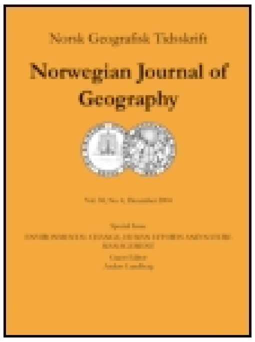

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There is a growing demand for reliable information about land cover and land resources. The Norwegian area frame survey of land cover and outfield land resources (AR18X18) is a response to this demand. AR18X18 provides unbiased land cover and land resource statistics and constitutes a baseline for studying changes in outfield land resources in Norway and a framework for a national land resource accounting system for the outfields. The area frame survey uses a systematic sampling technique with 0.9 km^2 sample plots at 18 km intervals. A complete wall-to-wall land cover map of an entire plot surveyed is obtained in situ by a team of fieldworkers equipped with aerial photographs. The use of sample plots with extended coverage (0.9 km^2) ensures that the survey also deals with local variation, thus strengthening the estimates well beyond simple point sampling. The article documents the methodology used in the survey, followed by a discussion of issues raised by the choice of methodology. These issues include the problem of calculating uncertainty and a confidence interval for the estimates, the focus on common rather than rare land cover categories, and the prospect of downscaling the results in order to obtain statistics for subnational regions.

Keywords: *area frame survey, land cover, systematic sampling, sampling uncertainty, vegetation*

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Introduction

The importance of land resources and the need for land resource surveys are internationally recognized (Klare 2000; Young 2000; Ramankutty et al. 2006). Land resource surveys have a long history in forestry and agriculture (Stephan 1948; Fecso et al. 1986; Frayer & Furnival 1999). More recently, public concern about the environment and climate as well as the rapid population growth accompanied by land use conflicts and increasing competition over land in general have all added to the need for more and better data about land resources.

It is a challenge to provide homogeneous, unbiased, and accurate land cover and land use statistics for many regions of the world. The combination of distance, geographical variation, and accessibility constitute serious, and often insurmountable obstacles to the implementation of full (wall-to-wall) field surveys with sufficient detail and precision. The challenge is most apparent on the global scale, where the solution frequently has been to employ satellite remote sensing, e.g. the MODIS Global Land Cover (Friedl et al. 2010) and the global land cover database for the year 2000 (Mayaux et al. 2004; Bartholomé & Belward 2005). Similar solutions are used for continental surveys, as in the study of land cover dynamics in Africa (Brink & Eva 2009); the FAO Africover dataset (Kalensky 1998); and the USGS (U.S. Geological Survey) land cover data set for the conterminous United States (Vogelmann et al. 2001). The same situation is found in Europe, where CORINE Land Cover – the land cover mapping initiative of the European Environment Agency that is the de facto standard for land cover information on the pan-European level – also is based on interpretation of satellite images (Bossard et al. 2000).

Remote sensing is furthermore used to compile land cover data for large countries and administrative regions with vast and inaccessible outfields. The land cover of Alaska was mapped from satellite images as part of the USGS 2001 National Land Cover Database (Selkowitz & Stehman 2011). A similar approach was followed for the construction of the land cover map of Northern Canada (Olthof et al. 2009). Unfortunately, evaluation of these and other, comparable land cover mapping programmes using satellite remote sensing show that the results are rather inaccurate (Czaplewski 1992; Foody 2002; Selkowitz & Stehman 2011) and often also biased (Gallego 2004; Wickham et al. 2010; Verburg et al. 2011). Supplementary or alternative methods are therefore needed.

The Food and Agriculture Organization (FAO) of the United Nations chose a slightly different approach for the Global Forest Resources Assessment 2010 (FAO 2010). This survey combined satellite image interpretation with systematic sampling. The methodology reduced the amount of image processing and allowed the FAO to involve national experts, who revised the sample areas. The results were reviewed by Steininger et al. (2009), who found them acceptable at the continental scale. A spatial sampling procedure combined with aerial photo interpretation, but with little or no field inventory involved, is in a similar manner employed by The National Resources Inventory conducted by the United States Department of Agriculture (Nusser & Geobel 1997). Such a hybrid approach is to a large extent combined with field inventory in medium-sized and small countries. The landscape monitoring programmes in Norway (Dramstad et al. 2002) and Sweden (Ståhl et al. 2011) both rely on area frame surveys where aerial photo interpretation is supplemented with observations from field inventories.

The combination of field inventories and systematic area frame sampling is uncommon at the continental scale, but was chosen when the European statistical agency (Eurostat) developed the LUCAS (Land use/cover agricultural survey) programme. LUCAS is a European area frame survey carried out in the EU countries (Eurostat 2003). Initially intended as an agricultural survey, LUCAS has since become a general-purpose land use/land cover survey supplementing CORINE Land Cover as the basis for information at the continental level in Europe. The sampling units of LUCAS were, in the initial phase, points located on the intersections of an 18 × 18 km grid mesh (Eurostat later changed the sampling frame to a 2 × 2 km grid). Each of these sampling points is the centre of a Primary Statistical Unit (PSU) of 1500 × 600 m. Ten additional points, called Secondary Statistical Units (SSUs), are located inside each PSU (Fig. 1). Measurements in LUCAS are mostly done on a c.7 m^2 plot around each SSU and along a transect through the five northernmost SSUs of each PSU.

Field inventories organized as statistical sampling procedures are more common at the national and subnational level. Forests constitute a land resource for which accurate data are needed for management and industrial planning at the national and subnational scale. The strategy chosen by the national forest inventories in the boreal region is habitually to collect data in the field rather than by remote sensing. In order to find a practical and economically feasible solution, these inventories tend to be organized as statistical sampling surveys (Lawrence et al. 2010).

