density of the grid differs between strata, for instance in the strata 8 and 9 (forest) half of the rows of squares have been deleted. In other strata (2 and 3)

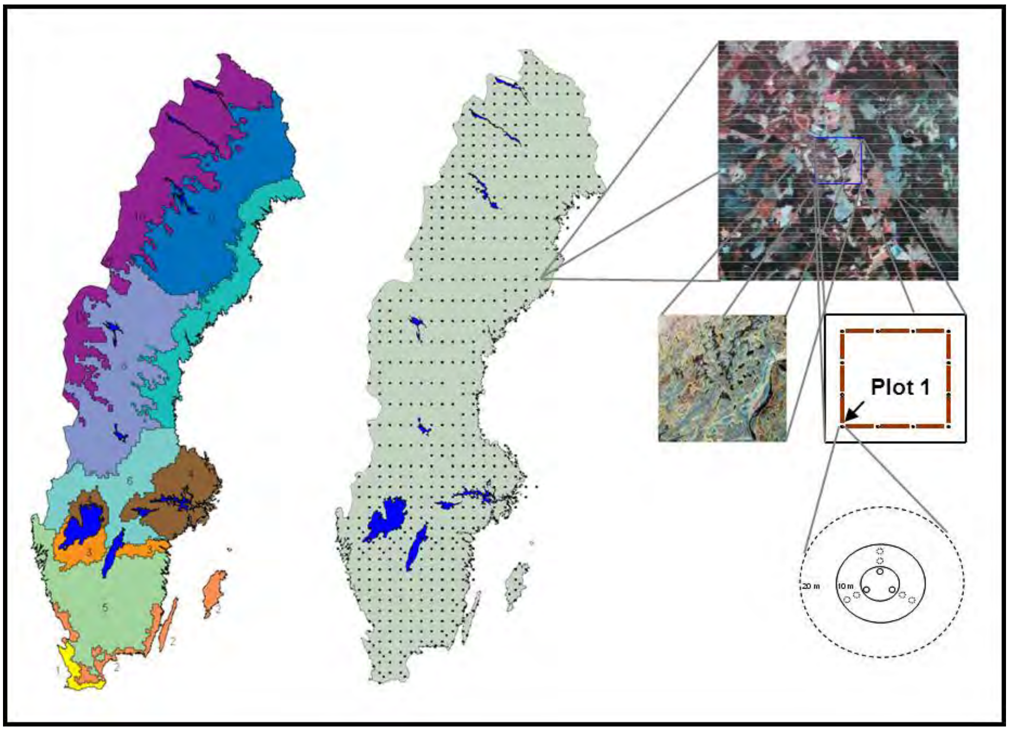

Figure 4.1: Sampling design and sampling units of NILS

sampling units have been added at the centre of the square grid cells. The total number of squares is 631. This total number and the allocation of these squares to the strata are based on the required power of statistical testing of hypotheses on the change of key variables.

4.2.4 Selection of sampling times

The sampling interval is five years. Information on the sampling period within a year was not provided.

4.3 Statistical inference

4.3.1 Estimation of sampling variance

Means and totals are estimated after each cycle of five years. In estimating the sampling variance of these estimated means and totals the sample data are treated as if they were generated by a stratified simple random sampling design. In such a design sampling locations are selected independently from each other. The estimator of the sampling variance therefore is an approximation of the true sampling variance.

4.3.2 Estimation of total length of linear objects

The total length of linear objects is estimated by an estimator for line intersect sampling, given by de Vries (1986, p. 275, Eq. 54). This formula stems from the so called Buffon's needle, which was thrown randomly to an area. In NILS a systematic pattern of lines is superimposed on an area. Implicitly it is assumed that the orientation of the linear objects has a uniform distribution. The occurrence of cyclic patterns in, for instance, rivers and brooks is obvious, however.

4.4 Evaluation

Similar to the Countryside Survey, NILS is based on classical sampling theory, i.e., sampling units are selected by probability sampling, which makes design-based inference feasible. However, several choices have been made that complicate the estimation of the sampling variance of the estimates. To spread the sampling units in geographical space, the Swedish have chosen for a systematic random grid, with stratification afterward. The density of the grid is different between strata. The flexibility of a systematic sampling design for adapting the sample sizes per stratum is restricted, and much smaller compared to stratified simple random sampling or stratified systematic random sampling (with independent grids within the strata). Contrary to the Countryside Survey, the grid was not subsampled, i.e., all the sampling units at the grid nodes were sampled. One of the flaws of the sampling strategy is the estimation of the sampling variance. As stated before, no unbiased estimator of the sampling variance exists for systematic random sampling. Treating the systematic sample within a stratum as a simple random sample generally leads to substantial overestimation of the sampling variance.

A further flaw of the sampling design is that the selection of sampling units in a given stratum is not independent from those in another stratum. This dependence of stratum-estimates must be accounted for in the estimation procedures. We would have preferred to select grid samples independently from the strata. This also increases the flexibility of adapting the (expected) sample sizes to the strata by adapting the spacing of the grid. A final comment is the non-random selection of transects and circular plots within 1 km squares. Due to this, model assumptions are required in order to quantify the sampling variance.

5 SISPARES (Spain)

Our evaluation is based on the following publications:

- Bolaños, F., J.M. García Del Barrio, P. Regato and R. Elena Rosselló, 2001. Spanish forested landscapes: classification and dynamics. In: Ü. Mander, A. Printsmann and H. Palang (Eds.): *Development of European landscapes. Proceedings of IALE European Conference, Volume 1*. Institute of Geography, University of Tartu, Estonia, p. 258-263.

- Ortega, M., R.G.H. Bunce, J.M. García del Barrio and R. Elena-Rosselló, 2008. The relative dependence of Spanish landscape patterns on environmental, geographical and temporal variables. *Investigación Agraria: Sistemas y Recursos Forestales* **17**(2): 114-129.

5.1 Aim

The aim of the SISPARES monitoring programme is to study the evolution of landscape on the Spanish Iberian peninsula and Balearic islands, and the human impact on landscape. Ortega et al. (2008): "Recently, rural Spanish landscapes have been monitored by the SISPARES system (Bolaños et al., 2001) providing a vast database of their modern landscape pattern and dynamics. These data give us a unique opportunity to study the correlations between landscape pattern and both geographical and environmental factors."

5.2 Sampling design

5.2.1 Spatial sampling units

The sampling units are 4 km $\times$ 4 km squares. The total number of sampling units is 209.

5.2.2 Type of space–time design

This monitoring project is a kind of retrospective research: aerial photographs were available from the years 1956, 1984 and 1998. Estimates for 1956 and 1984 are based on aerial photographs only. In 1998, photo-interpretations were validated by field visits. We are not entirely certain, but it seems that all squares selected in 1956 were 'revisited', which means in this case that aerial photographs have been re-analysed, in 1984 and 1998.

5.2.3 Type of spatial sampling design

Sampling units were selected by stratified random sampling. Strata are biogeoclimatic land classes; this biogeoclimatic stratification of Spain is referred to as CLATERES (CLAsificacin biogeoclimatica TERritorial de ESpaa).

A total number of 209 sampling units were selected from 215 strata (one per stratum, six strata were not sampled). The size of the spatial units used in the biogeoclimatic classification was 2 km $\times$ 2 km, whereas the sampling units are 4 km $\times$ 4 km squares. Only pure sampling units were selected, i.e., sampling units that belong as a whole to one stratum. Ortega et al. (2008): 'Each sample (de Gruijter et al. (2006): sampling unit) represents the landscape of one geoclimatic class and was analysed by delimiting patches of land cover and linear elements of road network from aerial photo interpretation. The scale of photos is 1 : 30,000 and the minimum patch size that has been interpreted is 1 ha.' Besides a threshold was used for the areal proportion urban (build-up). Squares with an areal proportion exceeding this threshold were deleted from the sampling frame. We conclude that SISPARES cannot be treated as a probability sample from the Spanish-Iberian peninsula and Balearic islands, as large parts of the rural landscape of Spain have a zero probability of being included in the sample.

5.3 Evaluation

We recommend that SISPARES should not be included in the European-wide EBONE monitoring network. The most important reason for this is that a very large part of the Spanish landscape was excluded from the sampling frame. All 4 km $\times$ 4 km squares that do not belong in their entirety to a single biogeoclimatic stratum were excluded. Besides, only one sampling unit is selected per stratum, whereas for unbiased estimation of the sampling variance of estimates at least two sampling units per stratum are required.

6 SINUS: monitoring of Austrian landscapes

Our evaluation is based on the following publications:

- Peterseil, J., T. Wrbka, Chr. Plutzar, I. Schmitzberger, A. Kiss, E. Szerencsits, K. Reiter, W. Schneider, F. Suppan and H. Beissmann, 2004. Evaluating the ecological sustainability of Austrian agricultural landscapes-the SINUS approach. *Land Use Policy* **21**: 307-320.
- Peterseil, J. and T. Wrbka (Eds.), 2003. *Landschaftsökologische Strukturmerkmale als Indikatoren der Nachhaltigkeit. Endbericht zum Forschungsprojekt SINUS. Projekt im Rahmen des Leitschwerpunktes Kulturlandschaftsforschung, Bundesministerium für Bildung, Wissenschaft und Kultur.* Institut für Ökologie und Naturschutz der Universität Wien, IECB.

6.1 Aim

Peterseil et al. (2004) formulated the aim of the SINUS project as follows: "The project 'Spatial INdices for land Use Sustainability (SINUS)' was designed to develop reliable, operational, and spatially explicit indicators of practical use in long-term monitoring and assessment of ecological sustainability of Austrian cultural landscapes. The use of landscape structure attributes for this assessment was tested and implemented in an assessment procedure. The main research question was: which attributes of the land-use mosaic have to be recorded to describe the landscape with respect to its ecological sustainability?". Note that this aim of development of indicators differs from the aim of estimating spatial means of these indicators or temporal changes therein for Austria as a whole or regions in Austria. Note further that the sampling universe is restricted to cultural landscapes. Mainly forested areas, for instance, were not part of the sampling universe.

6.2 Sampling design

6.2.1 Spatial sampling units

The spatial sampling unit is a square landscape plot of 1 km $\times$ 1 km, corresponding with the Austrian national grid. At the 1 km $\times$ 1 km squares (local level) field mapping was done at a scale of 1 : 10,000 on black-and-white aerial photographs. Base units for mapping were the landscape elements: the smallest distinguishable, homogeneous surface areas on the landscape level. For each of these landscape elements structural attributes (e.g. patch, matrix or corridor element, the size, width or shape of the elements), hemerobiotic state, trophic level, plant-species richness, origin type and patch dynamic were recorded (Wrbka et al., 1997). Ecological key processes that result in characteristic landscape patterns were described using the concept of 'origin types' (Forman, 1983, 1995; Forman and Godron, 1981, 1986). Landscape elements were affiliated to categories of landscape processes (disturbance, regeneration, human introduction, persistence) and the importance of environmental resources for the development of the landscape element was recorded in the field using indicator plant species (Ellenberg, 1974; Ellenberg et al., 1992). This resulted in a total number of 33 attributes recorded on the landscape element level, and four attributes recorded on the landscape level (e.g. landscape plot description, matrix and network characteristics, historical land use). Next the field maps were digitized into a geographical information system and stored in a database. Field work took place during two periods in the years 1996 and 1997.

