Sampling for validation of ecotope maps of floodplains in the Netherlands

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Abstract

Ecotope maps of five districts of main water courses in the Netherlands are validated on the basis of independent samples of field observations. Total map purity, and user's and producer's accuracy for each map unit were estimated. In four districts the validation samples were selected purposively in the past. For the fifth district a stratified two-stage probability sample was designed, such that the spatial pattern resembles that of the purposive samples. For the maps of the purposively sampled districts ratio-estimators of quality measures are calculated following a model-based approach, using a model for the spatial variation of classification errors. For the map of the randomly sampled district ratio-estimators of quality measures are obtained following a design-based approach, using the selection probabilities of the sampling points. Both user's and producer's accuracies show large variation among the map units, depending on the contribution of several sources of error in the mapping process and on observation errors during the fieldwork for validation. The total map purities vary from 56 to 76 %. We demonstrate 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. 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.

1 Introduction

An ecotope is defined as a spatially bounded ecological unit, which composition and development are determined by abiotic, biotic and anthropogenic aspects (Wolfert, 1996; Stumpel and Kalkhoven, 1978; Girel et al., 1997). Ecotopes are more or less homogeneous 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 (safety, EU Flood Directive), water quality (EU Water Framework Directive), ecological system knowledge (Flora- and Fauna Law, Nature Protection Law, EU Birds and Habitats Directive) and restoration- and development projects of the Dutch water systems. Ecotopes are monitored by surveys that are repeated each six years.

Ecotope maps have been made for five districts of the main watercourses in the Netherlands (Figure 1), in 2004 (Maas, IJsselmeer), 2005 (Rijntakken, Volkerak-Zoommeer) and 2006 (Rijn-Maasmonding). An ecotope map is a result of combining different kind of information layers by an overlay procedure using Geographic Information Systems (GIS). Depending on the type of water system (river system, lake system and tidal system) 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 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, is estimated for each of the five districts. Besides this, *user's accuracy* and *producer's accuracy* were estimated for each map unit. User's accuracy is the purity of map units: the correctly mapped area of an ecotope relative to the total area of this ecotope *at the map*. It reflects the reliability of the information about an 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*. It indicates the success of the procedures followed in mapping ecotopes.

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

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 model-based approach sampling points are selected by purposive sampling, and a model for the spatial variation of classification errors is used in estimating the map quality measures. In a design-based approach sampling points are selected by probability sampling, and the selection probabilities of the sampling points are used in estimating the map quality measures. We will argue that for validation purposes, a design-based sampling approach is recommendable.

2 Definitions of quality measures

The correctly classified proportion of the map or total map purity can be defined as the following areal fraction of an area A:

$$f = \frac{\int_{\mathbf{s}\in A} y(\mathbf{s})\mathrm{d}\mathbf{s}}{\mid A \mid}\ , \tag{1}$$

with $\mid A \mid$ the surface area of the area A, and

$$y(\mathbf{s}) = \begin{cases} 1 & \text{if} \quad \hat{c}(\mathbf{s}) = c(\mathbf{s}) \\ 0 & \text{else} \end{cases} \tag{2}$$

in which $\hat{c}(\mathbf{s})$ is the predicted or mapped ecotope at location $\mathbf{s}$ in area A, and $c(\mathbf{s})$ is the true ecotope at location $\mathbf{s}$. Map purity is a measure of user's accuracy, because it informs about the reliability of the map. At the level of individual ecotopes u, user's accuracy is defined as

$$f_{\text{user},u} = \frac{\int_{\mathbf{s}\in A} y_u(\mathbf{s})\mathrm{d}\mathbf{s}}{\int_{\mathbf{s}\in A} x_u(\mathbf{s})\mathrm{d}\mathbf{s}} \;, \tag{3}$$

with

$$y_u(\mathbf{s}) = \begin{cases} 1 & \text{if} \quad \hat{c}(\mathbf{s}) = c(\mathbf{s}) = u \\ 0 & \text{else} \end{cases} \tag{4}$$

and

$$x_u(\mathbf{s}) = \begin{cases} 1 & \text{if} \quad \hat{c}(\mathbf{s}) = u \\ 0 & \text{else} \end{cases} \tag{5}$$

The denominator in Eq. (3) is the surface area of map unit (ecotope) u. This area is known without error, as it can be determined from the map.

