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Trend monitoring of the areal extent of habitats in a subsiding coastal area by spatial probability sampling

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ABSTRACT

The European Habitats Directive requires a regular reporting of areal changes of the Habitat types defined under this Directive. To monitor changes in Habitat types in a dune and salt meadow area in the eastern part of the back-barrier island of Ameland (The Netherlands) a sampling scheme was designed suitable for both unbiased estimation of such changes and for mapping the Habitat types. As a space–time design a supplemented panel was chosen, with a proportion of permanent plots of 0.5. Sampling plots were selected by probability sampling, with sampling designs that spread the plots evenly over the study area. These design decisions are motivated in the paper. Eight vegetation types were distinguished, corresponding to six Habitat types. The areal extent of the 'grey dunes' type significantly decreased over the observation period, whereas the extents of two 'salt meadow' types significantly increased. This has to be considered as a loss of habitat quality. It is doubtful whether for the Natura 2000 area in its entirety, wherein we expect smaller rates of change compared to our study area, it will be possible to detect areal changes in Habitat types at acceptable costs and within the requested six-year periods. The supplemented panel design performed nearly equal to a pure panel design (all plots permanent) in terms of precision of estimated linear trends, but was by far superior to an independent synchronous design with all plots changing.

1. Introduction

The European Habitats Directive (Council of the European Communities, 1992) requires reports of both quantity and quality per Habitat type in six-year intervals. The rigorous use of sound sampling theory in designing monitoring networks for reporting ecological or environmental changes as required by the Habitats Directive, seems to be more the exception than the rule.

In designing monitoring networks many choices must be made (de Gruijter et al., 2006). One of the major choices is whether sampling locations (vegetation plots) will be selected by probability sampling or not. In probability sampling "*each unit in the population has a known probability of selection, and a chance method such as numbers from a random number table is used to choose the specific units to be included in the sample*" (Lohr, 1999). This choice should mainly be driven by the aim of monitoring (Brus and de Gruijter, 1997). Broadly speaking, for estimating summary statistics of the study area such as the mean, proportion (areal fraction) or total (areal extent), probability sampling is recommendable. For mapping, i.e. when interest is in the value at any location in the study area, non-probability sampling such as purposive sampling and sampling on a centred grid, can be advantageous.

Another important decision is the pattern of the observations in space–time. Various types of space–time design can be distinguished (Schreuder et al., 1993; de Gruijter et al., 2006). In a pure panel design, referred to as a static-synchronous design by de Gruijter et al. (2006), all plots are permanent, i.e. the plots are observed every sampling time. The opposite is to select new plots every sampling time; the plots at a given sampling time are selected independently from the plots of previous sampling times. This space–time design is referred to as an independent synchronous design by de Gruijter et al. (2006). A hybrid sampling design is a supplemented panel design, in which a proportion of the plots is observed all sampling times (permanent plots, the pure panel part) and the remaining plots only once (changing plots, the independent synchronous part).

The aim of this research was to design a monitoring network for a 70 ha sample area on the coastal plain of the island of Ameland (The Netherlands), suitable both for unbiased and accurate estimation of the areal extent of vegetation types and changes therein over time, and for mapping the vegetation types. The study area

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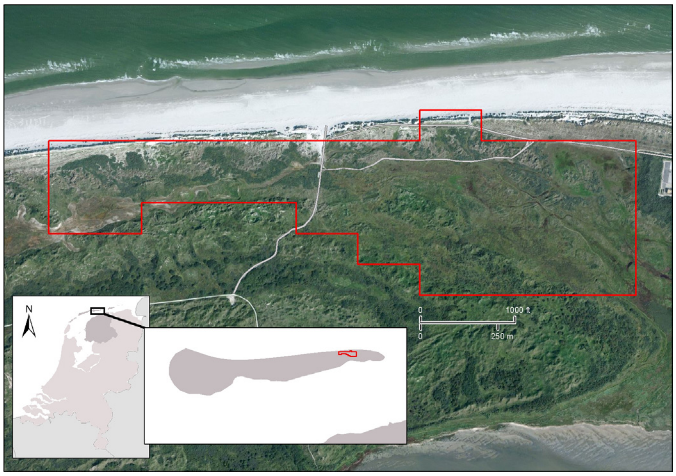

Fig. 1. The study site comprises 70 ha natural area on the island of Ameland, and covers the gradient from saltmarsh to grey dunes.

is open to the sea and therefore sensitive to effects of sea-level rise due to climate change (IPCC, 2007). Moreover, we expected vegetation changes in this area due to the following additional causes: (1) since 1986 natural gas has been extracted, causing a subsidence of the soil surface by up to 8 cm over the complete observation period (2001–2010) (Ketelaar et al., 2011); and (2) in winter 2005, a restoration project was carried out where dune scrub and topsoil were removed in part of the area in order to restore open wet dune slack vegetation. As a result of these causes we expected wetting and salinisation of the soil, and therefore a change of dry grassland or dune vegetation into saltmarsh vegetation (van Dobben and Slim, 2012). We concentrate on local vegetation types, defined by species composition and quantities per species, but this local typology can be seen as a refinement of the European Habitats typology (Council of the European Communities, 1992, Annex 1). In this paper only the first aim of the monitoring network is reported, the estimation of the areal extents of the vegetation types and trends in these extents; the vegetation types will not be mapped. A null hypothesis of no significant temporal trend in areal extent of the Natura 2000 Habitat types will be statistically tested.