Norway is a country where distance and terrain constitute a major obstacle to any initiative to provide homogeneous, unbiased, and accurate land cover and land use statistics. For many years, Norwegian land cover statistics were limited to nine categories and patched together from several sources, mostly with incomplete coverage (e.g. NOU 2001:7; see Table 2, which lists Norwegian governmental publications (NOU) and White Papers referred to in the text). The situation was improved in 2012 when Statistics Norway compiled and published new land use and land cover statistics,[1] which is harmonized and quite detailed for built-up land, but still superficial for the outfields. It is the combination of distance, geographical variation, and inaccessibility that constitutes the obstacle to a full (wall-to-wall) national survey of land resources. Key statistical figures illustrate this point (Table 1). Norway has vast, often inaccessible, outfields and a population of only 5 million, with a population density of 15.4 per km^2 (see endnote 1). Remote sensing is difficult because the summers are short and cloudy, the sun angle is low, and the topography is alpine. Land cover has to be interpreted in the field and the only feasible approach to a detailed survey on a national scale – including mountain areas – is to use statistical sampling. An area frame survey of land cover and land resources in the outfields was therefore initiated in 2004.

Table 1. Key statistical figures for land cover in Norway; the figures show the extent of the outfields and the remoteness of much of the country (source: see endnote 1).

Land cover	Area (km^2)	Area (%)
Built-up land	5297	1.6
Agriculture	10,970	3.4
Forest	120,746	37.3
Open mire	17,000	5.3
Water/Ice	22,741	7.0
Heath and mountain	146,989	45.4
Total	**323,743**	**100.0**

The ‘Norwegian land cover and land resource survey of the outfields’ (Arealregnskap for utmark, abbreviated to AR18X18) is based on the original methodology of the LUCAS survey outlined above. The 18 × 18 km grid was retained because intensifying the grid to 2 × 2 km (as Eurostat chose to do with LUCAS) was unattainable within the available budget, given the constraint of the Norwegian terrain. The Norwegian survey, has instead, like the FAO Global Forest Resources Assessment 2010 and the USDA National Resources Inventory, introduced a wall-to-wall land cover survey of the entire PSU, providing much more information than available from a point survey alone. The major innovation added by the Norwegian survey is that the wall-to-wall land cover survey of the PSU is carried out in the field, by a trained team of fieldworkers. This addition is a major improvement over the satellite image or aerial photo interpretation used by other surveys.

Systematic sampling, employed by LUCAS as well as the ‘Norwegian land cover and land resource survey of the outfields’ project (Arealregnskap for utmark), is assumed to be more efficient than random sampling, at least for spatially autocorrelated phenomena, i.e. when the correlation between observations is a decreasing function of the distance between them (Cochran 1977). Unfortunately, there is no way to make an unbiased estimate of the variance from a systematic sample (P.S.R.S. Rao 1988). Exploring the uncertainty of the estimates has therefore become an important challenge.

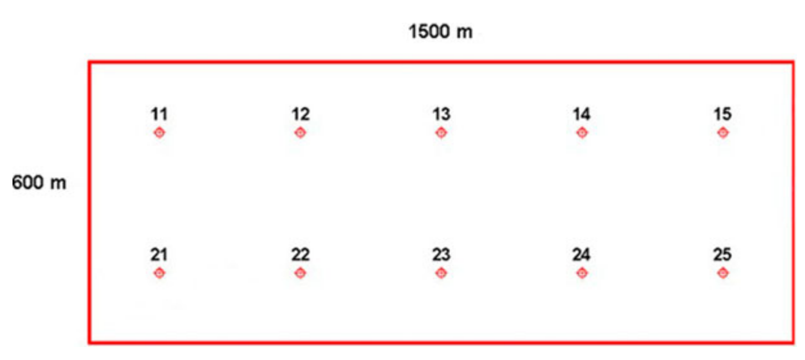

Fig. 1. The sampling unit in AR18X18 is a Primary Statistical Unit (PSU) of 1500 × 600 m.
In addition, 10 Secondary Statistical Units (SSUs) are located 300 m apart within each PSU; the five uppermost SSUs are labelled 11–15, and the five lowermost SSUs are labelled 21–25.

The purpose of this article is to document the methodology used in the 'Norwegian land cover and land resource survey of the outfields' and discuss certain issues raised by the choice of methodology. The article starts with a brief history of land monitoring in Norway. This account is followed by a documentation of the methodology. The subsequent discussion concentrates on three frequently asked questions linked to the sampling approach used in the survey. The first issue is related to the statistical properties of the survey, emphasizing the uncertainty of the estimates and the absence of an unbiased estimator for the variance when systematic sampling is used. The second issue is the disputed usefulness of a survey with limited ability to detect rare phenomena. Third, and finally, the discussion addresses how and to what extent the survey can be downscaled and used to provide information for subnational regions.

A brief history of land cover statistics in Norway

The need for national land resource statistics in Norway was articulated in NOU 1972:44 (Table 2). The decision to establish a land resource accounting system for Norway followed in the late 1970s based on recommendations given in NOU 1977:31 (see Table 2). Implementation was carried out by Statistics Norway (Statistisk sentralbyrå, SSB) with assistance from the Norwegian Mapping Authority (Kartverket) and a number of other national and local authorities. Existing data sources were explored (Lydersen & Nilsen 1977)[2] but the main method was an area frame survey based on maps and aerial photo interpretation. The statistical units of this survey were points. Fieldwork was rarely employed. The methodology is described by Sæbø & Engebretsen (1979), Sæbø (1983) and Engebretsen (1986). The first results were published in 1981 (SSB 1981). The programme continued on a smaller scale into the 1980s, mainly attempting to use satellite images, but was formally closed down in 1988.