6.2.2 Type of spatial sampling design

Stratified random sampling was applied. Peterseil et al. (2004) described the sampling procedure. The field survey was restricted to open agricultural landscapes with a forest cover below 60%, including the sub-alpine and alpine summer pastures. Larger settlements and industrialized areas, forested landscapes and larger wilderness areas, like the nival belt of the Alps, were excluded from the survey. A total number of 182 sampling units were selected using a stratified random sampling procedure to guarantee representation of the whole variety of Austrian agricultural landscapes in the sample (Southwood, 1978; Reiter and Grabherr, 1997; Szerencsits et al., 1999; Wrbka et al., 1999). The stratification was based on geomorphological features (such as altitudinal level and exposition), historical land-use pattern and preliminary coarse landscape types, see Figure 6.1. The number of strata is 41 (subgroups, forming twelve main groups).

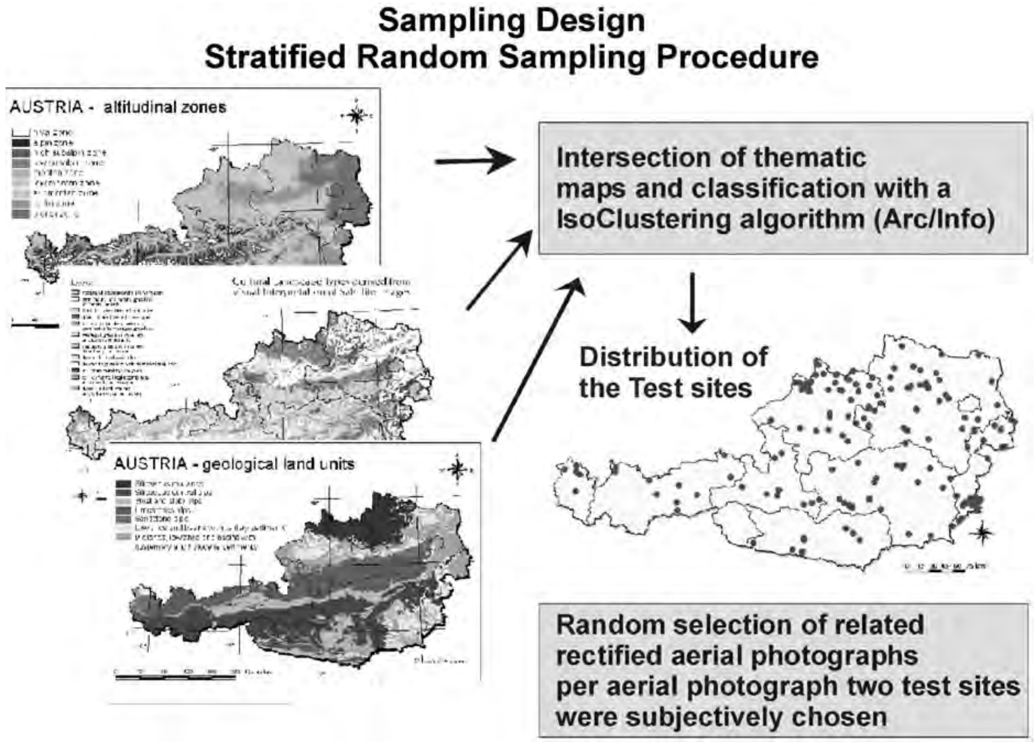

Figure 6.1: Sampling design: Scheme of the stratified random sampling procedure (from: Peterseil et al. (2004))

It is important to note that Peterseil and Wrbka (2003) gives the following details of the stratified random sampling design: "Innerhalb der zufällig ausgewählten Luftbildkarten (5 km × 5 km, MK) wurde eine subjective Auswahl einer Testfläche mit einer Kantenlänge von einem Kilometer (= Quadrant) getroffen. Die subjective Wahl in diesem Schritt der Stichprobenwahl stelt einen Kompromiss zwischen der Forderung nach statistischer Repräsentativität und Objectivität und der Machbarkeit im Rahmen der eines österreichweiten Ansatzes dar." Thus, in fact two stages can be distinguished. In the first stage 5 km × 5 km squares were selected following a stratified random sampling design. In the second stage a 1 km × 1 km square was selected *purposively* within the randomly selected 5 km × 5 km square.

6.2.3 Selection of sampling times

As far as we know the survey was not repeated yet.

6.3 Evaluation

As stated above SINUS is not designed for estimating spatial means of indicators and or changes therein for Austria as a whole or regions of Austria. The main aim was to find (develop) these indicators of ecological sustainability of cultural landscapes. This explains why some parts of the forested landscapes and larger wilderness areas, like the nival belt of the Alps, were excluded from the survey. For EBONE, these areas form part of the target population and therefore additional sampling plots must be selected. This also explains the subjective (purposive) selection of a 1 km square from the 5 km × 5 km squares. This subjective selection complicates the quantification of the sampling error in estimated spatial means of indicators and changes therein seriously.

7 The Small Biotope project and NOVANA in Denmark

Our evaluation is based on the following publications:

- Brandt, J.J.E, R.G.H. Bunce, D.C. Howard and S. Petit, 2002. General principles of monitoring land cover change based on two case studies in Britain and Denmark. *Landscape and Urban Planning* **62**: 37-51.
- Svendsen, L.M. and B. Norup (Eds.), 2005. *NOVANA. Nationwide Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments. Programme Description - Part 1.* National Environmental Research Institute, Denmark. NERI Technical Report No. 532.
- Svendsen, L.M., L. van der Bijl, S. Boutrup and B. Norup (Eds.), 2005. *NOVANA. National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments. Programme Description - Part 2.* National Environmental Research Institute, Denmark. NERI Technical Report No. 537.

7.1 Aim

An important goal of the Small Biotope project, started in 1981 by the Roskilde University, is 'to influence policy and decision-makers, by changing the focus of conservation interests to incorporate dispersed fragments of semi-natural vegetation' (Brandt et al., 2002). The Small Biotope project is continued as part of the NOVANA programme, to monitor structural landscape development in arable land with special emphasis on the trend with regard to small biotopes (Svendsen and Norup, 2005; Svendsen et al., 2005).

7.2 Sampling design

7.2.1 Spatial sampling units

Sampling units are squares of 4 km^2. The following information is collected:

1. detailed field records of all linear and areal biotopes less than 2 ha;
2. interviews with farmers concerning agricultural practice, including specific management practices for their Small Biotopes;
3. additional relevant information on the landscape and geo-related structures and drivers for each site, as far as possible stored in an integrated GIS.

7.2.2 Type of space–time design

The sites selected for the Small Biotope project were observed in 1981, 1986, 1991 and 1996, i.e. at a constant interval of five years. As far as we know the same 32 sites are observed in all four years, which makes the type of pattern in space–time static-synchronous.

Extensive and intensive stations are distinguished for monitoring of species and terrestrial natural habitats. Svendsen et al. (2005) (p. 118) explain the difference between both types of stations as follows: 'The difference between extensive and intensive stations is firstly, that intensive stations are monitored every year while extensive stations are monitored every sixth year, and secondly, that more chemical variables are measured at intensive stations than at extensive stations. The distribution of stations among the individual natural habitat types follows the following general rules:

1. Ten intensive stations is considered to be the minimum necessary to document interannual variations and describe the selected causal relationships. In the case of natural habitat types that are characterized by great heterogeneity and/or are subjected to a very varied range of pressures, the number of intensive stations is greater.

2. The number of extensive stations in each individual natural habitat type lies between 0 and 100. In the case of natural habitat types that are very rare in Denmark or which exhibit very little variation, no extensive stations have been established. In general, the number of stations depends on the number of individual habitats of each type and on the natural and anthropogenic variation within the natural habitat type.

The basis for the selection of monitoring stations is presented in Annex 1 of Part 3 of the Programme Description. The distribution of the intensive stations is based on the existing knowledge, whereas the final distribution of the extensive stations will be based on the results of the habitat charting.' Part 3 might give clarity about the procedure followed in selecting locations of stations. Unfortunately, Part 3 is in Danish.

7.2.3 Type of spatial sampling design

In the Small Biotopes project observations at 32 sites each of 4 km^2 were taken in 1981, 1986, 1991 and 1996. The site locations were selected "from regions defined by statistical analysis of the relevant agricultural, ecological and socio-economic data at the municipal level. Once defined, the sample sites were then selected, adding samples from less frequent, but typical landscape types e.g. reclaimed areas." (Brandt et al., 2002, p. 40). In total 32 sites are selected. There is no information on how these sites were selected.

7.2.4 Selection of sampling times

The sites selected for the Small Biotope project were observed in 1981, 1986, 1991 and 1996, i.e. at a constant interval of five years. The highest sampling frequency of NOVANA will be annual, due to economic constraints on the monitoring. As a result, variables that need more frequent measurements to be interpretable will not be included in the monitoring programme (Svendsen et al., 2005, p. 115).

7.3 Evaluation

As long as we have no detailed information on how the sites of the NOVANA programme are selected we cannot evaluate its suitability for incorporation in EBONE. The emphasis of the Small Biotopes project and NOVANA is on small biotopes. EBONE is not concerned only with trends in small biotopes, but in all biotopes.

8 Conclusions and recommendations

We evaluated the programmes for habitat monitoring in the United Kingdom, Sweden, Spain, Austria and Denmark. We conclude the following about the suitability of these networks for becoming part of the European-wide biodiversity monitoring network EBONE:

1. The Countryside Survey (United Kingdom) is a probability sample of spatial sampling units, enhancing model-free, valid estimation of stock and change, and is therefore suitable to become part of the EBONE network.

2. NILS (Sweden) is based on classical sampling theory, i.e., sampling units are selected by probability sampling, which makes design-based inference resulting in model-free, valid estimates of stock and change feasible. Therefore we conclude that NILS is suitable to become part of the EBONE network.

3. In our evaluation of SISPARES (Spain) we noted two inadequacies with respect to the aims of the Europe-wide network EBONE. First, a very large part of the Spanish landscape is excluded from the sampling frame. All 4 km $\times$ 4 km squares that do not belong in their entirety to a single biogeoclimatic stratum were excluded. Second, only one sampling unit is selected per stratum, whereas for unbiased estimation of the sampling variance of estimates at least two sampling units per stratum are required. Therefore, we recommend that SISPARES should not be included in the European-wide EBONE monitoring network.

