Sampling for validation of ecotope maps of floodplains in the Netherlands

A model-based versus a design-based approach

Martin Knotters, Dick J. Brus
Soil Science Centre
Alterra, Wageningen University and Research Centre
Wageningen, the Netherlands
martin.knotters@wur.nl

***Abstract*— Ecotope maps of five districts of main water courses in the Netherlands were validated by independent field observations of ecotopes. The map quality was quantified by the overall map purity, and by the user's and producer's accuracies of the map units. In four districts the validation locations were selected by purposive (targeted) sampling. In these purposively sampled districts the sampling points were clustered in a limited number of compact validation areas, in order to reduce travel costs. For the fifth district a stratified two-stage probability sample was designed, such that the spatial pattern resembles that of the purposive samples. In this way the same practical and budgetary constraints are met as in the purposively sampled districts. In the first stage the district was divided into eight geographical strata, representing the main river branches, and each stratum was divided into validation areas of approximately constant size (primary sampling units). In each geographical stratum two validation areas were selected by simple random sampling without replacement. In the second stage, in each selected validation area a simple random sample of points was selected (the secondary sampling units). At these locations ecotopes were observed in the field. For the maps validated by purposive sampling the quality measures were estimated by model-based inference based on a stochastic model for the spatial variation of classification errors. For the map validated by probability sampling the quality measures were estimated by design-based inference based on the inclusion probabilities of the validation locations. The total map purities varied from 56 to 76 % among the five districts. Both user's and producer's accuracies showed large variation among the map units, depending on the contribution of several sources of error in the mapping process. Stratified two-stage sampling combined with a design-based estimation method results in model-free estimates of total map purity, user's and producer's accuracies. This is an important advantage in validation, because the results do not depend on the quality of model assumptions. This means that the validity of the estimated map purities, user's and producer's accuracies is beyond discussion if a design-based approach is followed.**

Keywords: map accuracy; ratio estimator; two-stage sampling

I. Introduction

Ecotopes are more or less homogeneous ecological units at landscape scale, which are discernible from similarities and contrasts in geomorphology and hydrology, vegetation structure and land use. Ecotope maps are used as basic information for policy- and management purposes, regarding water quantity, water quality, ecological system knowledge and restoration- and development projects of the Dutch water systems.

Ecotope maps have been made for five districts of the main watercourses in the Netherlands. These maps result from an overlay procedure using Geographic Information Systems (GIS), in which an interpretation layer of aerial false colour photographs is combined with a water depth layer, a flood duration layer, morphodynamic layer, management layer or a salt gradient layer. The resulting ecotope map can be considered as a map at point support, that is, it predicts the ecotopes at point locations.

To assess the utility of the maps as well as the effectiveness of the mapping procedure, the accuracy of the maps was evaluated. Two major approaches can be followed in the validation of maps: a model-based approach and a design-based approach, see Stehman (2000) for a comparison of these two approaches with respect to validation of land-cover maps created by remote sensing techniques, and de Gruijter and ter Braak (1990) and Brus and de Gruijter (1997) for a more general discussion of design- and model-based inference. A design-based approach requires the validation data to be collected by probability sampling. Then the inclusion probabilities on which the statistical inference is based can be specified. In the model-based approach no restrictions are made on the sampling method, and a model of the spatial structure of map errors need to be postulated to enable statistical inference. Consequently, the results of validation by a model-based approach depend on model assumptions, the validity of which cannot be evaluated easily. To obtain valid results, independent of model assumptions, a design-based approach is preferable (Stehman,1999).

The quality of the ecotope maps is validated on the basis of independent samples of field observations. The total map purity, that is the correctly classified proportion of the map, and the user's accuracy and producer's accuracy for each map unit were estimated. User's accuracy is the correctly mapped area of an ecotope relative to the total area of this ecotope at the map. Producer's accuracy is the correctly mapped area of an ecotope relative to the total area of this ecotope in the field.

In four districts the validation samples were selected purposively. For the fifth district a probability sample was designed. Sampling points were selected such that the spatial pattern resembles that of the purposive samples.