Land resources were generally absent from the political agenda in Norway throughout the late 1980s and during the 1990s, but have received increased attention in the last 10 years. Examples are found in many of the Norwegian Official Reports (NOUs) and Government White Papers listed in Table 2. Economic growth and population increase have in recent years led to more and sometimes new demand for land resources. National authorities, policymakers, and the interested public in general are all demanding better information about the situation and scenarios for future land use (Rogstad et al. 1997). Various interest groups, including farmers, foresters, pastoralists, developers, tourist industry, hikers, and environmentalists are taking an interest in land management, resulting in conflicts over the use and protection of land resources.

CORINE Land Cover (Bossard et al. 2000) is implemented in Norway (Aune-Lundberg 2011; Heggem 2011). The CORINE Land Cover dataset is compiled according to a mapping system tailored to provide land cover information on a pan-European level. It involves generalization that inevitably leads to biased statistical results. Although still acceptable at the broad, pan-European scale, it is not suitable for the production of statistics and accounting systems on the national and subnational level (Strand 1997). Various other approaches based on satellite remote sensing have also been tested in Norway over the last 30 years. The experience is generally that the Norwegian topography represents an extraordinary challenge, that the results are highly uncertain, and that auxiliary data are needed in order to improve the map (Erikstad et al. 2009).

The demand for information about land resources can to some extent be met using data from existing surveys, including detailed maps (scale 1:1,000 or 1:5,000), the national forest inventory, the national monitoring of agricultural landscapes, and the agricultural soil maps. It is, however, a challenge that none of these sources have

Table 2. Overview of Norwegian Government White Papers (Stortingsmelding/Melding til Stortinget) and Official Norwegian Reports (NOU) relevant to the development of Norwegian land monitoring and mentioned in the article; the publications are not included in the listed references, but were accessed through the Norwegian Government's official Internet site: www.regjeringen.no.

Number	Title
Government White Papers	
Stortingsmelding 17 (1998–1999)	*Verdiskaping og miljø - muligheter i skogsektoren*
Melding til Stortinget, 9 (2011–2012)	*Landbruks- og matpolitikken, Velkommen til bords*
Official Norwegian Reports (Norges offentlige utredninger)	
NOU 1972:44	*Om statistikkbehovet i regional planlegging*
NOU 1977:31	*Ressursregnskap*
NOU 2001:2	*Retten til miljøopplysninger*
NOU 2001:7	*Bedre kommunal og regional planlegging etter plan- og bygningsloven: Planlovutvalgets første delutredning*
NOU 2001:35	*Forslag til endringer i reindriftsloven*
NOU 2002:9	*Jordskifterettenes stilling og funksjoner*
NOU 2004: 27	*Forsvarets skyte- og øvingsfelt*
NOU 2004:28	*Lov om bevaring av natur, landskap og biologisk mangfold (Naturmangfoldloven)*
NOU 2005:5	*Enkle signaler i en kompleks verden. Forslag til et nasjonalt indikatorsett for bærekraftig utvikling*
NOU 2006: 18	*Et klimavennlig Norge*
NOU 2007: 14	*Samisk naturbruk og retts-situasjon fra Hedmark til Troms*
NOU 2009: 16	*Globale miljøutfordringer – norsk politikk*
NOU 2010: 10	*Tilpassing til eit klima i endring*

complete and consistent national coverage. In 2012, Statistics Norway used GIS techniques to harmonize data from many of these sources along with data from various public registers. The result was the publication of new land use and land cover statistics (see endnote 1) for Norway, which is quite detailed for built-up land, but still superficial for the outfields. There is, however, still a need for a comprehensive, integrated land resource survey and a land resource accounting system in Norway.

A national area frame survey of land resources was proposed in 2000 (Strand 2002). The idea did not materialize immediately and was left dormant until 2003, when Statistics Norway approached the Norwegian Forest and Landscape Institute (NFLI; Norsk institutt for skog og landskap) in order to investigate the possibility for implementation of the LUCAS area frame survey in Norway The following deliberations led to the development of an operational methodology and a pilot implementation in the mountains of Hedmark County during the summer of 2004 (Strand & Rekdal 2005). Further adjustments were carried out during the next winter, initiating implementation on a national scale from 2005. The first iteration of the survey will be completed in 2015.

Methodology of the Norwegian survey

The 'Norwegian land cover and land resource survey of the outfields' (AR18X18) is based on the first generation of the European area frame survey LUCAS (described in the section headed 'Introduction', above). The sampling units are centred on points located at the intersections of an 18 × 18 km grid (Fig. 2). Each of these points is the centre of a Primary Statistical Unit (PSU) of 1500 × 600 m (as in Fig. 1). In the Norwegian survey, all PSUs are visited in the field by trained surveyors carrying stereo pairs of aerial photographs. The surveyors conduct a complete and detailed, wall-to-wall land cover inventory of an entire PSU (0.9 km^2) by drawing and classifying land cover polygons directly onto the aerial images. Ten additional points, called Secondary Statistical Units (SSUs), located inside each PSU are also visited and more detailed observations are made on a c.7 m^2 plot around each SSU and along a transect through the five northernmost SSUs of each PSU. The map and its derived statistical information provide a comprehensive inventory of the area, picking up considerable local variation and improving the probability for the inclusion of rare features.

A PSU is included in the survey as long as any part of it falls within the Norwegian mainland (including freshwater areas). The estimated total number of sampling sites in the survey is 1081, but the actual number may change slightly during the course of the survey as candidate PSUs along the complex coastline of central- and northern Norway remain to be studied in detail.

