Uncertainty analysis of habitat evaluation methods

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ABSTRACT: In the Netherlands, ecological rehabilitation of rivers, lakes and wetlands has a high priority in planning and policy for water and nature management. To assess the ecological impacts of rehabilitation measures, habitat evaluation methods based on the concept of Habitat Evaluation Procedures (HEP) have become a standard approach. These methods consist of ecological models and analytical procedures to use these models for habitat evaluation. For a general application of the ecological models it is essential to know the reliability of such models. Therefore, sensitivity of the model outcomes for input and parameters should be specified, uncertainty in the model prediction should be explored and the domain over which the model is applicable (e.g. temporal and spatial resolution) should be determined. To answer questions related to the reliability of the habitat evaluation methods applied, sensitivity and uncertainty analyses have been carried out for an application on Lake IJssel, the Netherlands. Results of the sensitivity analyses show that the habitat suitability is mostly determined by only two or three factors for each species, although sometimes models contain up to fifteen factors. The range in uncertainty of the habitat suitability determined by these factors is about an index value of 0.1 - 0.2 (the suitability index ranges from 0.0 to 1.0). The sensitivity and uncertainty analyses of the ecological models show that the concept of the HEP as applied in the Netherlands may be considered to be applicable for assessment of ecological rehabilitation measures for lakes.

1 INTRODUCTION

In the Netherlands, nature values of rivers, lakes and wetlands are endangered or have disappeared in the last decades due to water pollution, habitat loss and fragmentation, and deterioration of the quality of the remaining habitats (Reijnen et al. 1995, Ministry of Transport, Public Works and Water Management 1996, RIVM et al. 1997). Nowadays, flood protection and habitat restoration are the major policy issues of inland water management (Ministry of Transport, Public Works and Water Management 1999). Ecological rehabilitation of rivers, lakes and wetlands often aims at the improvement of the water quality and restoring natural hydrodynamic processes, e.g. water level fluctuation, stream velocity and inundation frequency (De Vriend & Iedema 1995, Duel et al. 1996, Duel & Vis 1997, Pedroli & Dijkman 1998). In the Netherlands, habitat evaluation methods based on the concept of Habitat Evaluation Procedure (HEP) have become a widely accepted approach for ecological impact assessment (US Fish and Wildlife Service 1980, Terrell et al. 1982, Duel et al. 1996, 1999).

Basically, the habitat evaluation framework in the Netherlands consists of four steps of ecological modelling (Fig. 1). The first step is the simulation of the spatial distribution of ecotopes, ecological units of which development is determined by factors related to hydrodynamics, morphodynamics and ecological succession (Klijn 1997). For example, differences in stream velocity,

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water depth and flooding frequency are applied for the definition of ecotopes of aquatic ecosystems in the Netherlands. The second step is the assessment of area of the available habitat for specific flora and fauna species based on the size and spatial distribution of ecotopes. The total area of available habitat includes all areas of ecotopes that provide life-cycle support for the species reviewed (Duel et al. 1996). The third step is the assessment of the habitat suitability based on the habitat requirements and preferences of the species reviewed. The habitat suitability considers both the needs of a species (nutrients, food, shelter etc.) as well as the threats (e.g. toxics). The fourth step is the assessment of the connectivity of suitable habitats into ecological networks. Although suitable habitats may be available, that does not necessarily mean that species will settle and/or survive. To support viable populations, it is important that habitats are large enough and sufficiently linked into ecological networks (Reijnen et al. 1995).