2. Materials and methods

2.1. Study area

Ameland (53°27′N, 5°53′E) is one of the barrier islands situated along the coast of The Netherlands, Germany and Denmark, separating the Wadden Sea from the North Sea (Fig. 1). For a general description of the history, landscape and ecological interest of the area, see van Dieren (1934), Dijkema and Wolff (1983), Ketner-Oostra and Sykora (2004). The eastern part of Ameland is a natural area with little human influence. On the northern side it is mostly protected by dunes, but on the southern side the Wadden sea has free access to the area, thus creating a gradient from saltmarsh to grey dunes. In our study area this gradient is present (Fig. 1). Part of the study site is well above the present sea level, and part is flooded by seawater or brackish water up to ca. 100 days per year (Krol, 2011). In the western part of the area (West of the NE-SW oriented path in Fig. 1) dune scrub and topsoil were removed in 2005 in the low-lying areas. A detailed description of the site, its topography, abiotic and biotic variation and the rationale behind the scrub removal is given by Slim et al. (2011). Further background information, especially on the vegetation changes since the start of the gas extraction in 1986, is given by van Dobben et al. (2011) and Dijkema et al. (2011).

2.2. Design of monitoring network

We selected vegetation plots by probability sampling. Probability sampling has the advantage that unbiased estimates of the spatial mean (areal fraction) and total (areal extent) can be obtained by design-based statistical inference. In design-based inference use is made of the inclusion probabilities of the vegetation plots. No use is made of a model of the spatial variation. As a consequence, the quality of the estimates are independent of the quality of model-assumptions, simply because no such assumptions are being made in a design-based approach (Brus and de Gruijter, 1997; Gregoire, 1998; Yoccoz et al., 2001). Contrarily, in a model-based sampling approach the statistical inference is based on a model of the spatial variation. This requires several modelling assumptions, for instance on stationarity in the mean and variance, isotropy *et cetera*. This all can be very legitimate for the aim of mapping the vegetation types. However, when mapping of the vegetation types is not strictly required, and it suffices to estimate the areal extent of the vegetation types and changes over time in these areal extents, then we favour a design-based sampling approach for reasons explained above.

Moreover, probability sample data can also be used in model-based mapping. Probability sampling in this respect is more flexible than non-probability sampling; probability samples can be used both in design-based and in model-based statistical inference, while non-probability samples can only be used in model-based inference. Vegetation plots were selected with spatial sampling designs that spread the plots evenly over the study area. Such sampling designs are referred to as spatially balanced designs. Spatial balance generally has a positive effect on the precision of the estimated mean. Nearby locations tend to be similar, so spatial clustering should be avoided (Cochran, 1977; Stevens and Olson, 2004). Moreover, spatial balance increases the applicability of the probability sample for mapping the vegetation types by non-spatial models (e.g. generalized linear models) or spatial interpolation (e.g. kriging).

As a space–time design a supplemented panel design was chosen, with a proportion of permanent plots of 0.5. This space–time design showed up as an efficient design in estimating the coefficients of a linear time-trend model for spatial means (totals) (Brus and de Gruijter, 2013). The permanent plots were selected with a systematic unaligned random sampling design (SY) (Quenouille, 1949). The area study is first divided into square cells of $100 \times 100\,m^2$, and one plot is selected in each cell, although not independently. A random *x*-coordinate is generated for each row of cells, and a random *y* coordinate for each column. The sampling plot in a cell is then found by combining the coordinates of its row and column. The resulting spatial pattern is irregular, but the locations are evenly spread over the study area (Fig. 2).

The changing plots were selected according to a stratified simple random sampling design (ST). The strata consisted of two neighbouring $100 \times 100\,m^2$ cells used in selecting the SY sample (Fig. 2). The geographical spread of these plots is not as good as for the permanent plots, but still pretty good. The two changing plots within a stratum were selected by simple random sampling. The sample sizes of both samples, SY and ST, equals 70 plots per year, so that the total sample size was 140 plots per sampling time. This supplemented panel design was not implemented perfectly (Fig. 3). There are two distortions. First, in 2001 only permanent plots were selected (no ST sample), so that the total sample size in 2001 equaled 70. Second, by accident in 2006 no new ST sample of plots was selected, but the ST sample of 2004 was revisited. As a