4. The aim of SINUS (Austria) was to develop indicators of ecological sustainability of cultural landscapes. This causes some inadequacies with respect to the aims of EBONE. First, some parts of the forested landscapes and larger wilderness areas, like the nival belt of the Alps, were excluded from the survey. Second, the purposive selection of a 1 km square from randomly selected 5 km $\times$ 5 km squares seriously complicates the quantification of the sampling error in estimated spatial means of indicators and changes therein. Because of these inadequacies we recommend that SINUS should not become part of the EBONE network.

5. We had no detailed information on how the sites of the NOVANA programme (Denmark) are selected. Therefore, we could not evaluate its suitability for incorporation in EBONE. It should be noted that the emphasis of the Small Biotopes project and NOVANA is on small biotopes. EBONE is not concerned only with trends in small biotopes, but in all biotopes. Therefore we recommend that NOVANA should not become part of the EBONE network.

We recommend that the Countryside Survey (United Kingdom) and NILS (Sweden) will be part of the EBONE network. For the remaining part of the target area we recommend the development of a Europe-wide monitoring programme, see Part II of this report.

Part II

Designing a European-wide space–time sample

9 Introduction

To support EU conservation policy it is essential to collect comparable and reliable information for all EU countries. Data need to be collected consistently to facilitate comparison of different conservation policies and management regimes, and sampling intensities need to be sufficiently large to provide reliable information on status and trends of properties of habitats.

In this part we will present a design of a new, European-wide monitoring network that provides reliable information on the current status of selected properties of the habitats, and also on trends over time. For spatial sampling we present two alternatives. The first alternative is stratified random subsampling of the LUCAS sample (Gallego and Delincé, 2010). The second alternative is stratified random sampling from compact geographical substrata within environmental strata.

We focus on monitoring of the size (spatial extent) and quality indicators of common, widespread habitats. For rare habitats more tailored monitoring designs are required, entailing, amongst others, targeted selection of sampling units (km squares).

In Chapters 10 and 11 we elaborate on important choices to be made in space–time sampling. In Chapter 10 we describe:

- the monitoring objectives, including a definition of the target population, target quantities and types of information (Sect. 10.1);
- type of space–time design (Sect. 10.2);
- mode of selecting 1 km squares: probability sampling, targeted sampling, haphazard sampling, or convenience sampling (Sect. 10.3);
- total number of 1 km squares per sampling time (Sect. 10.4).

In Chapter 11 we describe aspects of the two alternative spatial sampling designs:

- a brief introduction into the two types of spatial sampling design (Sect. 11.1);
- stratified random subsampling of the LUCAS sample (Sect. 11.2);
- stratified random sampling from compact geographical substrata within environmental strata (EnS) (Sect. 11.3);
- an analysis of the required sample size (required number of 1 km squares, Sect. 11.4).

Part II ends in Chapter 12 with concluding remarks and recommendations on statistical aspects of Europe-wide monitoring of biodiversity.

10 Basic design choices in space–time sampling

10.1 Monitoring objective

Europe is defined as the 27 EU-countries, supplemented by Norway and Switzerland. At a meeting in Brussels (June 16, 2009) it was discussed how to treat urban areas, water bodies and the coastline in the target area. It was concluded that, although EBONE does not specifically focus on aquatic, coastal or urban biodiversity at present, these regions may become important in the future. Excluding them from the target area in the design phase may give problems in the future. It was therefore decided to be as inclusive as possible. The target area is now defined as: 'All of the EU27, supplemented by Norway and Switzerland, above the mean low tide line'. Finally, the United Kingdom and Sweden were excluded from the sampling frame. These two countries do belong to the target area, but a monitoring network need not be designed for these two countries, as statistically sound nation-wide monitoring networks have already been implemented here, see Firbank et al. (2003) and Ståhl et al. (2011), respectively, and Chapters 3 and 4.

Sampling units are 1 km squares. For the selected 1 km squares a map of the habitats is constructed on the basis of aerial photographs and fieldwork using the BioHab mapping procedure (Bunce et al., 2008). In this procedure 'General Habitat Categories' are recorded, which are defined by plant life forms.

Reporting units are the target area in its entirety and the twelve environmental zones of Metzger et al. (2005). This means that separate estimates for the twelve environmental zones are required. It is expected that the total number of observed 1 km squares will be too small to obtain reliable estimates for the separate environmental strata (EnS, subdivisions of the environmental zones), as well as for the countries (except large countries). For the latter purpose the monitoring data of the EBONE sample can be combined with national data in order to obtain more reliable estimates of status and trend of habitat properties at the national level.

10.2 Space–time design

As a space–time design we propose a serially alternating design (Figure 10.1). In simulation experiments this type of space–time design has shown to be relatively efficient for estimating a linear temporal trend of spatial means (totals) (Urquhart and Kincaid, 1999; ter Braak et al., 2008; Brus and de Gruijter, 2011). Further, we propose a periodicity of five years. This means that the sets of 1 km squares observed in the first five years differ between the years. In the sixth year the 1 km squares of the first year are revisited *et cetera* (Figure 10.1). This serially alternating design with a periodicity of five years conforms to the National Inventory of Landscapes in Sweden (NILS) (Ståhl et al., 2011).

It is important that the 1 km squares of a given year are selected from the entire study area, not from a part of it (for instance from a subset of the strata). This enables unbiased estimation every year of the statistical parameters (area of habitat types *et cetera*) of the study area in its entirety.

An alternative space–time design is a static-synchronous design, also referred to as a pure panel (de Gruijter et al., 2006). In a static-synchronous design every sampling time the same sample of 1 km squares is observed. The rate of change in habitat properties generally will be rather slow, and therefore we expect revisiting 1 km squares every year to be inefficient. Revisiting every five years leads to the space–time design depicted in Figure 10.2. The Countryside Survey of the United Kingdom is a static-synchronous space–time design in which 1 km squares are observed every so many years Firbank et al. (2003). Note that in Figure 10.2 the sampling density (sampling fraction of 1 km squares) is five times the sampling density in the serially alternating design. This may cause in some environmental strata redundant information, and as a consequence less precise estimates of spatial means (totals) compared to the serially alternating design. More importantly, the static-synchronous design of Figure 10.2 leads to strong fluctuations in required capacity for fieldwork, which might be undesirable for organizational reasons.

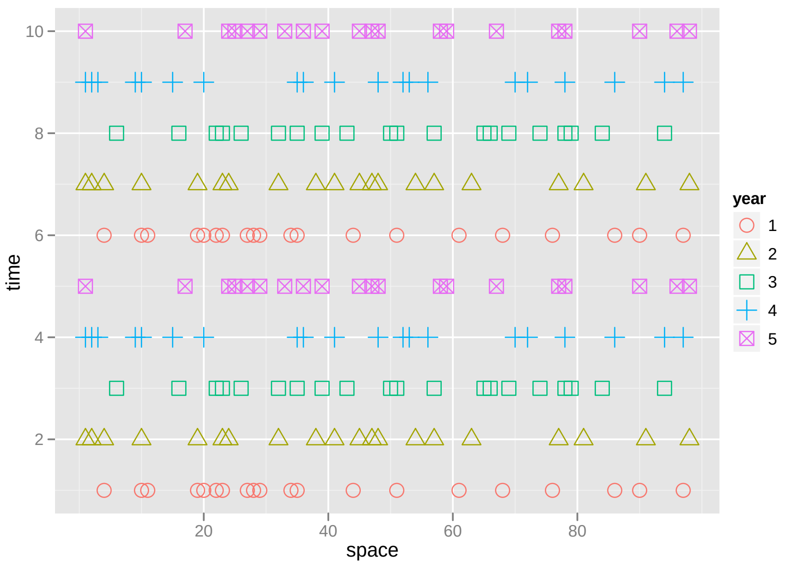

Figure 10.1: Serially alternating space–time design with a periodicity of five years

Figure 10.2: Static-synchronous (pure panel) space–time design with a periodicity of five years

10.3 Mode of selecting 1 km squares

We propose to select 1 km squares by probability sampling. This enables model-free, unbiased and valid estimation of target parameters and their standard errors (de Gruijter and ter Braak, 1990; Brus and de Gruijter, 1997). This is impossible with non-probability sampling, like haphazard sampling, targeted sampling or convenience sampling. With non-probability sampling a statistical model of the spatial variation (variogram) of the target properties is required. Calibrating such model for the EU can be quite demanding. Making assumptions on stationarity, isotropy *et cetera* cannot be avoided, and consequently the quality of the monitoring result will depend on the quality of these assumptions. Valid quantification of the uncertainty of the monitoring result is important to avoid discussions on the statistical significance of estimated time trends in quality indicators and other target parameters.

10.4 Total number of 1 km squares in EBONE sample and per EnS

For selecting the samples we must decide on the total number of 1 km squares and on their distribution among the environmental strata. The total number of 1 km squares in the EBONE sample was set at 10,000 (2,000 per year). This number was based on an internal report by R.G.H. Bunce et al., in which a number of 15 1 km squares per stratum, of which they had 145, was mentioned. This number is not based on a thorough statistical analysis of the minimum number of 1 km squares given a requirement on the quality of the monitoring result. In illustrating the types of spatial sampling design we used this tentative number of 10,000. In section 11.4 we elaborate on how this statistical analysis can be done. The number of 1 km squares per EnS *per year* was computed by multiplying the total number per year (2,000) by the relative areas of the EnS, i.e. the areas of the EnS outside the United Kingdom (UK) and Sweden (SE), divided by total area of target area outside UK and SE. This is referred to as proportional allocation of sample sizes. EnS 80 consists of 18 cells only, and was added to EnS 79. Similarly EnS 75 (643 cells) was added to EnS 76. The resulting sample sizes per EnS is shown in Table 10.1.