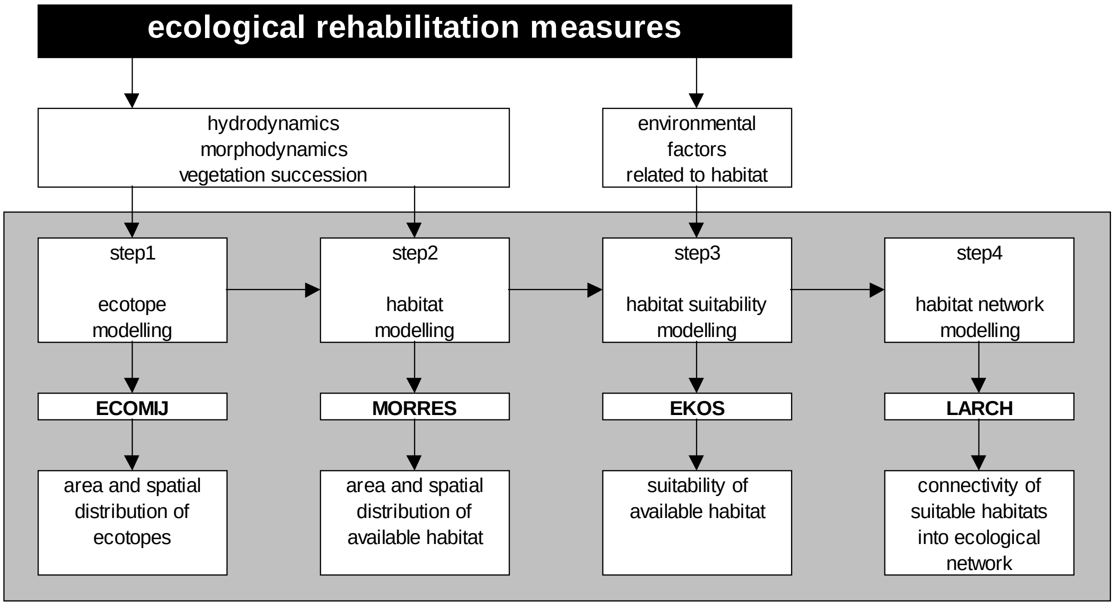

Figure 1. The habitat evaluation framework in the Netherlands.

Although, habitat evaluation methods are widely used in the Netherlands, there is little known about the reliability of such models. Therefore, analyses were carried out to determine the sensitivity of the model results for input and parameters and the uncertainty in the model predictions.

2 METHODS

2.1 *Selection of models*

Areas and distribution of ecotopes were estimated with model ECOMIJ (Jans et al. 2000). This model predicts a detailed map (10×10 m) of ecotopes from the observed in the field (100×100 m), the soil map, map with contour lines, map with actual vegetation management and average water level during summer and winter.

Next, the areas of available habitats based on the areas and distribution of the ecotopes were assessed with MORRES (Baptist & De Vries 1999). The total area of habitats includes habitats for breeding, spawning, foraging and/or resting. The habitat suitability of the available habitats is determined with the EKOS software package (De Vries & Borsboom 1994). The HSI-models are presently available for more than 70 flora and fauna species. The HSI-models include only the main environmental factors determining or limiting the population of species reviewed. Examples

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of such factors are water quality, water depth, stream velocity and vegetation cover (Fig. 2). The habitat requirements and preferences are derived from life history studies, field observation studies and statistical analysis of the characteristic environmental factors of the habitats used by the species. The models produce numerical rating, which represent the carrying capacity of the habitats reviewed. The range of the index rating is from 0.0 to 1.0, expressing the range from unsuitable to optimal habitat conditions. The overall habitat suitability is determined by the suitability index ratings of the habitat factors limiting the carrying capacity of the habitat (Duel et al. 1995, 1996).