The producer's accuracy is the extent to which ecotopes which are present in the field are reflected by the map. It indicates the successfulness of mapping procedures. The producer's accuracy can be defined as:

$$f_{\text{producer},u} = \frac{\int_{\mathbf{s}\in A} y_u(\mathbf{s})\mathrm{d}\mathbf{s}}{\int_{\mathbf{s}\in A} z_u(\mathbf{s})\mathrm{d}\mathbf{s}} \;, \tag{6}$$

with

$$z_u(\mathbf{s}) = \begin{cases} 1 & \text{if} \quad C(\mathbf{s}) = u \\ 0 & \text{else} \end{cases} \tag{7}$$

The denominator in Eq. (6) is the surface area of ecotope u *in the field*. This area is not known, and must be estimated from the sample.

3 Study areas and validation methods

3.1 Purposively sampled districts

3.1.1 Sampling pattern

Districts 1 to 4 (Figure 2a 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 that they 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. Table 1 summarizes the distribution of the sample units over the districts, the validation areas and the ecotopes.

3.1.2 Estimation of map purity

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:

$$y_{ij} = \bar{y}_i + \epsilon_{ij} \ , \tag{8}$$

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^2_{b}, and the stochastic quantity ϵ_{ij} has zero mean and variance σ^2_{w}. Further, we assumed that the covariance of ϵ_{ij} and ϵ_{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. Of course, the total area is known but by dividing by the *estimated* total area, the estimate generally becomes more accurate. In formula, the ratio estimator equals:

$$\hat{f} = \frac{\frac{N}{n}\sum_{i=1}^{n} A_i \hat{\bar{y}}_i}{\frac{N}{n}\sum_{i=1}^{n} A_i} = \frac{\sum_{i=1}^{n} A_i \hat{\bar{y}}_i}{\sum_{i=1}^{n} A_i} \;, \tag{9}$$

with N the total number of validation areas in the study area, n the number of selected validation areas, A_i the areal size of the ith validation area, and $\hat{\bar{y}}_i$ the sample average of the indicator as defined in Eq. (2) for the ith validation area. The ratio estimator is model-unbiased under model (8), whatever the areal sizes of validation areas are (Lohr, 1999, p. 165). We estimated the model variance of the correctly classified area following Lohr (1999, p. 165, Eq. (5.39)).

3.1.3 Estimation of user's and producer's accuracy

The ratio estimator for the user's accuracy of an individual ecotope u can be obtained by

$$\hat{f}_{\mathrm{user},u} = \frac{\sum_{i=1}^{n} A_i \hat{\bar{y}}_{u,i}}{\sum_{i=1}^{n} A_i \hat{\bar{x}}_{u,i}} \;, \tag{10}$$

with $\hat{\bar{y}}_{u,i}$ the sample average of the indicator as defined in Eq. (4) for ecotope u in the ith validation area, and $\hat{\bar{x}}_{u,i}$ the sample average of the indicator as defined in Eq. (5) for ecotope u in the ith validation area.

The producer's accuracy of an individual ecotope u is estimated as follows:

$$\hat{f}_{\mathrm{producer},u} = \frac{\sum_{i=1}^{n} A_i \hat{\bar{y}}_{u,i}}{\sum_{i=1}^{n} A_i \hat{\bar{z}}_{u,i}} \;, \tag{11}$$

with $\hat{\bar{y}}_{u,i}$ the sample average of the indicator as defined in Eq. (4) for the for ecotope u in the ith validation area, and $\hat{\bar{z}}_{u,i}$ the sample average of the indicator as defined in Eq. (7) for the for ecotope u in the ith validation area.