Table 10.1: Total number of 1 km grid nodes in entire study area (N) and in study area outside the United Kingdom and Sweden (M), number of points in LUCAS (second phase) sample (L), and planned number of 1 km squares in EBONE sample (E) per EnS

EnS	1	2	3	4	5	6	7	8	9	10
N	134246	95035	107706	111969	93347	69521	92523	102876	50519	19491
M	58410	81173	83950	40177	91615	69519	92523	14859	50519	19491
L	1500	3990	0	0	5287	4	5628	0	3392	0
E	145	200	210	100	225	175	230	35	125	50
EnS	11	12	13	14	15	16	17	18	19	20
N	34163	41665	35478	65178	32003	36284	110063	32015	18525	78687
M	34163	41665	0	23103	27161	36284	110063	32015	18525	4034
L	69	2496	0	46	1270	252	6549	1018	0	0
E	85	105	0	55	65	90	275	80	45	10
EnS	21	22	23	24	25	26	27	28	29	30
N	94103	31547	27337	30740	125306	28491	58010	116673	37540	102837
M	8369	20593	0	30740	94754	28491	58010	100577	37540	100128
L	491	1259	0	1533	5582	0	2941	6002	2048	4991
E	20	50	0	75	235	70	145	250	95	250
EnS	31	32	33	34	35	36	37	38	39	40
N	131931	23617	68116	92058	53426	126088	9973	97596	148814	64967
M	131931	23570	68116	89562	53426	46595	9973	96774	148814	49785
L	6848	1427	3370	5755	1208	2966	34	5214	8966	2827
E	330	60	170	220	135	115	25	240	370	125
EnS	41	42	43	44	45	46	47	48	49	50
N	3482	137343	15040	93460	58762	108021	171572	7398	93311	33549
M	3482	129403	15040	93460	58762	108021	171147	7398	93311	33549
L	203	7791	0	548	2818	6339	10488	10	80	1981
E	10	320	35	230	145	270	425	20	230	85
EnS	51	52	53	54	55	56	57	58	60	62
N	48465	28306	3275	101922	59761	59762	26527	32256	41905	42861
M	48465	28306	3275	101922	59761	59762	26527	32256	41905	42861
L	2040	1724	278	6214	3986	3926	1685	960	2684	2637
E	120	70	10	255	150	150	65	80	105	105
EnS	63	64	65	66	68	69	70	71	72	73
N	38472	56817	57209	39091	12261	44483	38063	61239	24107	75853
M	38472	56817	57209	39091	12261	44483	38063	61239	24107	75853
L	2125	4143	4532	3116	280	3002	2478	4198	1477	5890
E	95	140	140	95	30	110	95	150	60	190
EnS	74	75	76	77	78	79	80	81	82	83
N	49398	643	49427	52517	12067	70453	18	16264	38409	5499
M	49398	643	49427	52517	12067	70453	18	16264	38409	5499
L	3144	46	3173	3777	631	4484	0	572	2350	77
E	125	-	125	130	30	175	-	40	95	15

11 Spatial design

11.1 Types of spatial design

Probability samples can be selected by numerous selection methods (sampling design types). Hereafter we will elaborate on two types of spatial sampling design:

- stratified random subsampling of LUCAS sample;
- stratified random sampling from geographical substrata within EnS.

In both types of sampling design the environmental strata (EnS) of Metzger et al. (2005) are used as strata (Figure 11.1). In total there are 84 environmental strata, four of which are outside the target area (EnS 59, 61, 67 and 84) and two entirely fall in the United Kingdom and Sweden (EnS 13 and 23). This leaves 78 environmental strata to be sampled.

We now describe shortly the two spatial sampling design types. A sample will be selected with both design types as an illustration.

11.2 Stratified random subsampling of LUCAS sample

LUCAS (Land Use/Cover Area frame statistical Survey) was launched by Eurostat in 2001, in close collaboration with the Directorate General for Agriculture of the EU, and with support of the Joint Research Centre in ISPRA (Gallego and Delincé, 2010). For operational and financial reasons it can be attractive to locate the EBONE sampling units at (a subset of) the LUCAS sampling points. Sampling units in LUCAS are point locations (the nodes of a grid), whereas in EBONE these are 1 km squares. Colocation of both samples means that one of the corners of an EBONE 1 km square, for instance the southeast corner, is also a LUCAS sample point. Due to the difference in support of the EBONE and LUCAS sampling units, the savings of costs of fieldwork will be restricted.

LUCAS is a two-phase sample, i.e., a large sample (square grid of point-locations) that is subsampled. This subsample (second phase sample) consists of about 250,000 point locations, which is far too many for our design. This implies that the LUCAS subsample must be subsampled again, leading to a three-phase sample.

A drawback of subsampling LUCAS is the complexity of the resulting sampling design, leading to complicated estimators. Besides, with this sampling design no unbiased estimators exist of the precision (sampling variance) of the monitoring result (Gallego and Delincé, 2010). This is because the randomization of the 9×9 nodes of the subgrids is done only once (see Appendix). For these reasons we designed an alternative sample with a much simpler spatial sampling design, which is described in Section 11.3.

Design of LUCAS sample

The LUCAS sample (as selected in 2006) is a two-phase sample. In the first phase a square grid is randomly selected with a spacing of 2 km (LUCAS master sample) from EU25. Points located on small islands such as Baleares, Azores, Canary Islands, Cyprus, Malta, and Greek islands (except Creta) were excluded from the sample. Also points above 1200 m altitude (according to a digital terrain model) were discarded. Besides the following countries of the EBONE target area are not included in the LUCAS sampling frame: Norway (NO), Switzerland (CH), Bulgaria (BG) and Romania (RO). The nodes of the grid were classified into seven land use/cover classes by means of photo-interpretation. The nodes of the 2 km grid with similar land use/cover served as a stratum in subsequent subsampling (second phase). For this subsampling an 'intelligent design' has been developed, spreading out the sampling points across the study area, see Appendix. The sampling rate differs between the strata: arable land and permanent crops 50%, grassland 40%, remaining strata (woodland+shrubland, bare land, artificial areas, water) 10%. These sampling rates are needed for computation of the inclusion probabilities of the LUCAS sample, which on their turn are needed in unbiased estimation of target parameters (means, totals *et cetera*).

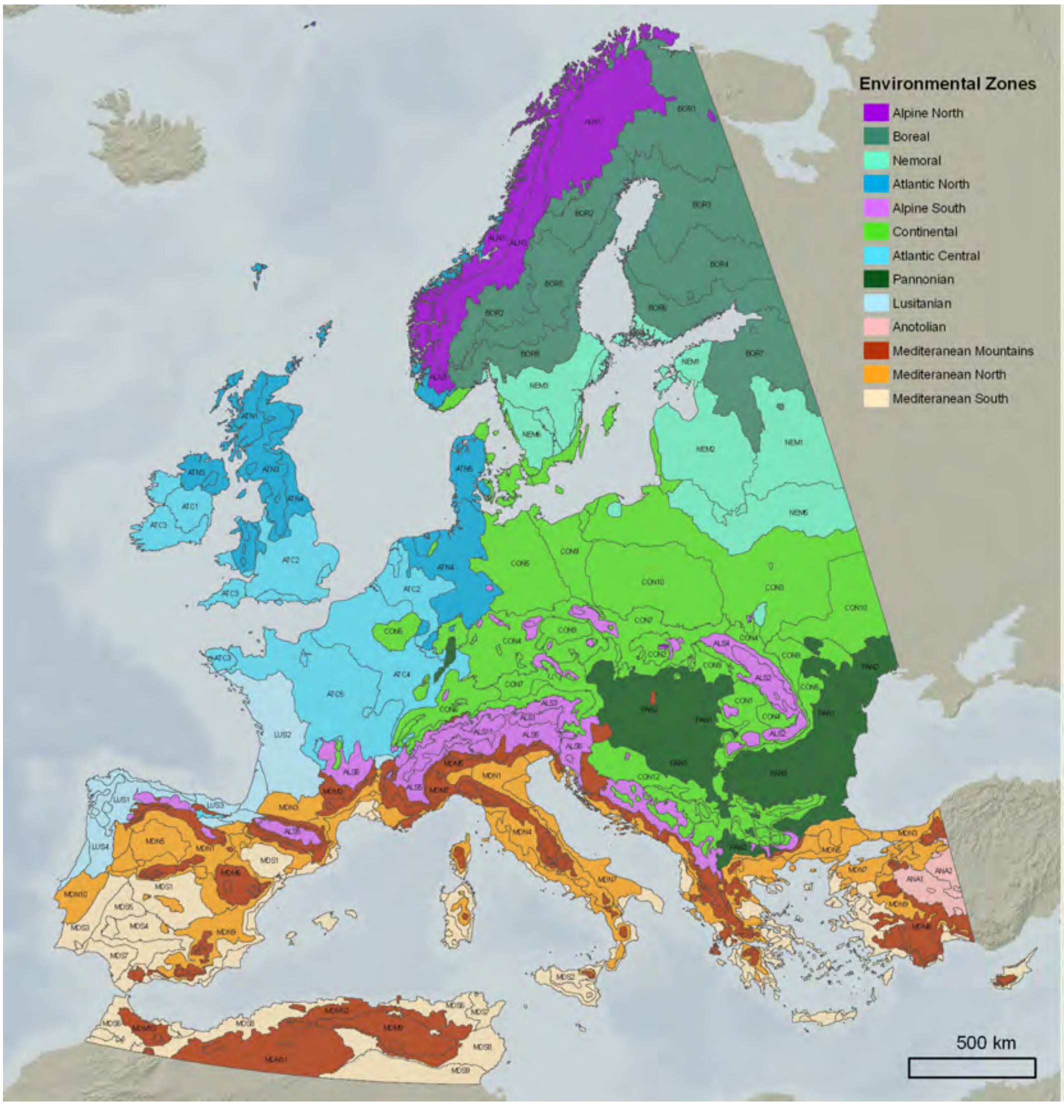

Figure 11.1: Environmental stratification of Europe after Metzger et al. (2005)

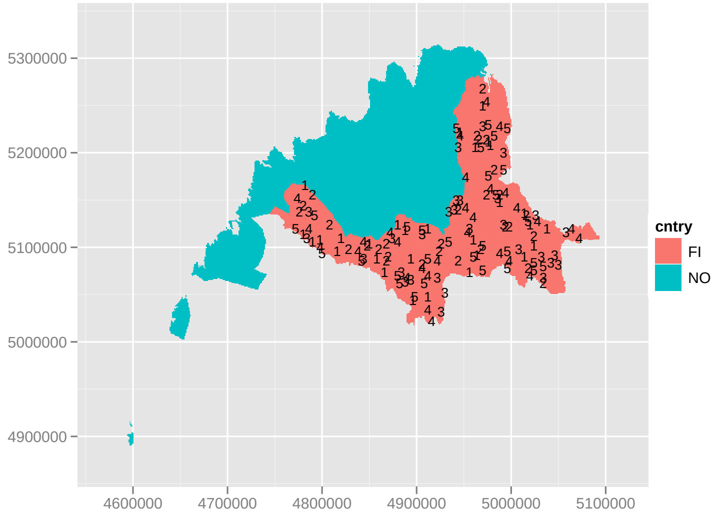

Figure 11.2: Subsample of 145 points from LUCAS (second phase) sample in environmental stratum (EnS) 1. Note that all 1 km squares are from Finland (Norway does not belong to target area of LUCAS)

Stratified random subsampling of LUCAS

The number of points in the LUCAS sample located in our study area, outside the United Kingdom and Sweden, equals 200,850. This is far too many for the EBONE sample, and therefore this LUCAS sample must be subsampled, leading to a three-phase sample. We subsampled the LUCAS sample by stratified random sampling, using the environmental strata (EnS) of Figure 11.1 as strata. We counted the number of points in LUCAS per EnS (Table 10.1). For the environmental strata (EnS) 3, 4, 8, 10, 13, 19, 20, 23, 26, 43 and 80 no LUCAS points are available. For these strata a sample still must be selected. For EnS 6, 11, 14, 48 and 49 the planned number of 1 km squares in EBONE exceeds the number of points in the LUCAS sample, so for these EnS additional 1 km squares must be selected. Figure 11.2 shows the LUCAS subsample selected from EnS 1.