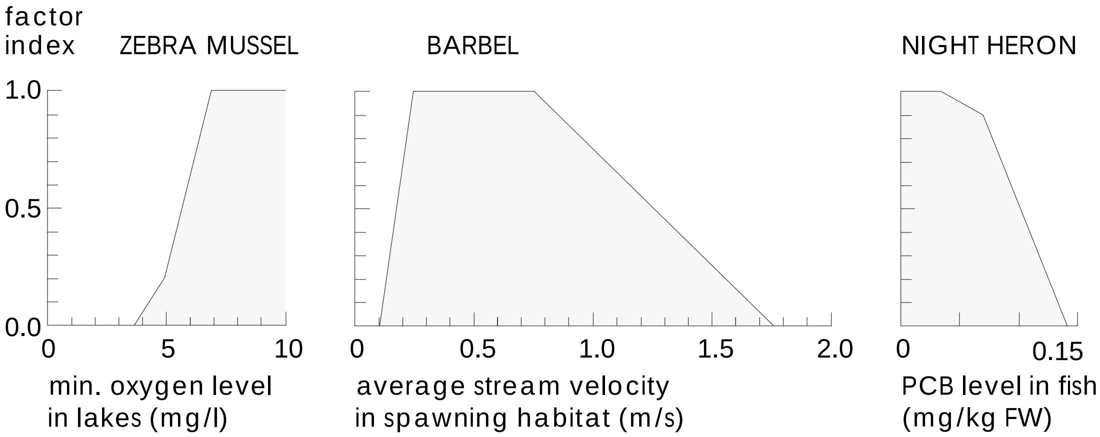

Figure 2. Examples of habitat functions in HSI-models (after Duel et al. 1996)

Finally, LARCH (Landscape ecological Analysis and Rules for the Configuration of Habitat) assesses the degree of viability of ecological networks for different species (Opdam et al. in prep., Verboom et al. in prep.). The core is the definition of key patches in the ecological networks. Key patches are areas large enough to support (potentially) viable population assuming net immigration from other habitat within the same network. This implies that the size of a key patch depends on the spatial cohesion of the habitat in the network. In fragmented areas key patches are larger than in less fragmented areas since less immigrants will arrive (Foppen & Chardon 1998, Otchagov et al. 1999). LARCH has the following characteristics:

a) It assesses the potential of habitat networks to support viable networks. It therefore uses data on habitat configuration rather then species distribution.
b) It is based on a conceptual framework of species indicating habitat fragmentation and spatial cohesion of habitat networks.
c) It is based on computer simulated thresholds for minimum viable key patch sizes, underpinned by empirical evidence;
d) It is based on expert knowledge and literature on dispersal distances.

LARCH contains over 100 fauna species. The input is a map of a landscape (scale independent) containing different vegetation types. First the habitat configuration of the landscape is analysed, ecological networks are made and finally the degree of viability is assessed. For each species the result is a map of viable patches. Other result and statistics like total area in a viable network can be generated. Aggregation of the results of different species can be used as a measure of biodiversity. In this analysis the results of EKOS were used as input maps.

2.2 *Case study: Lake IJssel area*

In order to answer the questions about the uncertainty of the results of habitat evaluation methods, the ecological models are applied to Lake IJssel, which is an area of interest in water management

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and biological conservation. Lake IJssel is with its 1200 km^2 one of the largest fresh water lakes in Western Europe. It is supplied with water by the river IJssel, the northern branch of the river Rhine in the Netherlands (Fig. 3). With respect to biodiversity, Lake IJssel is an area of international importance (Wolff 1989). Due to a large fish biomass and a high density of fresh water mollusks large numbers of piscivorous birds and molluscivorous birds are present in the area, especially during the winter period (Van Eerden 1998).

From the available HSI-models five species were selected to analyse the uncertainty in the application at Lake IJssel: pond weed (*Potamogeton pectinus*), zebra mussel (*Dreissena polymorpha*), cormorant (*Phalacrocorax carbo*), root vole (*Microtus oeconomus*) and fish otter (*Lutra lutra*). Size and connectivity of habitats were analysed for fish otter and root vole. For zebra mussel, the model results were compared with the results of the field oberservations.

Figure 3. Map of the Netherlands.

2.3 *Sensitivity and uncertainty analysis*

The sensitivity analysis consisted of a study on the effects of an absolute 0.1 deviation of the nominal values of the factor indexes determining the habitat availability and suitability. Values smaller than 0 and larger than 1 were adjusted to 0 and 1. Absolute deviations were preferred above relative deviations, to account for the expected large effects at low index values. For HSI-models, only the effect of individual perturbations was studied, because the output these models is determined by the lowest value of the indexes.