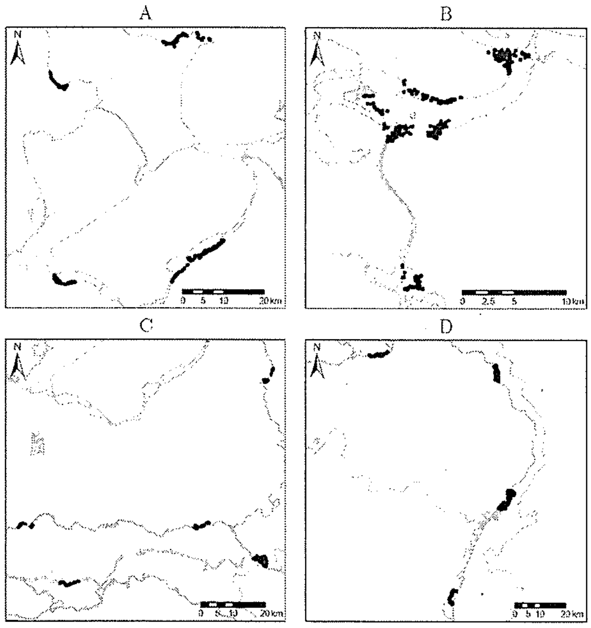

Figure 1. Sampling patterns in the purposively sampled districts. A: Ijsselmeer, B: Volkerak-Zoommeer, C: Rijntakken, D: Maas

The aim of the study is to compare two sampling approaches for validation of ecotope maps: a model-based and a design-based approach. In the design-based approach a stratified two-stage probability sample was designed, such that the spatial pattern resembles that of the purposive samples. In this way the same practical and budgetary constraints are met as in the purposively sampled districts, while valid estimates of quality measures are obtained.

II. STUDY AREAS AND VALIDATION METHODS

A. Purposively Sampled Districts

Districts A to D (Fig.1 a to d) were sampled purposively. In each of these districts, four to five compact 'validation areas' were selected purposively, such that they have a fair spreading over the district and contain all units of the ecotope map. In each of these validation areas a large number of field observations were made at purposively selected locations. The total numbers of validation locations in the four districts are 369, 266, 406 and 362, respectively.

Map purities for the four purposively sampled districts were estimated by model-based inference as described by Lohr (1999). Model-based means that we applied a statistical model of spatial variation of classification errors. We postulated the following simple random-effects model:

$$y_{ij} = \bar{y}_i + \varepsilon_{ij} \tag{1}$$

where y_{ij} is the indicator at validation point j in validation area i, being 1 if the location has been classified correctly and 0 if not; $\bar{y}_i$ is the areal fraction being correctly classified in validation area i; ε_{ij} is the deviation from this areal fraction at location j in validation area i. We assumed that the stochastic quantity $\bar{y}_i$ has mean μ and variance σ_b^2, and the stochastic quantity ε_{ij} has zero mean and variance σ_w^2. Further, we assumed that the covariance of ε_{ij} and $\varepsilon_{ik}, j \neq k$, equals 0.

We estimated map purity with the so called ratio estimator, i.e. by the ratio of the estimated area correctly classified and the estimated total area. The user's accuracy of each individual ecotope was estimated by the ratio of the estimated area in which the ecotope has been correctly classified and the estimated total area of the ecotope at the map. The user's accuracy of each individual ecotope was estimated by the ratio of the estimated area in which the ecotope has been correctly classified and the estimated total area of the ecotope in the field. The model variance of the estimated total map purity was estimated following Lohr (1999, p. 165, (5.39)).

B. Randomly Sampled District

A stratified two-stage probability sample was designed for district E, 'Rijn-Maasmonding', such that the spatial pattern resembles that of the purposive samples in districts A to D. In the first stage district E is divided into eight geographical strata, representing the main river branches, and each stratum is divided into validation areas (primary sampling units). In each geographical stratum two validation areas were selected by simple random sampling without replacement. In the second stage, in each selected validation area a simple random sample of points was taken (the secondary sampling units). Fig. 2 shows the selected validation areas and the sampling points.