The land cover survey of the PSU is carried out following the NFLI system for vegetation and land cover mapping at intermediate scale (1:20,000). This system has been developed through mapping projects throughout Norway over a

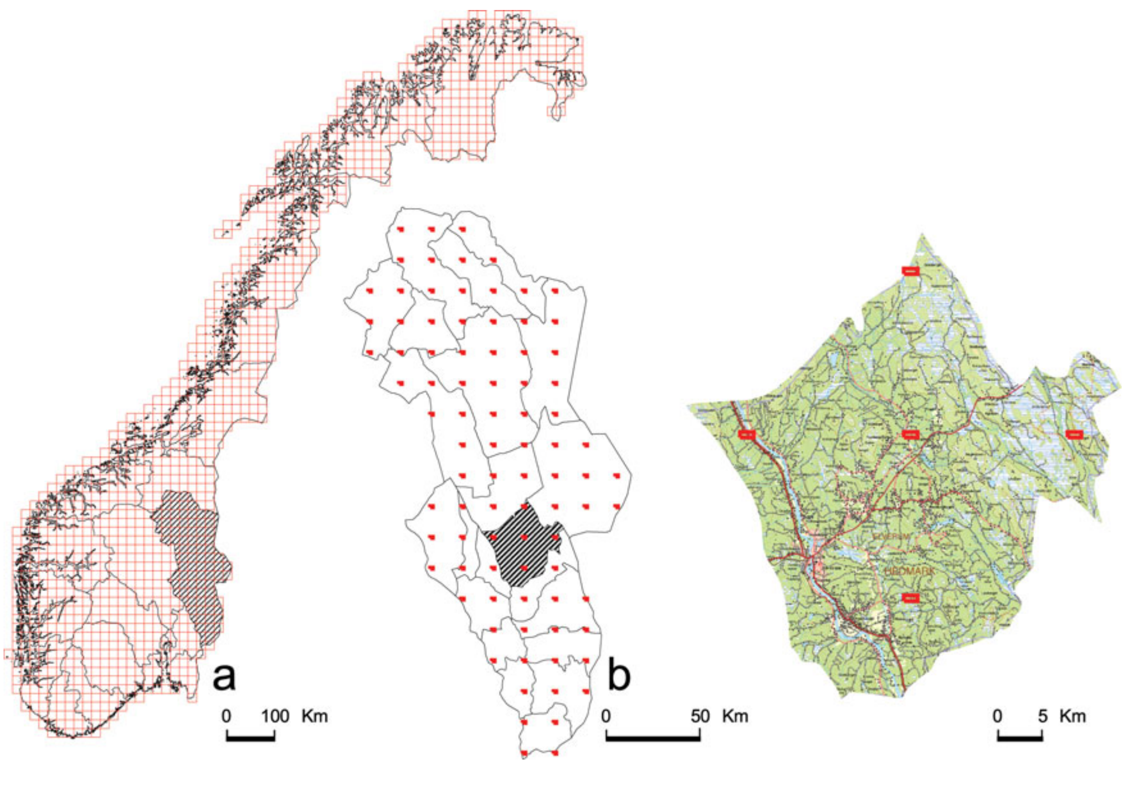

Fig. 2. AR18X18 is a systematic area frame sample with sampling units centred on points located at the intersections of an 18 × 18 km grid; a) 18 × 18 km grid mesh with one county (Hedmark) shaded; b) Hedmark with sample units and one municipality (Elverum) shaded; and c) Elverum with sample units (PSUs) (Base map © Norge digital).

period of 25 years (Rekdal & Larsson 2005). The system is thoroughly tested, the cost is acceptable (on average approximately EUR 1500 per sample plot including preparations and post-processing), and the results can be used for quantification and assessment of many aspects of the land resources.

The basic nomenclature of the NFLI system for vegetation and land cover mapping consists of 57 basic classes (land cover classes; Table 3). The majority (45) of these classes are vegetation types. A number of ancillary registrations can be added to the basic observations (Table 4) resulting in a key with c.1200 unique classes. Examples of ancillary registrations are rock outcrops, coverage percentage of lichen, willow or fern, and areas with particularly rich grass cover. There is close coherence between this mapping system and a classification system often used for detailed description of vegetation in Norway (Fremstad 1997). The main difference is that the NFLI system is less detailed for vegetation types covering small areas or requiring highly specialized botanical knowledge for identification. The hierarchical structures used in the two systems are also different because Fremstad uses a systematic approach whereas the NFLI system primarily is designed to be efficient during applied mapping in the field.

Table 3. The 57 basic classes used in the NFLI (Norwegian Forest and Landscape Institute) system for vegetation and land cover mapping at intermediate scale (1:20,000).

Code	Land cover class	Code	Land cover class
1a	Moss snowbed	8a	Damp forest
1b	Sedge and grass snowbed	8b	Bog forest
1c	Frozen ground, leeward	8c	Poor swamp forest
		8d	Rich swamp forest
2a	Frozen ground, ridge		
2b	Dry grass heath	9a	Bog
2c	Lichen heath	9b	Deer-grass fen
2d	Mountain avens heath	9c	Fen
2e	Dwarf shrub heath	9d	Mud-bottom fen and bog
2f	Alpine *calluna* heath	9e	Sedge marsh
2g	Alpine damp heath		
		10a	Coastal heath
3a	Low herb meadow	10b	Coastal calluna heath
3b	Low forb meadow	10c	Damp heath
		10d	Crags and thicket
4a	Lichen and heather birch forest	10e	Moist and shore meadows
4b	Bilberry birch forest	10f	Sand dunes and gravel beaches
4c	Meadow birch forest	10g	Pioneer alluvial vegetation
4d	Birch forest on lime soils		
4e	Alder forest	11a	Cultivated land
4f	Flood-plain shrubs	11b	Pastures
4g	Pasture land forest		
		12a	Barren land
5a	Poor broadleaf deciduous forest	12b	Boulder field
5b	Rich broadleaf deciduous forest	12c	Exposed bedrock
		12d	Built-up areas
6a	Lichen and heather pine forest	12e	Scattered housing
6b	Bilberry pine forest	12f	Artificial impediment
6c	Meadow pine forest	12g	Glaciers and perpetual snow
6d	Pine forest on lime soils		
		13a	Water courses (fresh)
7a	Lichen and heather spruce forest	13b	Water bodies (fresh)
7b	Bilberry spruce forest	13c	Estuaries
7c	Meadow spruce forest	13d	Sea and ocean

Table 4. Ancillary features supplementing the basic classification (see Table 3) in the NFLI system for vegetation and land cover mapping at intermediate scale (1:20,000).