Analogously, the uncertainty analysis was focused on the uncertainty in the HSI-models due to uncertainty in single habitat functions. Single habitat functions consist of discontinuous linear functions or sets of classes. Discontinuous linear functions are described by values of habitat function indexes at the function transition points; sets of classes are described by a different index

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for each class. To perform an uncertainty analysis, the uncertainty of each index within a habitat function must be known. The uncertainties of habitat factors were estimated by a panel of experts. The experts were asked to estimate the 5% and 95% percentiles of the distribution of the indexes describing the single habitat functions. Furthermore, the experts had to attribute an expertise score to themselves ranging between 0 and 1. Using these expertise scores, a weighted average was calculated of the series of 5% and 95% percentiles estimated by the experts. The distributions of the indexes describing the single habitat functions were assumed to be uniform.

The uncertainty analysis has been performed by Monte Carlo simulation (Hammersley & Handscomb 1979, Lewis & Orav 1989), which is a suitable method for models with discontinuous functions, such as HSI-models. In a Monte Carlo simulation the model is run repeatedly with input values that are randomly sampled from their joint distribution. The simulation results form a random sample of the real distribution of the model result. When the sample is sufficiently large, the statistical properties of the real distribution can be estimated. In this study a number of 200 runs was used, which was sufficiently large for our purpose, according to results obtained by Van Dijk & Kwaad (1999) and Van Vooren (1997). For each Monte Carlo run, values were sampled from the distributions of the indexes (characterized by the 5% and 95% percentiles).

In the sampling of values two assumptions were made. Firstly, it was assumed that the uncertainty of the index was constant over the range of the explaining factor within a single habitat function. Secondly, it was assumed that the uncertainty of indexes in one single habitat function was not related to the uncertainty in another habitat function. Therefore, for each single habitat function a different random number was used to sample values of indexes. With the Monte Carlo simulation results, the average and standard deviation of the model results were calculated, as well as the probability that the habitat model results deviated more than an index value of 0.1 of the average, which is assumed as a measure of the acceptability of the model results for applications in research and management.

The resulting habitat quality and related uncertainty was passed on to a habitat connectivity model to assess whether the distribution of the available habitats with their estimated quality are sufficient to support viable (potential) populations.

3 RESULTS

3.1 *Sensitivity of habitat models*

The results of the sensitivity analysis show that the variations in the outcomes for the availability of habitats for the species studied are significant, but not extreme. The variation in the total area available habitat is for zebra mussel 15% and for the other selected species 10-12%. So the model was considered not too sensitive to the input parameters and data to assess the habitat availability in an appropriate way.

The results of the sensitivity analysis of the parameters in HSI-models show that the results of the models are mostly determined by only two or three sensitive factors, although sometimes models contain up to fifteen factors. For example, the sensitive habitat factors for zebra mussel are substrate and mud content in the upper layer of the lake sediment.

The uncertainties in habitat suitability of course effect the results of LARCH, because this model uses information on habitat suitability as input. Analysis of the transformation of uncertainties by LARCH indicated that the range of uncertainty in the output of habitat connectivity was comparable to the relative level of uncertainty in habitat suitability.

3.2 *Uncertainty of HSI-models*

The uncertainties in the model predictions for habitat suitability were addressed using the results of the sensitivity analysis. For zebra mussel, cormorant and otter, the uncertainty in the sensitive habitat factors results in a range in habitat suitability of about an index value of 0.1. For root vole and pond weed this range is about an index value of 0.15 - 0.2.

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To illustrate the uncertainties in the habitat suitability index model predictions, the results of the uncertainty analyses of the HSI-model for zebra mussel are presented in more detail. The model predictions of the habitat suitability for zebra mussel in the southern part of Lake IJssel are shown in figure 4 (without uncertainties in habitat functions) and figure 5 (with uncertainties in habitat functions).

Surprisingly, the uncertainties in habitat functions do not result in striking differences in the model outcomes. In general, the probability that the habitat suitability index for zebra mussel in Lake IJssel differs more than an index value of 0.1, is less than 10%.