11.2.1 Statistical estimation

Inclusion probabilities of 1 km squares

For design-based estimation of the means and totals at a given year the inclusion probabilities of the selected 1 km squares are needed. These inclusion probabilities are the product of the inclusion probabilities at the three phases:

$$\pi_i = \pi_{1,i} \cdot \pi_{2,i} \cdot \pi_{3,i} \tag{11.1}$$

with $\pi_{1,i}$ the inclusion probability in the first phase, et cetera. These inclusion probabilities can be computed by

$$\begin{aligned} \pi_{1,i} &= \frac{n_1}{A} \\ \pi_{2,li} &= \frac{n_{2,l}}{n_{1,l}} \\ \pi_{3,lhi} &= \frac{n_{3,lh}}{n_{2,l}} \end{aligned} \tag{11.2}$$

with n_1 the number of points in the LUCAS master sample (2 km $\times$ 2 km grid), A the area of the LUCAS target area, $n_{1,l}$ the total number of points in the LUCAS master sample in landuse/cover stratum l, $n_{2,l}$ the selected number of points in the LUCAS second phase sample from stratum l, and $n_{3,lh}$ the selected number of points (1 km squares) in the EBONE sample in the intersection of environmental h and landuse/cover stratum l.

Having computed the inclusion probabilities. the total can be estimated by

$$\hat{Y} = \sum_{i=1}^{n} \frac{y_i}{\pi_i} \tag{11.3}$$

11.3 Stratified random sampling from compact geographical substrata within EnS

With this sampling design the 78 environmental strata (EnS) of Fig. 11.1 served as the main strata. These EnS were further subdivided into compact geographical substrata using the method proposed by (Brus et al., 1999). This geographical substratification takes care of a good spatial coverage of the 1 km squares observed in a given year within an EnS. In this method all 1 km squares within a given EnS are clustered by the k-means algorithm into $L_{EnS} = n_{EnS}/5$ clusters (n_{EnS} is the number of 1 km squares to be selected from environmental stratum EnS). The two spatial coordinates of the centre of the 1 km squares are used as classification variables in k-means clustering. We used the R-package spcosa for constructing the compact geographical substrata, hereafter shortly referred to as geostrata (Walvoort et al., 2010a,b). With $L_{EnS} = n_{EnS}/5$ within each geostratum five 1 km squares are selected by simple random sampling *without replacement* (Figure 11.3, subfigure at top). The order of selection of the 1 km squares is registered. The set of 1 km squares of the same order are sampled in the same year. We also clustered the 1 km squares of a given EnS into $L_{EnS} = n_{EnS}/10$ geostrata. In this case from each geostratum ten 1 km squares are selected, so that we have each year two 1 km squares in each geostratum (Figure 11.3, subfigure at bottom). This has important advantages for estimating the sampling variance of the estimates. The size (area) of the geostrata within a given EnS is not constant. The reason for not restricting the geostrata to equal area is that many environmental strata are not contiguous areas, but consist of several isolated polygons. Constraining the geostrata to equal area may lead to non-contiguous geostrata, which is clearly suboptimal. The differences in size (area) of the geostrata must be accounted for in the statistical estimation of target parameters, see hereafter.

11.3.1 Statistical estimation

Spatial means and totals at a given year

This section describes how to obtain unbiased estimates of the spatial mean at a given year for the EU in its entirety and for the twelve environmental zones. These means will be estimated by design-based inference, i.e. based on the sampling design used for the selection of the 1 km squares. First note that the areas (total number of 1 km squares) of the geostrata is not constant. This implies that the sampling fractions vary between geostrata, and as a consequence the unweighted average of the values observed on the selected 1 km squares in a given year is a biased estimate of the spatial mean of the EU or the environmental zone in that year. An *unbiased* estimate can be obtained by (de Gruijter et al., 2006)

$$\hat{\bar{y}}(t) = \sum_{h=1}^{L} w_h \hat{\bar{y}}_h(t) \tag{11.4}$$

with L the number of geostrata within the EU (environmental zone), $w_h = N_h/N$ the relative size of geostratum h (N_h is total number of 1 km squares in geostratum h, N is total number of 1 km squares in area), and $\hat{\bar{y}}_h(t)$ the estimated mean of geostratum h in year t:

$$\hat{\bar{y}}_h(t) = \frac{1}{n_h} \sum_{i=1}^{n_h} y_{hi}(t) \tag{11.5}$$

with n_h the number of 1 km squares selected in geostratum h, and $y_{hi}(t)$ the value of target variable y observed on the i^{th} 1 km square in geostratum h in year t. With $n_h = 1$ the estimated mean of a geostratum equals the observed value of the target variable on this single 1 km square: $\hat{\bar{y}}_h(t) = y_{hi}(t)$. Estimates of

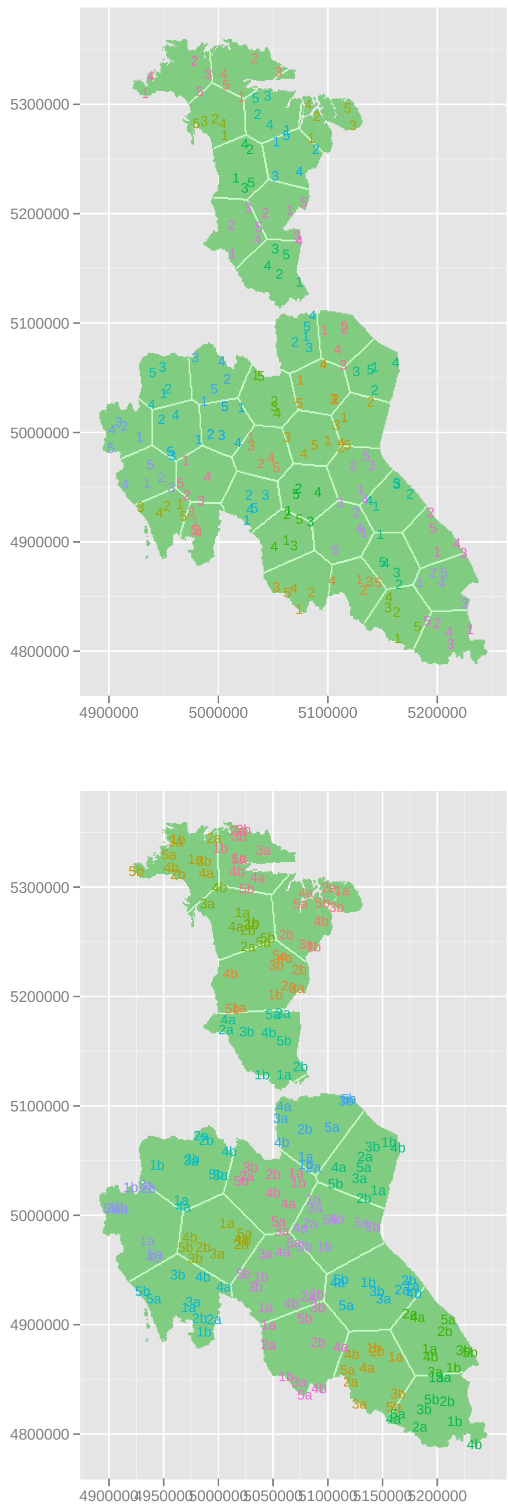

Figure 11.3: Compact geographical substratification of EnS 2 with five (one per year) 1 km squares per geostratum (upper) and ten (two per year) 1 km squares per geostratum (lower)

totals such as total area of a habitat category, can simply be obtained by multiplying the estimated mean by the total number of 1 km squares in the study area (environmental zone):

$$\hat{Y}(t) = N \cdot \hat{\bar{y}}(t) \tag{11.6}$$

The sampling variance of the estimated mean can be estimated by (de Gruijter et al., 2006)

$$\hat{V}(\hat{\bar{y}}(t)) = \sum_{h=1}^{L} w_h^2 \hat{V}(\hat{\bar{y}}_h(t)) \tag{11.7}$$

with $\hat{V}(\hat{\bar{y}}_h(t))$ the estimated sampling variance of the estimated mean of geostratum h in year t. This sampling variance can be estimated by

$$\hat{V}(\hat{\bar{y}}_h(t)) = \frac{S_h^2(y(t))}{n_h} \tag{11.8}$$

with $S_h^2(y(t))$ the estimated spatial variance of $y(t)$ in geostratum h:

$$S_h^2(y(t)) = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} (y_{hi}(t) - \hat{\bar{y}}_h(t))^2 \tag{11.9}$$

With one 1 km square per geostratum, $n_h = 1$, the spatial variance $S_h^2(y)$ cannot be estimated. In this case the 'collapsed strata method' can be used to obtain an approximate estimate of the sampling variance (Cochran, 1977, p. 138). The sampling variance of an estimated total can simply be obtained by multiplying the sampling variance of the estimated mean by the *squared* total number of 1 km squares:

$$\hat{V}(\hat{Y}(t)) = N^2 \cdot \hat{V}(\hat{\bar{y}}(t)) \tag{11.10}$$

Ratio estimation of spatial mean

A complication in the statistical estimation of spatial means is that not all 1 km squares in the target area have equal area. For 1 km squares on the border of the target area, the area will be < 100 ha. The spatial mean at a given year t is defined as the total *per areal unit* (for instance ha)

$$\bar{y}(t) = \frac{\sum_{i=1}^{N} y_i(t)}{A} \tag{11.11}$$

With sampling units of unequal area selected with equal probability, the unweighted average of the means determined for the selected sampling units is a biased estimate of the spatial mean. In this case an unbiased estimate of the spatial mean can be obtained by estimating the total and dividing this estimated total by the total area of the study area:

$$\hat{\bar{y}}(t) = \frac{\hat{Y}(t)}{A} \tag{11.12}$$

The total $Y(t)$ is not estimated by Eq. 11.6 but by

$$\hat{Y}(t) = \sum_{i=1}^{n} \frac{y_i}{\pi_i} \tag{11.13}$$

with y_i the total (for instance area or length) for the i^{th} 1 km square, and π_i the probability that this 1 km square is included in the sample (inclusion probability). To determine the values y_i for a 1 km square that partly falls outside the target area, this part outside the study area is ignored. For stratified simple random sampling the inclusion probability of a 1 km square in stratum h equals the sampling fraction of that stratum:

$$\pi_{hi} = \frac{n_h}{N_h} \tag{11.14}$$

Alternatively, the spatial mean can be estimated by dividing the estimated total by the *estimated* total area of the study area:

$$\hat{\bar{y}}(t) = \frac{\hat{Y}(t)}{\hat{A}} = \frac{\sum_{i=1}^{n} \frac{y_i}{\pi_i}}{\sum_{i=1}^{n} \frac{z_i}{\pi_i}} \tag{11.15}$$

with z_i the total area of 1 km square i within the study area. This estimator generally is more accurate, despite its slight bias, because the estimated quantities in the numerator and denominator are positively correlated (Särndal et al., 1992, p.182).