3.2 Randomly sampled district 'Rijn-Maasmonding'

3.2.1 Sampling constraints

The sampling strategy for the validation of the ecotope map of 'Rijn-Maasmonding' had to meet the following budgetary and practical constraints:

1. The maximum number of observations is 50 per fieldworker per day. Three fieldworkers are available during ten days. Travel time must be limited in a way that a total sample size of about 1,000 is realistic.

2. Non-accessible terrain, such as swamps with soft soils, are not part of the target population.

3. All branches of the rivers must be sampled.

4. All ecotopes must be validated, excluding water and built-up areas.

3.2.2 A stratified two-stage sample

To meet the first and third constraint, we decided to select sampling points by stratified two-stage sampling. An important advantage of this strategy is that statistical inference is relatively simple as compared to other strategies, such as cluster sampling (de Gruijter et al., 2006). The sampling points were selected such that the spatial pattern resembles that of the purposive samples. This makes practical implementation more easy, because the planning and execution of fieldwork in 'Rijn-Maasmonding' is similar to the purposively sampled districts. The procedure of stratified two-stage sampling is as follows:

1. In the first stage the district 'Rijn-Maasmonding' is divided into eight geographical strata, representing the main river branches, and each stratum is divided into validation areas (primary sampling units). Figure 3 shows these geographical strata. In each geographical stratum two validation areas are selected by simple random sampling and without replacement.

2. In the second stage, in each selected validation area a simple random sample of points is taken (the secondary sampling units). Figure 4 shows the selected validation areas and the sampling points.

In two-stage sampling the number of sampling points within the primary units must be fixed before the primary sampling units are selected. This condition guarantees that the selection probabilities of the sampling points are known. We made the number of sampling points proportional to the surface areas of the validation areas. Since these surface areas vary, the *total* sample size is not fixed, but varies between samples drawn with the stratified two-stage sampling design. To prevent for large variations of the total sample size in repeated sampling, we delineated the validation areas in such a way that their surface areas within a geographical stratum are approximately constant. The *expected* total sample size is 1,000.

3.2.3 Estimation of map purity

We estimated map purity with the separate ratio estimator. In this estimator first for each stratum the map purity is estimated by the ratio estimator (see Lohr (1999), p. 148):

$$\hat{f}_h = \frac{\sum_{i=1}^{n_h} A_{hi}\hat{\hat{y}}_{hi}}{\sum_{i=1}^{n_h} A_{hi}} \ , \tag{12}$$

in which A_{hi} is the area of the ith selected primary unit in stratum h, and $\hat{\hat{y}}_{hi}$ the estimated areal fraction being correctly classified in the ith primary unit in stratum h. This fraction is estimated by the sample average of the indicators of Eq. (2) at the m_{hi} sampling points in validation area i in geographical stratum h:

$$\hat{\hat{y}}_{hi} = \frac{1}{m_{hi}} \sum_{j=1}^{m_{hi}} y_{hij} \ . \tag{13}$$

Finally, The ratio estimator of the map purity of the total area is estimated by

$$\hat{f} = \sum_{h=1}^{\ell} w_h \hat{f}_h \ , \tag{14}$$

with

$$w_h = \frac{A_h}{\sum_{h=1}^{\ell} A_h} \ .$$

For the calculation procedure of the sampling variance of the ratio estimators we refer to Lohr (1999, p. 148).

3.2.4 Estimation of user's and producer's accuracy

The user's accuracy or map purity per ecotope was again estimated by the *separate* ratio estimator.