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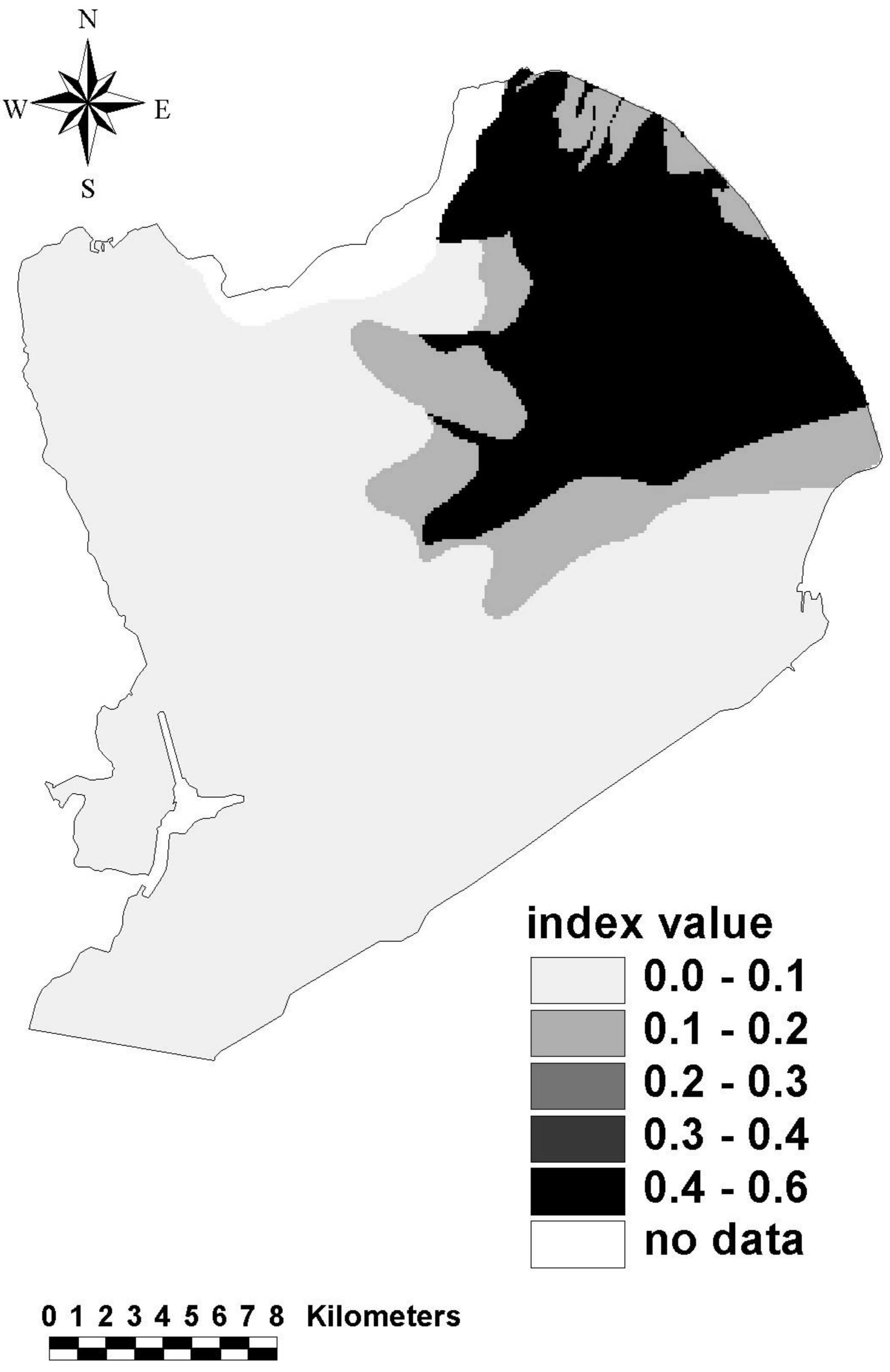