Change of spatial mean

The change of the spatial mean between two years can be estimated by the difference in the estimated spatial means at the two years:

$$\hat{\bar{d}}(t_2, t_1) = \hat{\bar{y}}(t_2) - \hat{\bar{y}}(t_1) \tag{11.16}$$

The sampling variance of this estimated difference can be estimated by the sum of the sampling variances of the two estimated means minus the sampling covariance. With the space–time design depicted in Figure 10.1, the two samples of any pair with a time-lag unequal to five years are selected independently. The sampling covariance of the estimated spatial means then equals 0, so that we obtain:

$$\hat{V}(\hat{\bar{d}}(t_2, t_1)) = \hat{V}(\hat{\bar{y}}(t_2)) + \hat{V}(\hat{\bar{y}}(t_1)) \tag{11.17}$$

When the time lag is five years, $t_2 - t_1 = 5$, paired differences can be computed for the 1 km squares, and the change of the mean can be estimated by

$$\hat{\bar{d}}(t_2, t_1) = \sum_{h=1}^{L} w_h \hat{\bar{d}}_h(t_2, t_1) \tag{11.18}$$

with

$$\hat{\bar{d}}_h(t_2, t_1) = \frac{1}{n_h} \sum_{i=1}^{n_h} d_{hi}(t_2, t_1) \tag{11.19}$$

In this case the sampling variance of the estimated change can be estimated by

$$\hat{V}(\hat{\bar{d}}(t_2, t_1)) = \sum_{h=1}^{L} w_h^2 \hat{V}(\hat{\bar{d}}_h(t_2, t_1)) \tag{11.20}$$

with $\hat{V}(\hat{\bar{d}}_h(t_2, t_1))$ the estimated sampling variance of the estimated mean change of geostratum h between years t_1 and t_2. This sampling variance can be estimated by

$$\hat{V}(\hat{\bar{d}}_h(t_2, t_1)) = \frac{S_h^2(d(t_2, t_1))}{n_h} \tag{11.21}$$

with $S_h^2(d(t_2, t_1))$ the estimated spatial variance of the paired differences $d(t_2, t_1)$ in geostratum h:

$$S_h^2(d(t_2, t_1)) = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} (d_{hi}(t_2, t_1) - \hat{\bar{d}}_h(t_2, t_1))^2 \tag{11.22}$$

Temporal trend of spatial mean

Following Breidt and Fuller (1999) and Brus and de Gruijter (2011) we define the linear temporal trend as a linear combination of the spatial means:

$$b = \sum_{j=1}^{r} w_j \bar{y}(t_j) \tag{11.23}$$

with r the number of sampling times (years), $\bar{y}(t_j)$ the (errorless) spatial mean at time t_j, and w_j the weight attached to the mean at time t_j:

$$w_j = \frac{t_j - \bar{t}}{\sum_{j=1}^{r} (t_j - \bar{t})^2} \tag{11.24}$$

With this definition the temporal trend is a population parameter, not a model parameter.

Defined as a population parameter, the linear trend can simply be estimated by

$$\hat{b} = \sum_{j=1}^{r} w_j \hat{\bar{y}}(t_j) \tag{11.25}$$

The sampling variance of the estimated linear trend can be estimated by

$$\hat{V}(\hat{b}) = \mathbf{w}' \hat{\mathbf{C}}(\hat{\bar{y}}) \mathbf{w} \tag{11.26}$$

with $\mathbf{w}$ the vector of length r with weights (Eq. 11.24), and $\hat{\mathbf{C}}(\hat{\bar{y}})$ the $r \times r$ matrix with estimated sampling variances and covariances of the estimated means.

11.4 Computation of required number of 1 km squares

An important advantage of statistical methods for survey is that the precision of the survey results (estimates) can be quantified. In the formulas for the sampling variance of the estimated total for simple random sampling (SI) and stratified simple random sampling (STSI) *spatial* variances (within the area as a whole or within strata) show up, that are estimated from the same sample. If we are able, prior to the sampling, to make a first guess at these spatial variances, then we can compute in advance the number of sample locations required to achieve a given minimum quality of the estimated target parameter. We will illustrate this for estimating the areas of habitat types given a quality constraint. Three quality constraints will be used, a constraint on the sampling variance or on the coefficient of variation (Section 11.4.1), and on the probability of an absolute or relative error of a given size (Section 11.4.2). Computations of the required number of 1 km squares for estimating spatial *means* at a given year, and of changes of totals or means between two years are entirely analogous. Computations will be illustrated with an example on a simulated population. In a final section (Section 11.4.3) we will elaborate on the required sample size for statistical testing of the temporal trend in the area of a habitat. In this case the quality constraint is defined in terms of the maximum tolerable error rates of a conclusion on the absence or presence of a trend.

11.4.1 Constraint on sampling variance or coefficient of variation

Simple random sampling

The simplest situation is when the quality constraint is formulated in terms of the sampling variance or standard deviation of the estimated mean or total. For SI the sampling variance of the estimated total (area) at a given year equals

$$\widehat{V}\left(\hat{Y}_{\mathsf{SI}}\right) = N^2 \frac{\widehat{S^2}(y)}{n} , \tag{11.27}$$

where N is the total number of 1 km squares in the study area, and $\widehat{S^2}(y)$ is the estimated *spatial* variance of the areas of a habitat type among the sampling units (1 km squares) in the study area:

$$\widehat{S^2}(y) = \frac{1}{(n-1)} \sum_{i=1}^{n} \left(y_i - \hat{\bar{y}}_{\mathsf{SI}}\right)^2 . \tag{11.28}$$

with $\hat{\bar{y}}_{\mathsf{SI}} = \frac{1}{n} \sum_{i=1}^{n} y_i$. Note that in the above equations we dropped the argument t, i.e. $y = y(t)$ *et cetera*. For SI, the required sample size can then simply be obtained by rewriting (11.27), and substituting the prior estimate of the spatial variance of y among the 1 km squares in the area, $\breve{S}^2(y)$, for the estimated spatial variance, $\widehat{S^2}(y)$:

$$n_{\mathsf{req}} = \frac{N^2 \breve{S}^2(y)}{V_{\mathsf{max}}} . \tag{11.29}$$

In case of a constraint on the coefficient of variation, the same procedure can be used. It requires a prior estimate of the area, which is used to compute the maximum value of the sampling variance of the total (area), V_{max}.

Example We simulated areas (in hectares) of a habitat type within 1 km squares for 1,000 1 km squares ($N = 1,000$), using a uniform distribution with lower bound 0 and upper bound 100. The simulated total area of the habitat type was 49,940 ha (which is close to $50 \times 1,000$). The spatial variance of the areas among 1 km squares, $S^2(y)$, was 875 ha^2. Suppose we have a perfect prior estimate of this spatial variance: $\breve{S}^2(y) = S^2(y)$. Using a maximum standard deviation of the estimated total area of 5,000 ha ($V_{\mathsf{max}} = 25 \cdot 10^6$) gives a required sample size n_{req} of 35 1 km squares.

Now suppose we require that the coefficient of variation equals 0.10 at maximum. Further suppose that the prior estimate of the total area of the habitat type equals 45,000 ha. The maximum standard deviation can then be computed by multiplying the required coefficient of variation and the prior estimate of the total area, giving a maximum standard deviation of 4500 ha ($V_{\mathsf{max}} = 20.25 \cdot 10^6$). Inserting this maximum variance in Eq. 11.29 gives a required sample size of 43.2 (rounded upward to 44) 1 km squares.

Stratified simple random sampling

For STSI, prior estimates of the spatial variances within strata can be used to compute the optimal allocation, i.e. the numbers of sample locations per stratum that result in the minimum sampling variance of the estimated total, given the total sample size (de Gruijter et al., 2006, p. 94). The required total sample size for a specified maximum allowable sampling variance of the estimated total can then be calculated with

$$n_{\text{req}} = \frac{1}{V_{\text{max}}} \cdot \left(\sum_{h=1}^{L} N_h \, \breve{S}_h(y) \right)^2 , \tag{11.30}$$

with $\breve{S}_h(y)$ the prior estimate of the spatial standard deviation of y within stratum h. Eq. (11.30) assumes equal cost per sample location for the strata. We refer to de Gruijter et al. (2006, p. 95) if these costs are unequal for the strata. For proportional allocation, the required sample size can be calculated with (Lohr, 1999, p. 105)

$$n_{\text{req}} = \frac{N \sum\limits_{h=1}^{L} N_h \, \breve{S}_h^2(y)}{V_{\text{max}}} . \tag{11.31}$$

Example We sorted the N 1 km squares on the basis of their simulated areas. The first 500 1 km squares formed stratum 1, and the second 500 1 km squares stratum 2. The average and variance of the areas (within 1 km squares) for stratum 1 equaled 24 ha and 220 ha^2, respectively, and for stratum 2 the average and variance was 76 ha and 201 ha^2, respectively. Note that the variance within the strata is much smaller than within the total area (875 ha^2). For optimal allocation (assuming the sampling cost per 1 km square are equal for both strata) and a maximum standard deviation of 5,000 ha, Eq. 11.30 gives a required total sample size of 8.4 (rounded upward to 9) 1 km squares. Using Eq. 11.31, the required total sample size with proportional allocation also equaled 8.4 (rounded upward to 9) 1 km squares. These equal total sample sizes for proportional and optimal allocation can be explained by the approximate equal spatial variances within the strata (220 and 201 ha^2). As the total number of 1 km squares per stratum, N_h, are also equal, this implies that the stratum sample sizes, n_h, for proportional and optimal allocation are equal.

11.4.2 Constraint on probability of error

This section describes how to calculate the required sample size if the quality constraint is formulated in terms of the probability of occurrence of the error in the estimated area. If an absolute error e has been specified with an allowed probability of exceedance α, then the maximum allowable sampling variance can be derived from e and α as

$$V_{\text{max}} = \left(\frac{e}{u_{1-\alpha/2}} \right)^2 , \tag{11.32}$$

where $u_{1-\alpha/2}$ is the $(1-\alpha/2)$ quantile of the standard normal distribution. The derived value of V_{max} is then inserted in Eq. (11.29), (11.30) or (11.31) to obtain the required sample sizes.

If instead of the absolute error, the relative error $|(\hat{Y} - Y)/Y|$ should be smaller than a specified limit e_{rel}, the required sample size can be used by replacing e in the numerator of (11.32) by $e_{\text{rel}} \breve{Y}$, with $\breve{Y}$ a prior estimate of the area, and continuing the procedure as before.

Example Suppose that we require that the probability that the absolute error, e, in the estimated total area exceeding 5,000 ha must be smaller than 0.10 ($\alpha = 0.10$). For a standard normal distribution the quantile corresponding with $1-\alpha/2$, $u_{1-\alpha/2}$, equals 1.645. This means that for a standard normal distribution (normal distribution with mean 0 and variance 1) the probability that a random number drawn from this distribution exceeds 1.645 equals 0.05. Using Eq. 11.32 gives $V_{\text{max}} = 3040^2$. Inserting this result in Eq. 11.29 gives a required sample size for simple random sampling of 95 1 km squares. For stratified random sampling and optimal allocation (Eq. 11.30) this quality constraint leads to a minimum sample size of 23 1 km squares.