Code	Explanation
1A	25–50% exposed bedrock
1B	50–75% exposed bedrock
2A	Willows: 25–50% coverage
2B	Willows: >50% coverage
3A	Lichen: 25–50% coverage
3B	Lichen: >50% coverage
4	Grass-rich vegetation (> 50% coverage)
5	> 50% coverage of grey mosses on open land
6	Scattered vegetation (10–25% coverage)
7	Vegetation on sandy soils with marine shells
8	Tree species (11 classes)
9	Fern (> 75% coverage)
10	Juniper (> 75% coverage)
11	Calciferous vegetation
12	Shrubs (> 50% coverage)

Vegetation and land cover mapping following the NFLI system is carried out in the field using aerial photographs usually at a scale of 1:40,000. Both black and white, colour, and IR photos can be used, but IR photos are preferred if available. Vegetation polygons are drawn directly onto the photos (Fig. 3 upper image) and later digitized and processed using GIS software.

The minimum polygon size is usually 0.5 ha but polygons down to 0.1 ha can be recorded in order to include rare features. A mosaic of two different land cover classes can be registered for a polygon when each class covers at least 25% of the area. For statistical purposes, the dominant land cover class is counted as covering on average 62.5% of each polygon, whereas the secondary class is counted for the remaining 37.5%. The lower image in Fig. 3 shows a simplified land cover map based on measurements shown in the upper image.

The field measurements taken at the SSU points include a subset of a standard field form used by Eurostat in the LUCAS survey. The part that has been retained for the Norwegian survey concentrates on observations of land use and on detectable impact from environmental hazards (e.g. storms, forest fires, and landslides). Other parts of the original LUCAS field form have been excluded because the information collected in Norway can be obtained from official statistics or public registers. Photographs are also taken in the four cardinal directions from one SSU point, according to a similar procedure used in the LUCAS survey (Fig. 4).

Further, the original LUCAS survey included interviews with farmers, but such interviews are omitted from the Norwegian survey because better information regarding the agricultural practices can be obtained from the Census of Agriculture and Forestry carried out by Statistics Norway (Steinset 2006). However, information about the vegetation class based on the detailed system used in Norway (Fremstad 1997) is recorded onsite for each SSU. These registrations provide information about the vegetation at a more detailed level and will in the future be used to examine the variability within each of the NFLI land cover classes.

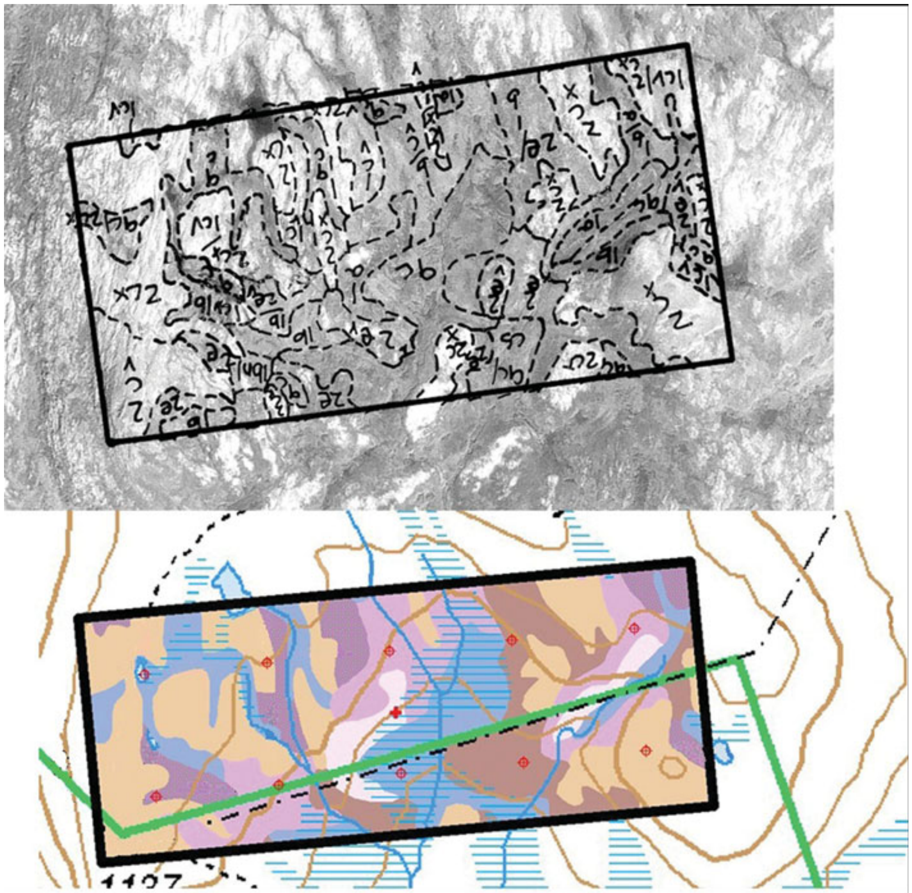

Fig. 3. AR18X18 includes a wall-to-wall land cover map of the PSU in its entirety, showing how land cover is interpreted in situ on aerial photographs (upper image), and later digitized and processed using GIS software (lower image) (Base map and imagery © Norge digital).