Figure 4. The model predictions of habitat suitability for zebra mussel in the southern part of Lake IJssel (HSI-model without uncertainties in habitat functions)

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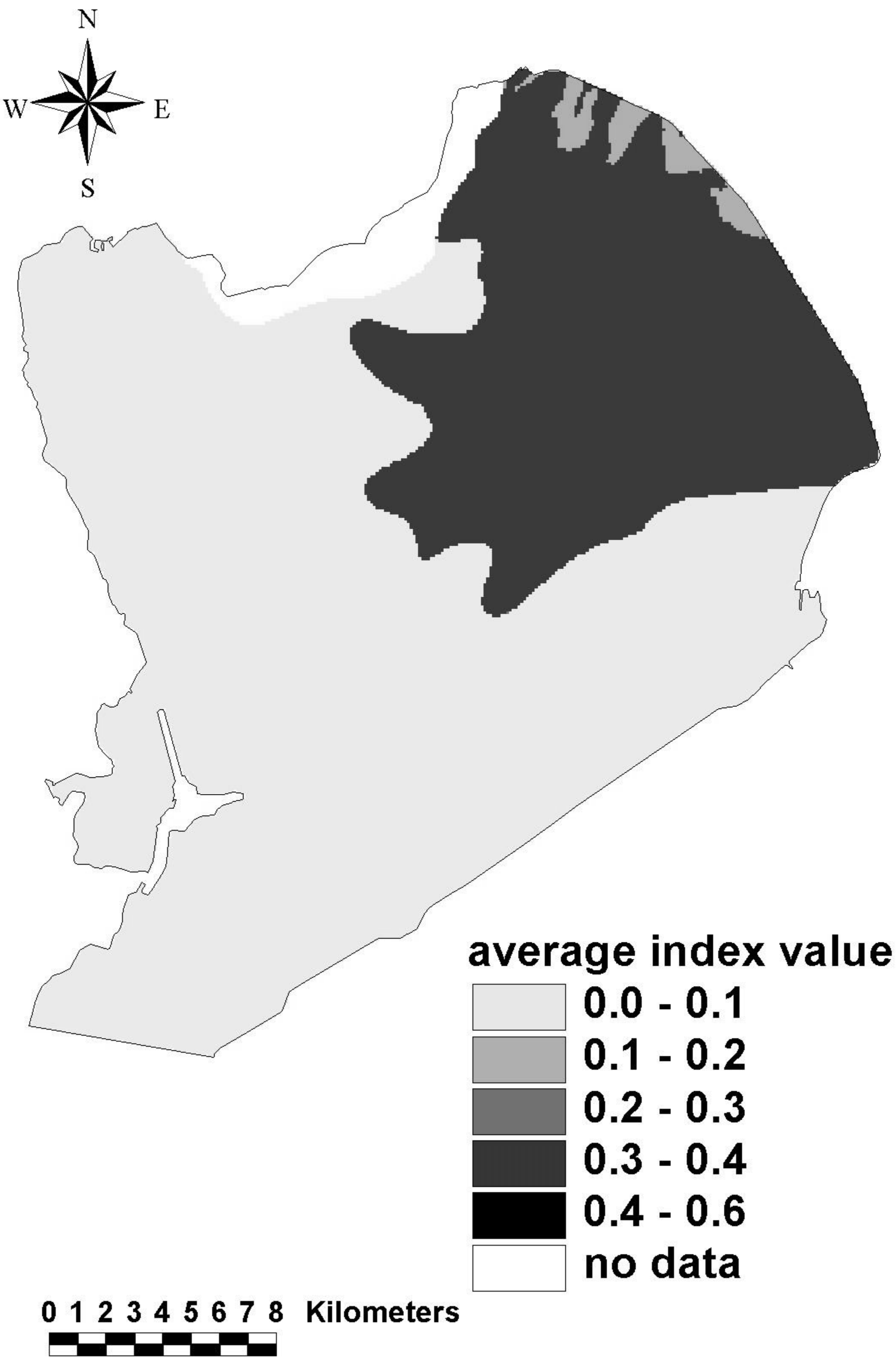

Figure 5. The model predictions of habitat suitability for zebra mussel in the southern part of Lake IJssel (HSI-model with uncertainties in habitat functions).