Now we require that the probability of the absolute value of the relative error exceeding 0.10 must be smaller than 0.10. Using the above mentioned prior estimate of the total area of 45,000 ha, gives an absolute error of 4500 ha. Proceeding as above this gives $V_{\text{max}} = 2736^2$. This gives a minimum sample size of 28.1 (rounded upward to 29) 1 km squares.

11.4.3 Constraint on power of statistical test of trend

We may also want to know how many 1 km squares are needed in order to detect with a given probability a small, but still relevant linear trend in the area or some other property of a given habitat. In statistical terms this boils down to computing the required sample size for hypothesis testing. Let us take as the null-hypothesis that there is no trend: $\mathrm{H}_0 : b = 0$. First, we must decide on the maximum probability that H_0 is rejected (we conclude that there is a trend) while H_0 is in fact true (in reality there is no trend). This maximum tolerable probability of false rejection (type I error) is denoted by α. Second, we must decide on an upper limit for the probability of false acceptance (type II error), β, when the true trend equals some chosen value for the smallest relevant trend, b_1. The value $1 - \beta$ is referred to as the power of the test. Once we have chosen values for α, β and b_1, the required sample size can be computed as follows:

1. estimate the sampling variances and covariances of the estimated areas at years $t, t = 1 \cdots r$ for a range of sample sizes n
2. estimate the standard error of the estimated trend (Eq. 11.26).
3. compute the critical value for the trend beyond which H_0 is rejected:
$$b_{\text{crit}} = \Phi^{-1}\left(1 - \alpha/2; 0; \sqrt{\hat{V}(\hat{b})}\right) \tag{11.33}$$
4. compute the power $1 - \beta$ by
$$1 - \beta = 1 - \Phi\left(b_{\text{crit}}; b_1; \sqrt{\hat{V}(\hat{b})}\right) \tag{11.34}$$
5. plot the power against the sample size, and determine the minimum sample size at which the required power is achieved

Example Suppose we accept a maximum probability α of false rejection of the null-hypothesis of 0.10. As a minimum relevant trend, b_1, we choose 100 ha year^{-1}, which is 0.2% of the total area. If the true trend equals 100 ha year^{-1}, then we would like to have a probability of 0.90 that we reject the null-hypothesis. This is equivalent to a maximum probability β of 0.10 of false acceptance of the null-hypothesis. Figure 11.4 shows the power as a function of the total sample size for the serially alternating space–time design depicted in Figure 10.1, for three and four sampling years, and stratified random sampling in space with proportional allocation (see Example in paragraph 'Stratified random sampling' in Section 11.4.1). For three sampling years the minimum sample size is 78 1 km squares per year; with four sampling years this sample size is reduced to 31 1 km squares per year. For five and more sampling rounds we need estimates of the sampling covariances of the estimated areas in the first year and fifth year *et cetera* for computing the power graph.

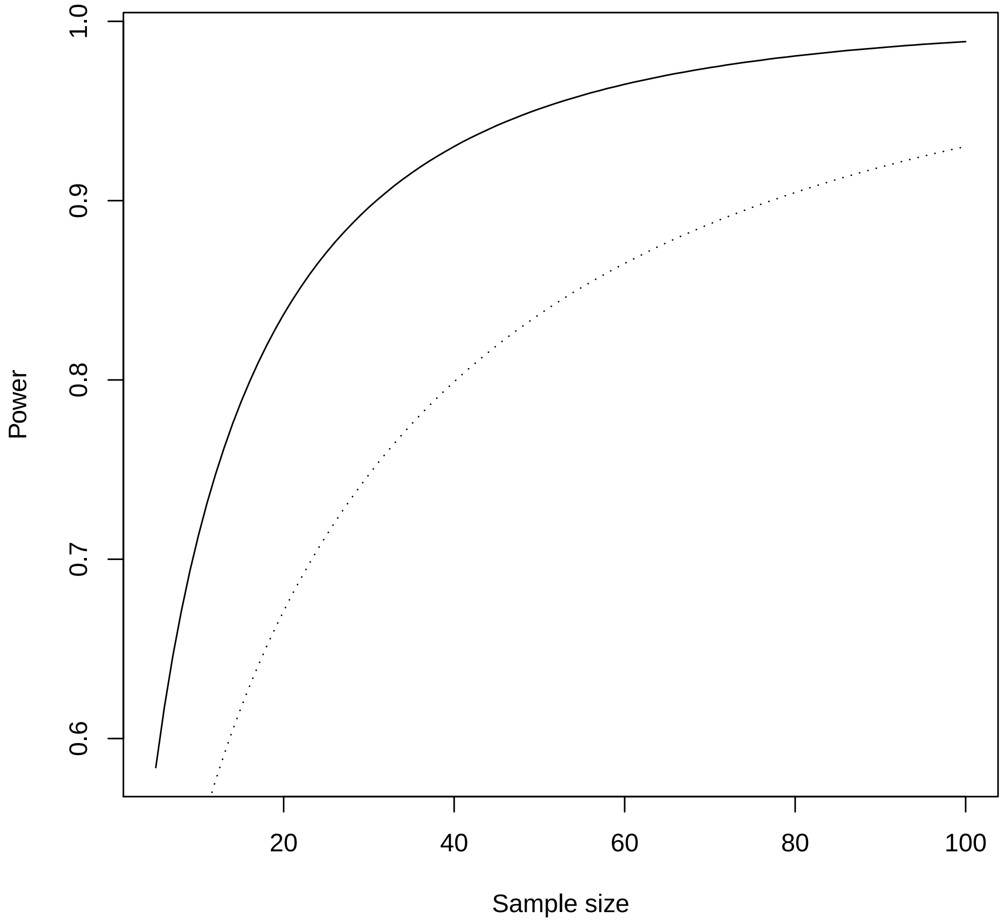

Figure 11.4: Power of test on trend as a function of the total sample size for serially alternating space–time design (Figure 10.1) with three (dotted line) and four sampling years (solid line); stratified random sampling in space with proportional allocation

12 Conclusions and recommendations

We presented a new design of a new, European-wide monitoring network that provides reliable information on the current status of selected properties of the habitats, and also on trends over time. We excluded Sweden and the United Kingdom from the sampling frame, as statistically sound nation-wide monitoring networks have already been implemented in these countries, see Ståhl et al. (2011) and Firbank et al. (2003), respectively. The basis of the presented design is probability sampling, which enables model-free, unbiased and valid estimation of status and trend parameters and their standard errors. This is crucial given the aim of EBONE to develop a framework for monitoring which enables Europe-wide statistically reliable, geographically referenced and comparable data collection of species and habitats of interest.

For spatial sampling we presented two alternatives: the first alternative is stratified random subsampling of the LUCAS sample (Gallego and Delincé, 2010), the second alternative is stratified random sampling from compact geographical substrata within environmental strata. In both alternatives the sampling units are fairly distributed in the geographical space, which makes the collected data suitable for spatial interpolation. The first alternative, based on the LUCAS sample, might have some organizational advantages. The design of the second alternative is much simpler, however, which is an advantage in data processing.

13 General conclusions and recommendations

The aim of this report was to evaluate existing national programmes for monitoring of landscape features, and to present a design of a new, European-wide monitoring network that provides reliable information on the current status of selected properties of the habitats, and also on trends over time. We evaluated the programmes for habitat monitoring in the United Kingdom, Sweden, Spain, Austria and Denmark. We conclude that the monitoring programmes of Spain (SISPARES), Austria (SINUS) and Denmark (NOVANA) do not answer the aims of the EBONE programme. We recommend that the Countryside Survey (United Kingdom) and NILS (Sweden) will be part of the EBONE network, since the statistical basis of these networks enables model-free, unbiased and valid estimation of status and trend parameters and their standard errors. For the remaining part of the target area we presented a design of a new, European-wide monitoring network that provides reliable information on the current status of selected properties of the habitats, and also on trends over time. The basis of the presented design is probability sampling, which enables model-free, unbiased and valid estimation of status and trend parameters and their standard errors. This is crucial given the aim of EBONE to develop a framework for monitoring which enables Europe-wide statistically reliable, geographically referenced and comparable data collection of species and habitats of interest.

The aim of the EBONE programme is to develop and implement a terrestrial biodiversity observation network that is transmissible, cost effective and provides added value to the currently independent data sources of *in situ* data and Earth Observation (EO). The EBONE project includes the development of a framework for monitoring which enables Europe-wide statistically reliable, geographically referenced and comparable data collection of species and habitats of interest. Given this aim we recommend that unremitting attention should be paid to a conscientious sampling design, now and in future.

A The LUCAS second phase sampling design

For subsampling the 2 km grid (LUCAS master sample) a sophisticated design has been developed. First the 2 km grid is divided into square subgrids of 9×9 nodes. Subsequently, the nodes in a subgrid are numbered in such a way that spatial clustering of successive numbers is avoided. The numbering is achieved by implementation of the following algorithm:

1. Select first point simple randomly (this point receives number 1).
2. Select second point randomly from group of points at maximum distance from first point.
3. Select third until 81^{th} point randomly from group of points that maximizes the minimum distance to points already selected.

In the above algorithm the distance between two points is not simply computed as the Euclidian distance. This would lead to a concentration of small numbers near the edge, and consequently to a concentration of sampling points near the edges of the squares. Distance is defined as (J. Gallego, personal communication):

$$d = \sqrt{[\min\{(x_1 - x_2)\text{mod}(9), (x_2 - x_1)\text{mod}(9)\}]^2 + [\min\{(y_1 - y_2)\text{mod}(9), (y_2 - y_1)\text{mod}(9)\}]^2} \quad \text{(A.1)}$$

Figure A.1 shows the distance to the lower-left (top subfigure) and to the mid-left cell (bottom subfigure) computed with Eq. A.1. As can be seen from the subfigure at the top the cell in the bottom row ($y = 1$) at the largest distance of the lower-left cell is not the cell at the utmost right but the two cells with x-coordinates 5 and 6, respectively. The lower-right cell ($x = 9$) is at distance 1, in other words it is the nearest neighbour of the lower-left cell ($x = 1$). This can be imagined by connecting the lower-left and lower-right cells, so that the bottom row of cells become a circle. Distances between cells are computed as the shortest distance along the circle. The same pattern of distances can be seen in the left column of cells.

Figure A.2 shows two realizations of the random numbering. The randomization of the numbers is done only once, i.e. the randomization in all subgrids is identical. Now, suppose we want to select n_h nodes from a given stratum h. All nodes that fall in stratum h with a similar number form a subset. Sampling nodes are selected by selecting complete subsets, starting with subset 1. This is continued until the remainder of points to be selected is smaller than the number of nodes in the next subset. The remainder is selected simple randomly from this subset.