We estimated the total map purity and the user's and producer's accuracies of individual ecotopes with the combined ratio estimator (Cochran, 1977, p. 165). The ratio estimator is expected to be more precise than the π-estimator, because the estimated total area varies between samples as a result of the varying surface areas of the primary units (validation areas). The variance of the combined ratio estimator for the overall map purity was approximated by the variance of the π-estimator (Cochran, 1977, p. 303, (11.24)), which might be slightly conservative.

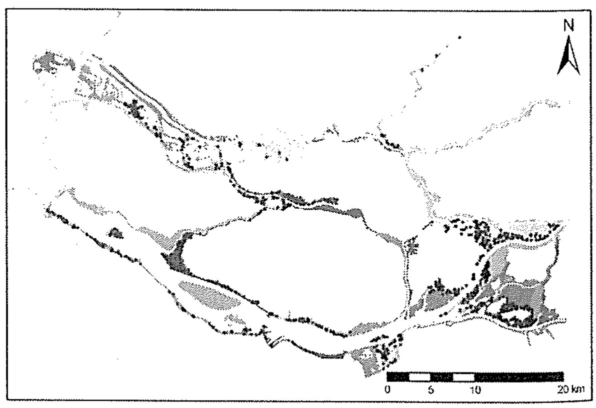

Figure 2. Locations of validation areas (colours) and sampling points in district E, 'Rijn-Maasmonding'

TABLE I. VALIDATION RESULTS. U = USER'S ACCURACY (%), P = PRODUCER'S ACCURACY (%)

Ecotope group	District									
	A		B		C		D		E	
	U	P	U	P	U	P	U	P	U	P
Arable land	30	73	-	0	78	89	79	82	62	96
Bare	70	92	50	73	62	78	47	73	82	86
Rough herbage	27	45	29	12	58	55	37	36	36	19
Forest	64	67	60	79	68	77	74	87	81	84
Grassland	89	68	75	62	73	83	90	90	89	86
Helofytes	78	68	45	77	69	59	0	0	71	78
Osier-thicket	-	-	-	-	0	0	-	0	43	73
Shrub	27	44	42	66	48	41	36	44	38	34
Solid substrate	82	100	100	32	87	48	67	68	28	11
Water	-	-	-	0	-	-	-	-	-	-
Total purity (s.e.)	70(5)		56(9)		69(5)		74(7)		76(3)	

estimator is expected to be more precise than the π-estimator, because the estimated total area varies between samples as a result of the varying surface areas of the primary units (validation areas). The variance of the combined ratio estimator for the overall map purity was approximated by the variance of the π-estimator (Cochran, 1977, p. 303, (11.24)), which might be slightly conservative.

III. RESULTS

The first eight columns in Table I show the validation results for the four purposively sampled districts, the last two columns contain the validation results for the randomly sampled district E. Relatively low accuracies might have several sources. During the time that elapsed between the shots of aerial photographs and the validation fieldwork the vegetation might have changed. The geographical information used in mapping the ecotopes is not perfect, and errors might have been made in interpreting this information. Cartographic errors might have been made in delineating ecotopes. During the fieldwork for validation observation errors have been made, for instance due the impossibility to observe in the field all values of the several indicators (for example flood duration) which are used to generate an ecotope map.

The overall map purities varied from 56 to 76 %. The relatively accurate estimate of map purity for district E can be explained from (i) a larger number of sampling points (902 versus 266 to 406), and (ii) a better spatial distribution of the validation areas (16 versus 4 to 5).

IV. DISCUSSION AND CONCLUSIONS

Two methods of validating ecotope maps were compared: purposive sampling combined with a model-based estimation method, and probability sampling combined with a design-based estimation method. In both methods the sampling points were spatially clustered in a limited number of compact validation areas, in order to reduce travel costs. We demonstrated that stratified two-stage sampling is an alternative to purposive sampling, answering to the same practical and budgetary constraints. Stratified two-stage sampling combined with a design-based estimation method results in model-free estimates of map purity, user's and producer's accuracies. This is an important advantage in validation, because the results do not depend on the quality of model assumptions (Brus and de Gruijter, 1997; Stehman, 1999). This means that the validity of the estimated map purities, user's and producer's accuracies is beyond discussion if a design-based approach is followed.

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