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3.3 *Model results and field observations*

Since an important criterion for the acceptance or rejection of the model results is the comparison of the model results with field observations, the results of the model simulations for zebra mussel were compared with the densities of zebra mussel observed in field surveys (Fig. 6). The observed densities of zebra mussel in the southern part of Lake IJssel are not fully predicted by both the models and the experts, especially the spots with relatively high densities of zebra mussel. Moreover, low densities of zebra mussel were observed in areas with (moderate) suitable habitats. Possible causes for these differences are the following: the dynamics in the thickness of the mud layer in the lake due to wind induced currents and the consumption by molluscivorous birds (Slager 1988, Lammens & Hosper 1998). However, the observed densities in large areas of the southern part of Lake IJssel are very low similar to the poor habitat quality as predicted by both the model and the experts. The highest observed densities are comparable with 20-30% of the optimum value. This is similar to an index value of about 0.2 - 0.3.

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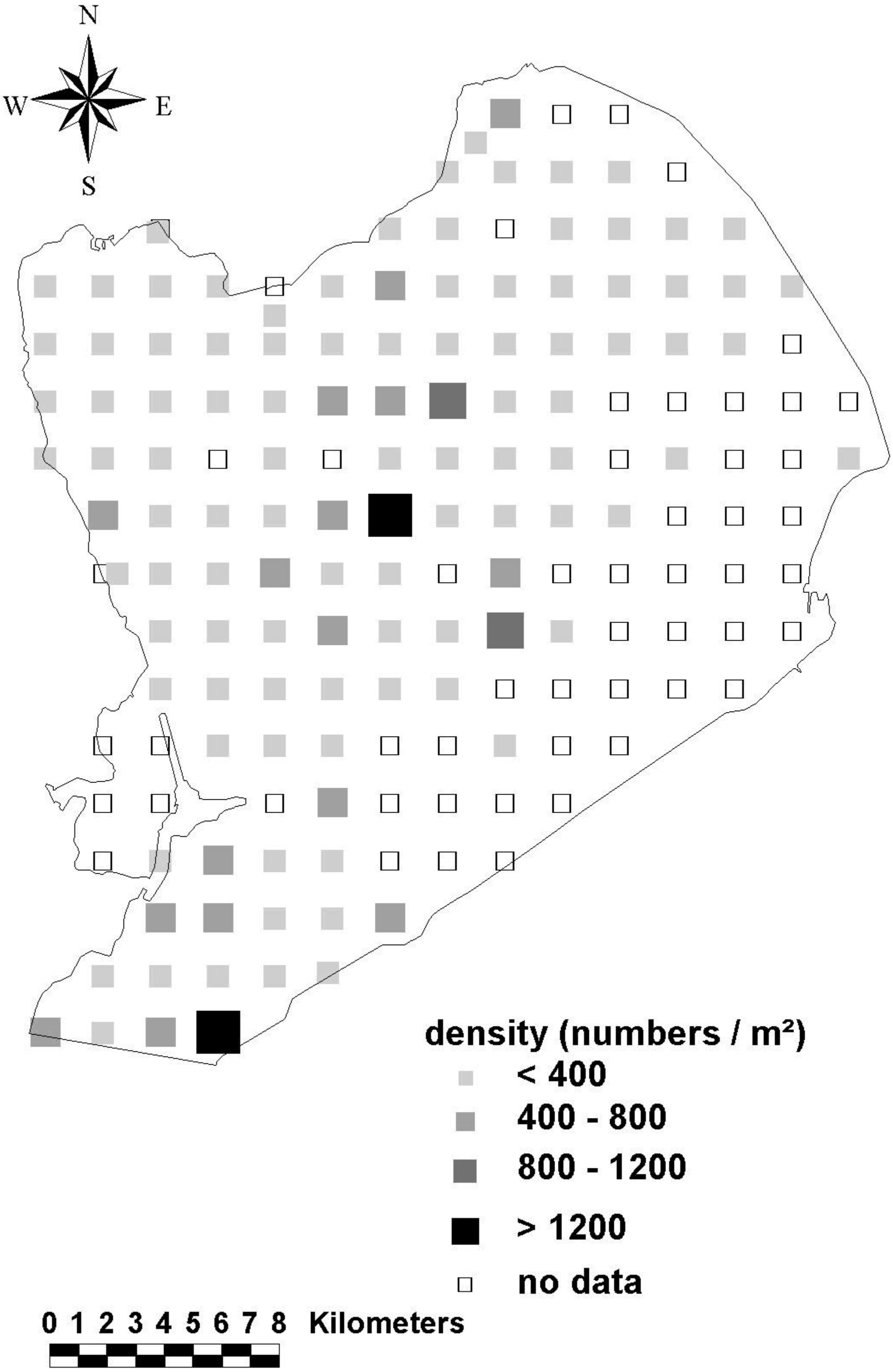