The user's accuracy of map unit u in stratum h was estimated by

$$\hat{f}_{\text{user},u,h} = \frac{\sum_{i=1}^{n_h} A_{hi}\hat{\hat{y}}_{u,hi}}{\sum_{i=1}^{n_h} A_{hi}\hat{\hat{x}}_{u,hi}} \ , \tag{15}$$

with $\hat{\bar{y}}_{u,hi}$ and $\hat{\bar{x}}_{u,hi}$ the sample averages of the indicators of Eqs. (4) and (5), respectively, for ecotope u in the ith validation area in the hth stratum.

For the district 'Rijn-Maasmonding' the user's accuracy of ecotope u is estimated by:

$$\hat{f}_{\text{user},u} = \sum_{h=1}^{\ell} w_h \hat{f}_{\text{user},u,h} \; . \tag{16}$$

The producer's accuracy of an ecotope u in stratum h was estimated by

$$\hat{f}_{\text{producer},u,h} = \frac{\sum_{i=1}^{n_h} A_{hi}\hat{\bar{y}}_{u,hi}}{\sum_{i=1}^{n_h} A_{hi}\hat{\bar{z}}_{u,hi}} \, , \tag{17}$$

with $\hat{\bar{z}}_{u,hi}$ the sample average of the indicator of Eq. (7) for ecotope u in the ith primary unit in stratum h. The producer's accuracy of ecotope u for the total area of 'Rijn-Maasmonding' is estimated with

$$\hat{f}_{\text{producer},u} = \sum_{h=1}^{\ell} w_h \hat{f}_{\text{producer},h,u} \; . \tag{18}$$

4 Results

The first eight columns in Table 2 show the validation results for the four purposively sampled areas, the last two columns contain the validation results for the randomly sampled district "Rijn-Maasmonding". Note that areal fractions have been converted to percentages. Relatively low accuracies might have several sources, such as:

1. 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;

2. During the time between the shots of aerial photographs and the fieldwork for validation the vegetation might have changed;

3. The information on which the maps are based might be imperfect;

4. Errors might have been made in interpreting this information;

5. Cartographic errors might have been made in delineating ecotopes.

The total map purities vary from 56 to 76 %. The map purity of the randomly sampled district "Rijn-Maasmonding" is estimated more accurately than those of the four purposively sampled districts: a standard error of 2 % vs. standard errors varying from 5 to 9 %. Note that the standard errors of map purities for the four purposively sampled districts were possibly underestimated, because in the random effects model we assumed that the errors were spatially uncorrelated. The relatively accurate estimate of map purity for "Rijn-Maasmonding" 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).

5 Discussion and conclusions

This study compared two methods of validating ecotope maps: 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 clustered in a limited number of compact validation areas, in order to reduce travel costs. In estimating map purities and user's and producer's accuracies for IJsselmeer, Volkerak-Zoommeer, Rijntakken and Maas a random effects model was applied, which implied assumptions on the distribution of the classification errors. 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). 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.

As a consequence of the model assumptions made in the validation of IJsselmeer, Volkerak-Zoommeer, Rijntakken and Maas the standard errors of the estimated map purities were possibly underestimated. The design-based approach followed for Rijn-Maasmonding has the advantage that no model is used in calculating standard errors of map purities.

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Table 1: Summary of validation samples in the four purposively sampled districts

District	number of validation areas	total number of validation points	number of validation points per validation area
IJsselmeer	4	369	69, 137, 94, 69
Volkerak-Zoommeer	5	266	78, 43, 36, 51, 58
Rijntakken	5	406	82, 44, 47, 143, 90
Maas	4	362	76, 128, 106, 52

Table 2: Validation results. U = user's accuracy (%), P = producer's accuracy (%)