The AR18X18 area frame survey produces a systematic random sample. The systematic element is that a location is surveyed at 18 km intervals along both dimensions of a grid mesh. The random element is that the starting point of the grid as well as the first sample location within the grid is located randomly. This systematic sampling strategy is in reality a *cluster sample* consisting of a single, randomly selected cluster where every element in the cluster is included in the sample. It is thus the elements included in the cluster itself that constitute the systematic part of the sample.

It is possible to construct 360 different clusters based on the chosen survey strategy: each of the survey plots is 0.9 km^2 (1500×600 m), the plots are interspaced 18 km in both directions and $18^2/0.9 = 360$. The sampling frame thus consists of 360 clusters, each representing a national coverage of equally interspaced sampling plots. By choosing a random starting point, one of these clusters is selected and all the plots in that particular cluster are included in the survey. The population is thus $N = 360$ and the sample size is $n = 1$, since 1 out the 360 possible clusters is selected.

Spatially distributed phenomena, including land resources and related features, are usually autocorrelated (Cressie 1991; Haining et al. 2010). Autocorrelation is the effect that places located close to each other tend to be more similar than places located further away from each other. The systematic random sample is particularly efficient for spatial surveys because it avoids selection of elements located close together (Thompson 2002). The systematic sampling strategy increases the prospect that the variance within the cluster is high compared to the variance between the clusters. As a result, there is a high likelihood that the sample reflects much of the variation found in the population.

To profit from this strategy, it is important to include all the elements of the cluster in the sample. The practical implication is that also sample plots falling partially outside the population are included in the sample. Sample plots partly located in Sweden or covering a substantial area of ocean are all included as long as they also contain part of the Norwegian land area, but only the part of the sample unit falling inside Norway is actually mapped. This rule also applies when the area frame survey is used to estimate land resources for smaller regions. All sampling units containing a part of the specific region being studied should be included in the sample, contributing to the statistical estimation with the subsection actually falling within the study area.

Fig. 4. Photographs taken in the four cardinal directions, North (top left), East (top right), South (bottom left), and West (bottom right), at SSU no. 13 in PSU 2319 Grasberget, Elverum (Photo © Geir-Harald Strand, Skog og landskap, 2009).

The calculations based on the systematic sample are straightforward as long as the above-mentioned preconditions are observed. An unbiased estimator of the total of any parameter x for a region is

$$\hat{\tau} = 360 \times \sum_i^m x_i$$

where m is the number of locations in the sample and x_i is the measurement of x for the part of location i falling within the region in question. A pragmatic adjustment can be made when the total area A of the study region is known, by including the measurement a_i of the size of the area of each location falling within the study region:

$$\hat{\tau} = \frac{A \times \sum_i^m x_i}{\sum_i^m a_i}$$

where $A/\sum a_i$ is c.360.

The systematic sample is a sample with only one element, since the clusters are being sampled, not the locations. The sample consists of exactly 1 out of the 360 possible clusters. It is therefore not possible to calculate an unbiased estimate of the variance and standard error based on the sample itself (since sample size is a single cluster ($n = 1$) leading to a denominator of $n-1 = 0$). The within-cluster variance can, however, be calculated. This provides a biased, usually too high and thus conservative estimate of the sampling variance (Thompson 2002). The simple variance estimate s^2 calculated as if the sample was a simple random sample is

$$s^2 = \frac{\sum_i^m (x_i - \hat{x})^2}{m-1}$$

and the variance of the estimated total is

$$Var(\hat{\tau}) = M(M-m)\frac{s^2}{m}$$

where M is the size of the population (the assumed number of possible survey plots in Norway) and m is the number of survey plots in the sample. This variance estimate is biased but can be used to find a conservative estimate of the confidence interval of the projected totals.

Discussion

The systematic sampling approach used in AR18X18 is cost-efficient and practical. However, the survey also raises several questions, three of which are addressed here. The first question concerns the uncertainty of the results, the second relates to the ability to detect rare phenomena, and the third concerns how the survey, together with other data sources, can be used to provide information at the subnational scale.

Uncertainty

Systematic sampling as it is employed in AR18X18 is presumed to be more accurate than random sampling when data are spatially autocorrelated. It is, however, not possible to make an unbiased estimate of the variance from a systematic sample (Cochran 1977; P.S.R.S. Rao 1988). This shortcoming is a disadvantage for the survey. A better understanding of, and ultimately a method for handling, the uncertainty involved when the estimates are based on systematic sampling is therefore imperative.

The simple and frequently used solution is to treat the sample as an ordinary simple random sample and use the traditional estimate of variance for a simple random sample (as described in the section headed 'Methodology of the Norwegian Survey', above). The outcome is generally an overestimation of the variance and a result very close to the actual variance of a simple random sample of the same size (Smith 1976; Gallego & Bamps 2008). Methods for improved calculations of the true sample variance do, however, exist (e.g. Murthy & Rao 1988). Various solutions for the one-dimensional case (systematic sampling along a line) have been developed and tested in forestry (Yates 1948; Finney 1950).

Some of the proposed methods use an approach where the sample is divided into several subsamples, for example by splitting the sample into two halves. Koop (1971) examines this method and concludes that it can lead to serious bias. An alternative method using estimators taking neighbourhood into account is examined for a one-dimensional situation by Wolter (1984). This approach is further developed in Wolter (2007, 298–353) where eight different estimators are explained, tested, and compared. However, the testing was carried out with data related to establishments and people, and the author points out that it is uncertain how the results apply to measurements of land cover and land use.