Figure 6. Field observations of zebra mussel density in southern part of Lake IJssel in 1999.

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4 DISCUSSION

Sensitivity and uncertainty are important criteria for credibility of models (Van der Molen 1999). During sensitivity analyses the appropriateness of the model structure can be examined and during uncertainty analysis the uncertainties in model predictions can be addressed and quantified to a certain extent. A measure for the acceptability of the uncertainties in HSI-model results for applications in water management is the probability that the uncertainties result in a range of an index value of more than 0.1. As this is less than 10% the HSI-models are considered to be suitable for applications. Considering the application for Lake IJssel, the HSI-models for zebra mussel, cormorant and otter are acceptable. On the other hand the uncertainty analysis of the HSI-models for pond weed and root vole shows that, in general, the uncertainty in model results for Lake IJssel is more than an index value of 0.1. For root vole is the inundation frequency of the marshes an uncertain habitat factor and for pond weed the wind exposure. It is known that root vole habits frequently flooded areas, but there is no quantitative data on the habitat requirements with respect to the flooding frequency. Field data is required to improve this habitat function. For pond weed the habitat function for wind exposure is based on statistical analysis of field observations in Lake IJssel between 1975 - 1985 (Scheffer et al. 1992). However, the opinion of consulted experts differs significantly with the statistics.

It is striking that the habitat factors that determine the uncertainty in habitat suitability for the selected species (pond weed, zebra mussel, cormorant, root vole and otter) for Lake IJssel are factors that can not be measured easily in the field or have not been described to full extent in literature. This relates to factors such as mud content in the upper layer of the lake sediment, inundation frequency of the lacustrine marshes PCB-levels in fish, wind exposure. Furthermore, the experts in this field often do not have the same opinion on the above habitat factors resulting in a relatively high uncertainty.

However, the resulting uncertainties of the model results for the Lake IJssel application is judged to be acceptable for usage of the model results in planning and water management. Still, considerable progress could be achieved if more detailed measurement results and field observations will become available on the most critical habitat factors.

5 CONCLUSIONS

The main conclusions drawn from this application at Lake IJssel are:

a) the uncertainties in habitat evaluation methods can be determined by means of expert judgements on habitat factors;
b) within the framework of habitat evaluation methods the uncertainties in results are related to a large extent to the uncertainties in habitat suitability;
c) results of the sensitivity analyses show that the habitat suitability is mostly determined by only two or three habitat factors;
d) the sensitivity and uncertainty analyses show that the concept of HEP as applied in the Netherlands can be considered to be applicable for assessments of ecological rehabilitation measures for lakes;
e) since uncertainty is an important criteria for credibility of models and model results, it is recommended to include uncertainty analysis in the procedures for the application of habitat evaluation measures and to make the uncertainties in habitat evaluation for every application explicit.

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