Ecotope group	District									
	IJsselmeer		Maas		Rijntakken		Volkerak-Zoommeer		Rijn-Maasmonding	
	U	P	U	P	U	P	U	P	U	P
arable land	30	73	79	82	78	89	-	0	69	99
bare	70	92	47	73	62	78	50	73	76	97
rough herbage	27	45	37	36	58	55	29	12	39	51
forest	64	67	74	87	68	77	60	79	82	61
grassland	89	68	90	80	73	83	75	62	88	51
helofytes	78	68	0	0	69	59	45	77	74	62
osier-thicket	-	-	-	0	0	0	-	-	35	83
shrub	27	44	36	44	48	41	42	66	43	63
solid substrate	82	78	67	68	87	48	100	32	17	18
water	-	-	-	-	-	-	-	0	-	-
Total purity (s.e.)	70(5)		74(7)		69(5)		56(9)		76(2)	

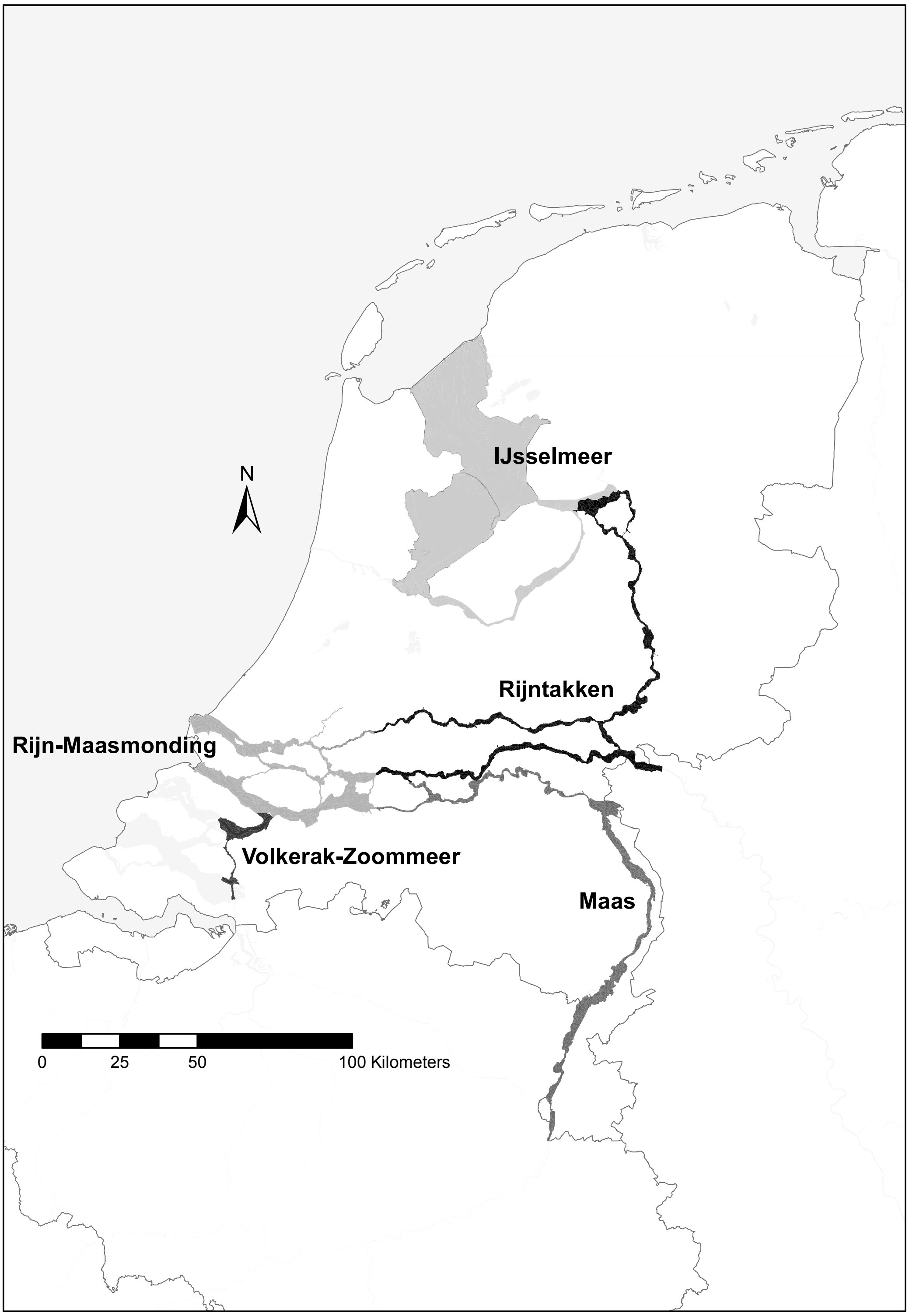

Figure 1: Districts of main watercourses in the Netherlands

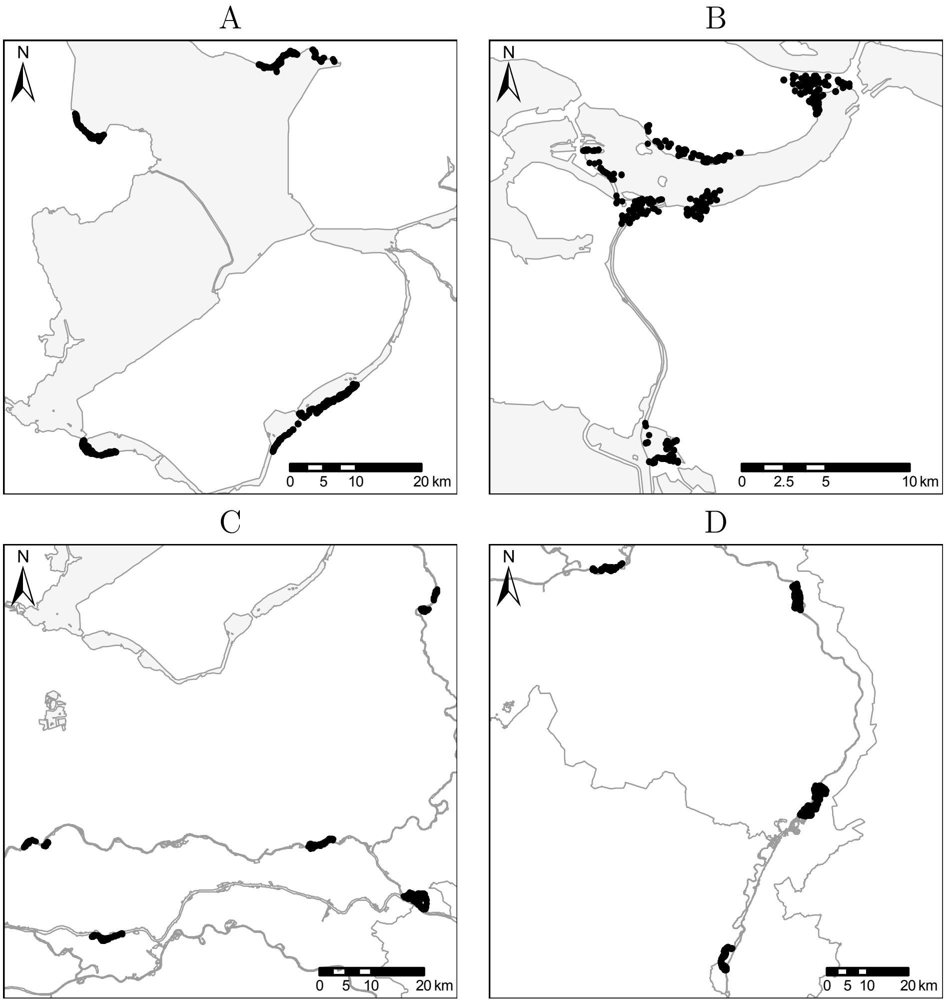

Figure 2: Sampling patterns in the purposively sampled districts. A: IJsselmeer, B: Volkerak-Zoommeer, C: Rijntakken, D: Maas