The efficiency of the systematic sample is linked to autocorrelation. By spreading out the sample locations and avoiding sample units located close together, systematic sampling characterizes the variation in the population more efficiently than a simple random sample when autocorrelation is present. This observation calls for a geostatistical approach to uncertainty. Along this line of thought, Matérn (1986) proposes a method where each observation is compared to observations made in its geographical vicinity. Aubry & Debouzie (2000), following such an approach, report that the geostatistical error estimate is a more reliable tool than the simple random sample variance estimate for calculating a confidence interval of the mean because the location and size of the sampling units can be taken into account.

Within the domain of land cover, Gallego & Bamps (2008) likewise suggest that the bias of the variance estimator can be reduced by substituting the traditional variance estimate with a local indicator of variance. They tested this assumption on LUCAS data, using the European CORINE Land Cover data set as a pseudo-truth and found that the variance was only slightly overestimated when they used the local error estimator. This and similar approaches still have to be tested for the Norwegian survey, also taking the particular approach with wall-to-wall mapping of the entire PSU into account.

Detectability

Many biological and ecological research communities emphasize mapping and monitoring of rare or endangered species or uncommon habitats and land cover types, and criticize broader mapping initiatives for their failure to detect the exceptional. This critique is misguided. First, focus on the exceptional can itself lead to biased results (ter Steege et al. 2011). A more important consideration is that there is also a need for information about the normal, ordinary land cover, as emphasized in the growing literature on gap analysis (Jennings 2000) and by experiences from European habitat monitoring (Lengyel et al. 2008; Mazaris et al. 2010)

It is true that land use and land cover types covering very small areas only occasionally will be detected by the land cover mapping method used in AR18X18. This is a question of detectability and the problem is related to choice of Minimum Mapping Unit (MMU) as well as to the selection of method of measurement, although sometimes incorrectly attributed to the sampling method. Vegetation found near springs and farm ponds are two examples of features usually covering areas that are too small to be included in the survey simply because the areal extent of such land cover types is smaller than the MMU used in the survey. The exclusion of such small features from the survey is not a result of the sampling strategy but a deliberate choice made by the survey initiative in order to balance priorities against budgetary considerations.

Small features can be identified, measured, and included in the survey if the necessary budget is available. The preferred methodology would either be to register these features as points or to represent their presence as an attribute at the level of the PSU itself (using a form to register presence or absence). Detectability is also an issue when topics of a highly esoteric nature require specially trained observers. Examples are the presence of certain moss and lichens considered important in a biodiversity context. It is a challenge to balance appropriate observation methods for arcane features with the need to keep fieldworkers' workloads at an acceptable level and within a realistic and acceptable budget.

The systematic area frame survey is suitable for detecting uncommon or even rare phenomena as long as the occurrence is spatially random. Problems arise when the spatial distribution of rare features is highly autocorrelated. Systematic sampling is in general an efficient method for surveys of autocorrelated phenomena. A phenomenon that is both rare and highly autocorrelated will, however, only be detected accidentally and is easily overestimated when and if it is found. The solution is to increase the sampling intensity in order to increase the probability of detecting the phenomenon in the first place and then to employ *adaptive sampling* (Thompson 1990) as an extension of the systematic sampling method in the areas where the rare phenomenon is found. Again, the decision to implement this methodology will mainly be a budgetary question.

The concern about small areas and rare features is related to the broader discussion of scale in ecology and macroecology (Blackburn & Gaston 2002). Where ecology mainly is concerned with the relationship between individual organisms and how these organisms form local communities, macroecology deals with patterns of distribution and diversity over large regions. The relationships and patterns observed and explained in macroecology are different from those observed and explained in detailed ecological studies. There is now broader acceptance of the viewpoint that analyses at different scales contribute complementary knowledge about species distribution and ecological processes (Jenkins & Ricklefs 2011). The same applies to land cover and land resource surveys. The AR18X18 survey provides information about the distribution of common vegetation types at the national level, clearly supplementing the large number of detailed but geographically restricted studies carried out by biologists and ecologists at the local and micro-local level.

Downscaling

It has been observed that the statistical support of the AR18X18 survey easily can be strengthened by including more sample plots (e.g. by using a 9 × 9 km grid). This would improve the precision of the estimates, and is in of particular relevance when the goal is to provide statistics for smaller regions. The appropriateness of this approach is demonstrated by Eva et al. (2010), who intensified data from the FAO global sampling scheme with additional samples in French Guyana in order to estimate deforestation and then compared the results to national inventory data. A similar intensification has been tried for assessment of local outfield pasture in parts of Norway, but the results have not yet been evaluated (Rekdal & Angeloff 2007 Rekdal et al. 2009).

It is also possible to use the area frame survey for downscaling exercises employing auxiliary data combined with variants of the small area estimation (SAE) technique (J.N.K. Rao 2003). The feasibility of this approach is demonstrated by Strand & Aune-Lundberg (2012) in a study where data from AR18X18 was combined with a less detailed land cover map in order to provide statistics for a small region in eastern Norway. The results were compared to a complete field inventory of the target area and showed that AR18X18 and small area estimation used together provide a good approximation of the distribution of land cover classes when the purpose is to describe the overall land cover composition and not to provide exact estimates for the individual land cover classes. Gallego (2004) documents several similar approaches in his overview of methods used to derive land cover area estimation from satellite images. Small area estimation is frequently used in forest inventories (Gillis et al. 2005; Tomppo 2006; Breidenbach & Astrup 2012) and it provides a viable methodology for extended use of the AR18X18 survey.

Conclusions

Extensive experience with the AR18X18 method has been gained during the pilot and implementation phase since 2004. By the end of 2012, 961 out of 1081 locations (89%) had been surveyed (Fig. 5) and preliminary reports had been published for eight counties in Norway. This has provided sufficient material and experience for a preliminary valuation of the method. The overall assessment is that adaption of the LUCAS survey methodology is successful in terms of providing relevant information about land cover and outfield land resources. The AR18X18 method is statistically sound and efficient. The systematic sample strategy ensures that the sample is spread out as much as possible, thus creating a representative replica of the population and covering maximum variability.