Suppose all nodes of a subgrid belong to the same stratum, and that we want to select n_c nodes from this subgrid. With the distance criterion of Eq. A.1 the probability that a point is selected in one of the draws (probability of inclusion in the sample) is equal for all 81 nodes (personal communication J. Gallego). This is supported by a simulation study in which we randomized the numbering 100,000 times, and counted for all nodes the number of times the node is selected. Figure A.3 shows the result for $n_c = 2$. The inclusion probability for this number of sampling nodes equals $2/81 = 0.0247$. As can be seen the estimated inclusion probability fluctuates around this value, and the spatial pattern seems to be completely random.

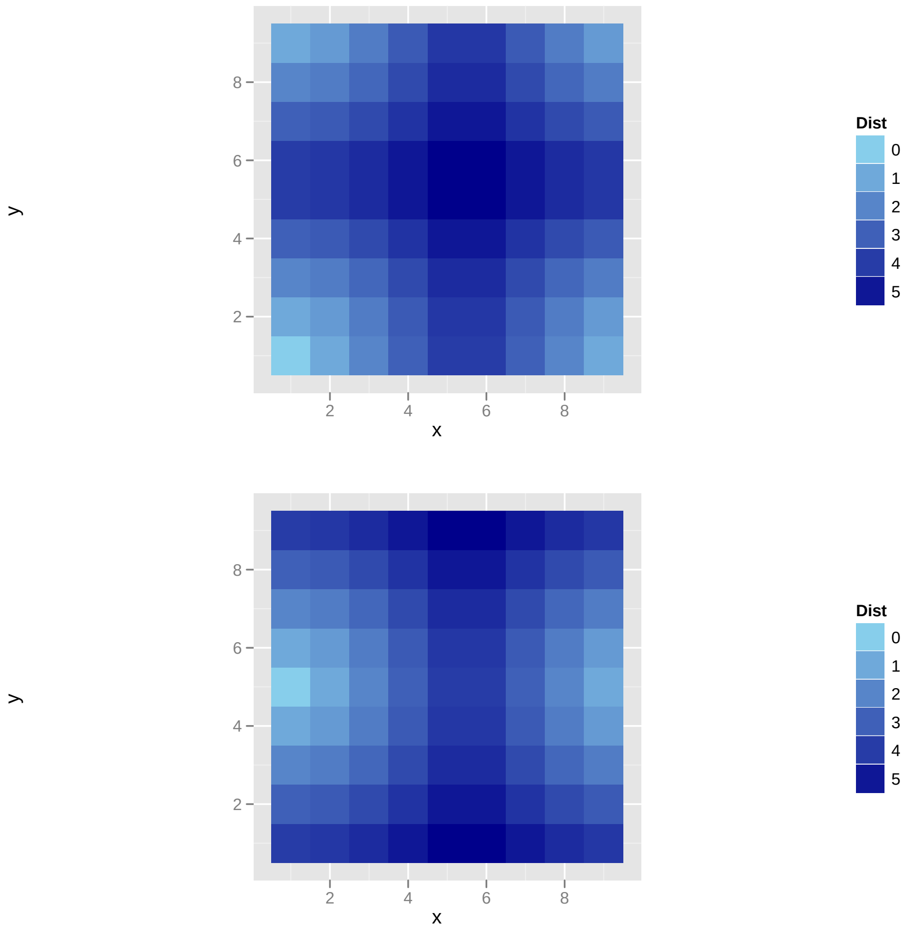

Figure A.1: Distance to lower-left (top) and mid-left cell (bottom) as computed with Eq. A.1

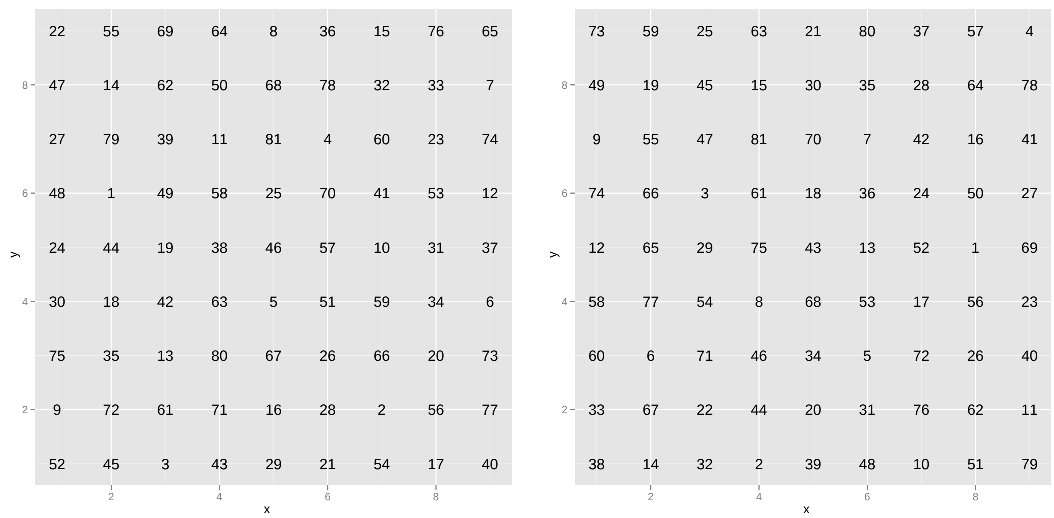

Figure A.2: Two realizations of random numbering of subgrid of 9×9 nodes with algorithm implemented in LUCAS

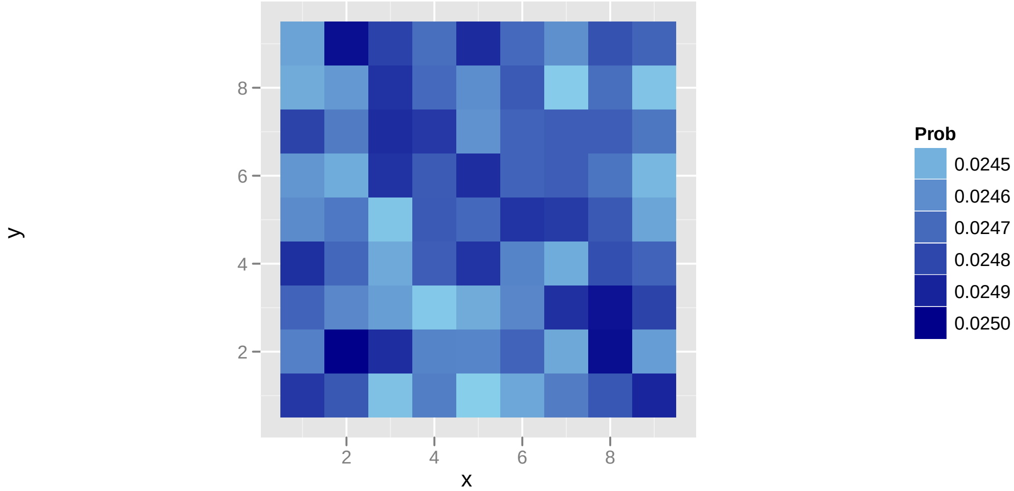

Figure A.3: Estimated inclusion probabilities with selection of two nodes by algorithm implemented in LUCAS

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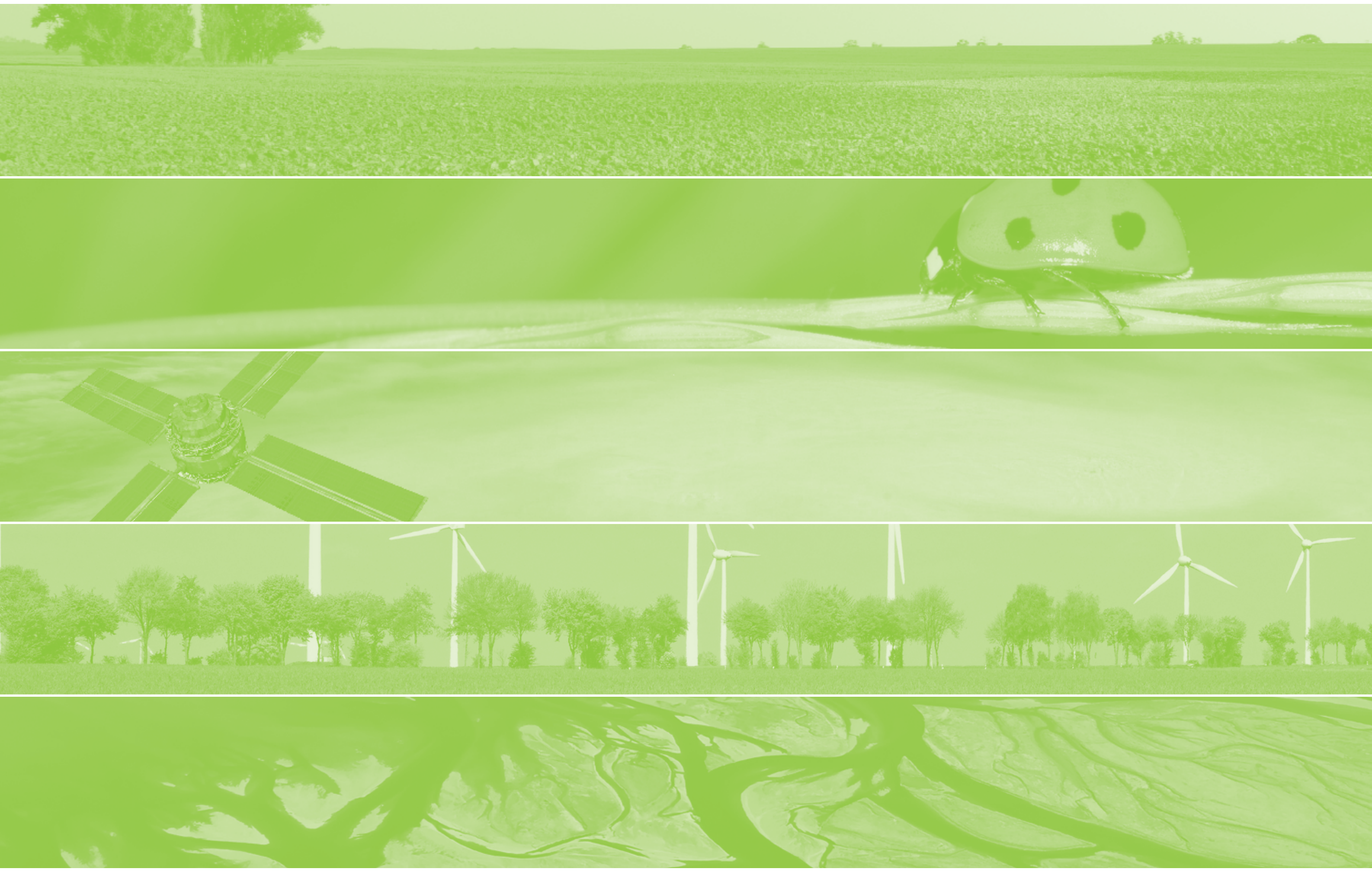

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