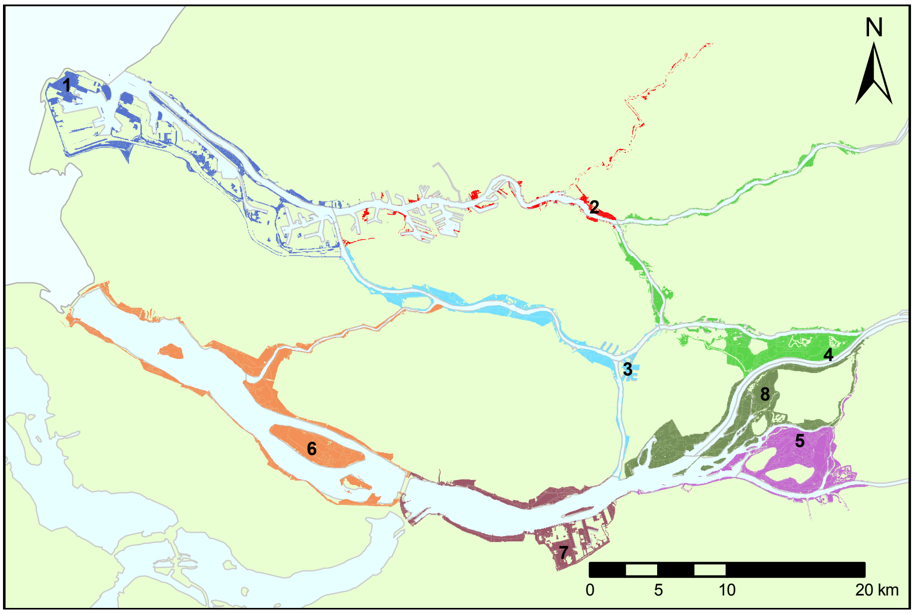

Figure 3: Geographical strata of the district 'Rijn-Maasmonding'

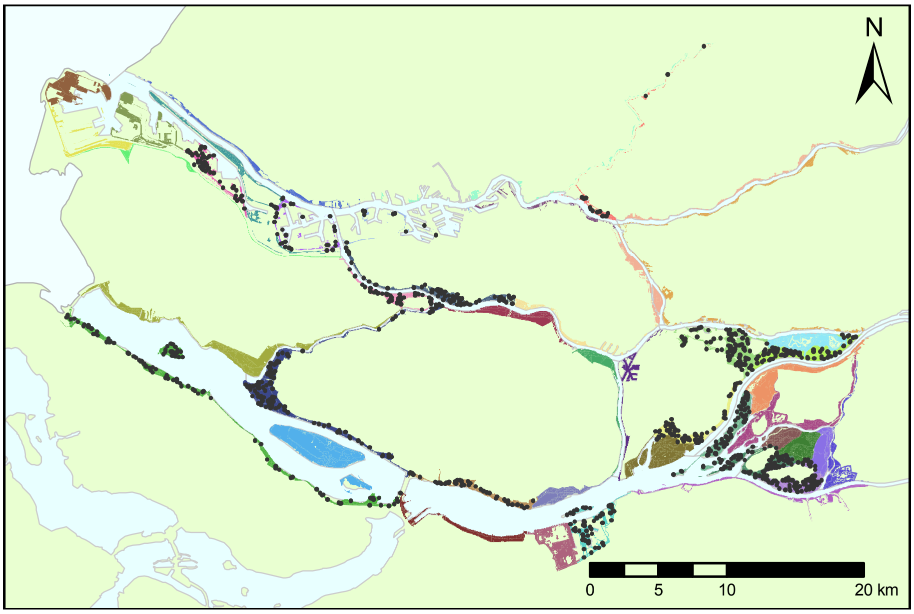

Figure 4: Location of validation areas and sampling points in "Rijn-Maasmonding"