The wall-to-wall land cover map of the entire PSU – a Norwegian addendum to the methodology – has several advantages. First, local variation is efficiently covered by using the 0.9 km^2 plot instead of a cluster of points as sampling units. Furthermore, the likelihood of covering rare land cover classes increases as long as the size of these rare categories exceeds the minimum mapping unit of the survey. The remoteness of the Norwegian outfields also implies that the cost of access is high relative to the cost of mapping once the survey location has been reached. This variant of the survey method is therefore cost efficient and recommended for other surveys of inaccessible areas employing field inventory.

Variance estimates and consequently also confidence intervals for the statistical estimates based on the survey are two challenging issues. This is a concern shared with other mapping and monitoring initiatives using systematic spatial sampling. Considerable progress has been achieved by various research groups in this field. It remains to adapt the results to the plot-based approach used in Norway. One way to do this could be to simulate the survey by sampling from an existing data set with national coverage. The existing data set would then act as a pseudo-truth and the proposed variance estimates could be validated against the pseudo-truth.

The simplicity of the method used in AR18X18 leads to high flexibility. Statistics can easily be prepared for any regional subset of the data. Examples are administrative units (e.g. counties), topographic units (e.g. mountains), and thematic units (e.g. protected areas). Post-stratification using remote sensing or (in the Norwegian case) a less detailed land cover or land resource map, has proved to be a workable solution for downscaling exercises of this kind.

Small and rare phenomena are imperfectly covered by the survey, but this is rather a question of detectability, priorities, and resources than an inadequacy of the method itself. The AR18X18 survey is a cost-efficient way to meet the demand for information about the 'ordinary' land cover and outfield land resources, and create the basis for a land

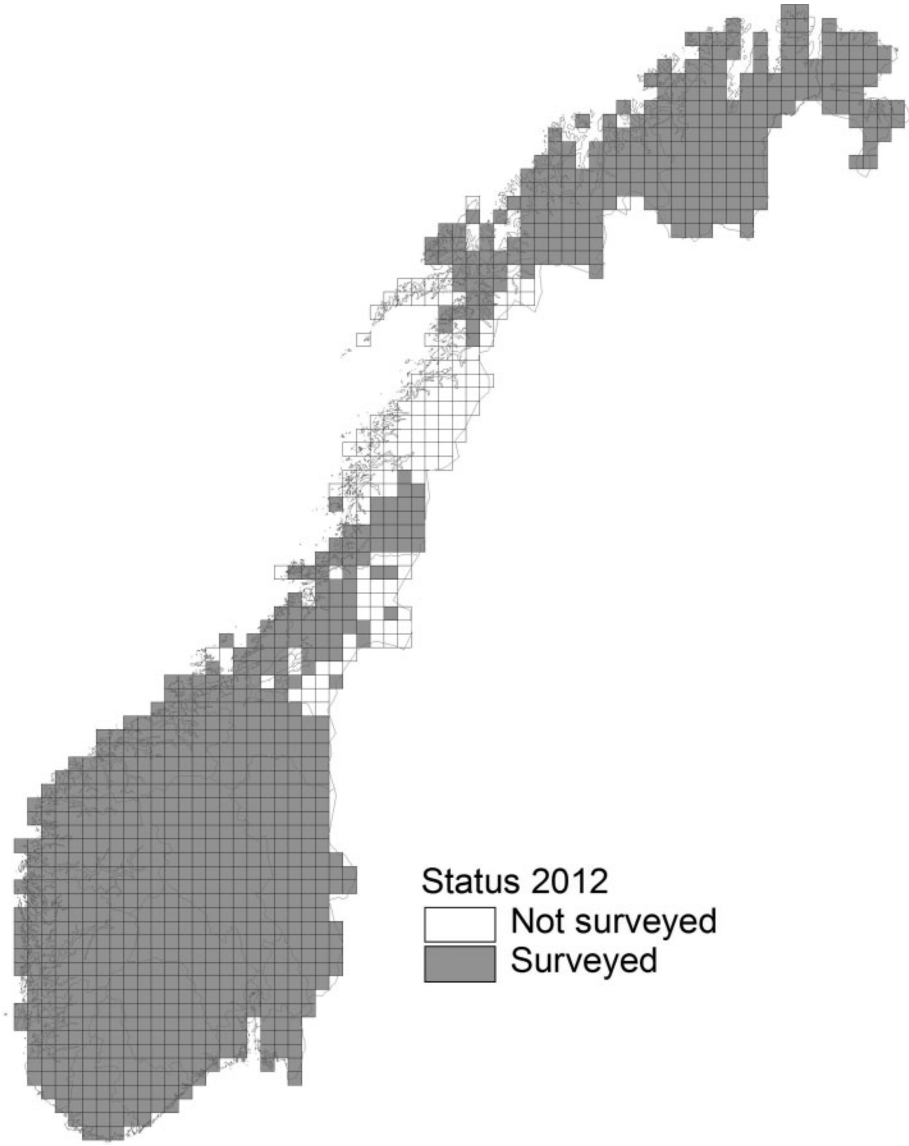

Fig. 5. Status of the survey by the end of 2012; the survey was completed for 961 out of 1081 locations (89%).

resource accounting system. The open issues regarding variance, detectability, and downscaling are challenging and demand further investigation and research, but they do not present any serious obstacle to the fulfilment of the main purpose of the monitoring programme.

Notes

1 Source: Statistisk sentralbyrå. 2012. http://statbank.ssb.no (accessed 11 December 2012)

2 See also an unpublished memo from 1976 by O. Einevoll, titled 'Jordregisteret som arealrekneskap' (31 pp.), Jordregisterinstituttet, Ås.

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