Habitat Modelling of Rivers and Lakes in the Netherlands:

An Ecosystem Approach

Harm Duel[1], Guda E.M. van der Lee[1], W. Ellis Penning[1] and Martin J. Baptist[1,2]

ABSTRACT

In the Netherlands, ecological rehabilitation of rivers, lakes and wetlands has a high priority in water and nature management. As a consequence of recent EU policy and regulations, water managers have to take measures to improve the ecological functioning and quality of rivers and lakes towards 'good or high quality status'. To achieve those ecological objectives, measures must be taken to improve water quality and to restore the natural hydro– and morphodynamic conditions. To assess the effectiveness of the ecological rehabilitation measures, habitat modelling and evaluation methods can be of high importance. However, an ecosystem approach of applying habitat evaluation techniques is essential. In this paper, we describe the state–of–the–art of habitat modelling in the Netherlands and recent developments within the context of EU directives and policies. Due to these new developments, existing Dutch habitat modelling tools are currently being merged into one generic modelling framework. This framework is based on GIS and will contain ecological databases and links with hydraulic, hydrological, morphological and water quality models.

RÉSUMÉ

Au Pays–Bas, la réhabilitation des cours d'eaux, lacs et milieux humides est une grand priorité en gestion des milieux aquatiques et des ressources hydriques. Afin d'évaluer l'impact écologique des mesures de réhabilitation, les méthodes d'évaluation de l'habitat sont normalement utilisées. Nous présentons ici l'état des connaissances et les nouveaux développements pour la modélisation des habitats. La première étape consiste à simuler la distribution spatiale des écotopes, qui sont les unités écologiques sur lesquelles sont évaluées les aménagements en termes hydrodynamiques, morphométriques et en termes de succession écologique. Par exemple, les différences de vitesse, de profondeur et de fréquence de crues sont utilisées pour la définition des écotopes d'écosystèmes aquatiques. La seconde étape consiste à évaluer l'aire d'habitat utile pour différents espèces de flore et de faune à partir des surfaces et de la

[1] WL Delft Hydraulics, Inland Water Systems Division, Netherlands
[2] Delft University of Technology, Faculty of Civil Engineering and Geosciences, Netherlands

distribution spatiale des écotopes. L'aire totale disponible inclut toutes les superficies d'écotopes qui supportent un stade de vie pour l'espèce étudiée. La troisième étape est l'évaluation de l'adéquation de l'habitat évaluée à partir des besoins en habitat et des préférences des espèces étudiées. On tient compte à la fois des besoins de l'espèce (nourriture, refuge, etc.) et les dangers (e.g. contaminants chimiques). La quatrième étape est l'évaluation de la connectivité de ces habitats dans un réseau écologique. Le fait que des habitats soient disponibles ne garantit pas qu'ils soient utilisés. Il faut qu'ils soient suffisamment grands et liés entre eux dans un réseau écologique.

La réhabilitation des lacs et rivières des Pays–Bas ne porte pas sur l'évaluation par une seule espèce, mais plutôt sur un nombre d'espèces ciblées pour la gestion de l'eau et des écosystèmes. Parmi elles, on retrouve certaines espèces rares ou vulnérables de même que certaines espèces indicatrices de l'intégrité du fonctionnement de l'écosystème. Conséquemment, l'application de modèles d'habitats pour les rivières et les lacs est toujours faite pour de nombreuses espèces. Depuis la publication de la Directive de l'Union Européenne (2000) sur la gestion de l'eau, l'amélioration de la qualité des écosystèmes aquatiques est devenu une grande priorité. La modélisation des habitats peut jouer un rôle de premier plan pour la mise en œuvre de cette directive. Nous allons démontrer ici l'applicabilité des méthodes d'évaluation des habitats pour des fins de réhabilitation.

INTRODUCTION

The Netherlands is situated in the delta of the Rhine and Meuse Rivers, an area densely populated and with intensive land use. Since a substantial part of the delta is below sea level, it will not come as a surprise that flood risk management is the main task of the water managers in the Netherlands. Much investment and effort in controlling the water levels in rivers, lakes, canals and wetlands are made. The ecological quality of rivers and lakes is relatively poor due to water quality problems and the regulation of the water levels (Van Dijk and Marteijn, 1993; De Vriend and Iedema, 1995). During the last decades, measures have been taken to improve the ecological quality of rivers and lakes. Due to recent EU regulations and policies, such as the Water Framework Directive, the Habitat Directive, the Bird Directive and Natura2000, the need for ecological rehabilitation of rivers and lakes and the protection and conservation of habitats for endangered species have become an inevitable consequence. As the biodiversity of the Netherlands is mainly related to rivers, lakes and wetlands (Wolff, 1989), ecological rehabilitation of water systems and protection of water systems with good ecological quality will become more and more important.

Habitat modelling plays a very important role in the assessment of ecological rehabilitation measures of rivers and lakes. In this paper, the habitat modelling framework in ecological rehabilitation projects will be presented and the application of this framework will be illustrated by presenting two examples. As the reliability of habitat models is often unknown, uncertainty analysis is presented in this paper as a method to evaluate the applicability of habitat models for ecological rehabilitation studies.

HABITAT MODELLING APPROACH IN THE NETHERLANDS: STATE–OF–THE–ART

Ecosystem Approach

Habitat evaluation methods have become a widely–accepted approach for ecological impact assessment of lake and river management strategies and ecological rehabilitation projects in the Netherlands (Duel *et al.*, 1996, 1999; Semmekrot *et al.*, 1996; Kerle *et al.*, 2002). To determine the ecological impact of rehabilitation measures, an ecosystem approach for habitat evaluation is developed. In this approach, habitat modelling of rivers and lakes is not only focused on the aquatic habitats, but wetland habitats are considered as well, as the adjacent wetlands of rivers and lakes are a part of the riverine and lacustrine ecosystems, respectively. Another feature of this approach is that habitat modelling of rivers and lakes is carried out for a range of target species in water and nature management. The target species encompass rare and endangered species as well as indicator species for the ecological functioning and quality of the riverine or lacustrine ecosystems (Duel *et al.*, 1996, 1999). In the ecosystem approach, an assessment of the impact of rehabilitation measures on the carrying capacity of rivers and lakes for the target species is made. The carrying capacity is expressed in numbers of individuals, biomass or density. Assessing the viability of populations habitat connectivity is a part of the habitat evaluation as well. Other important aspects of the ecosystem approach are (a) the determination of the hydrodynamic and morphodynamic conditions that are essential to support the ecosystem development or ecological objectives, (b) analysis of the seasonal and annual variation in the habitat availability and suitability due to river dynamics, (c) vegetation succession modelling and (d) habitat modelling on species scale and ecosystem scale.

Habitat Modelling Framework

A habitat modelling framework based on the ecosystem approach has been developed over the last decade. Basically, this approach consists of four steps of habitat modelling (Figure 1). The first step is the simulation of the spatial distribution of ecotopes, ecological units of which the development is determined by factors related to hydrodynamics, morphodynamics and ecological succession (Klijn, 1997). For example, differences in stream velocity, water depth and flooding frequency are applied as hydrodynamic criteria for the definition of river ecotopes (Rademakers and Wolfert, 1996; Van der Molen *et al.*, 2000).

The second step is the assessment of the area of 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 habitat suitability based on the habitat requirements and preferences of the species reviewed. Habitat suitability considers both the needs of a species (nutrients, food, shelter, etc.) as well as the threats (e.g. toxic chemicals). Habitat requirements and preferences are derived from life
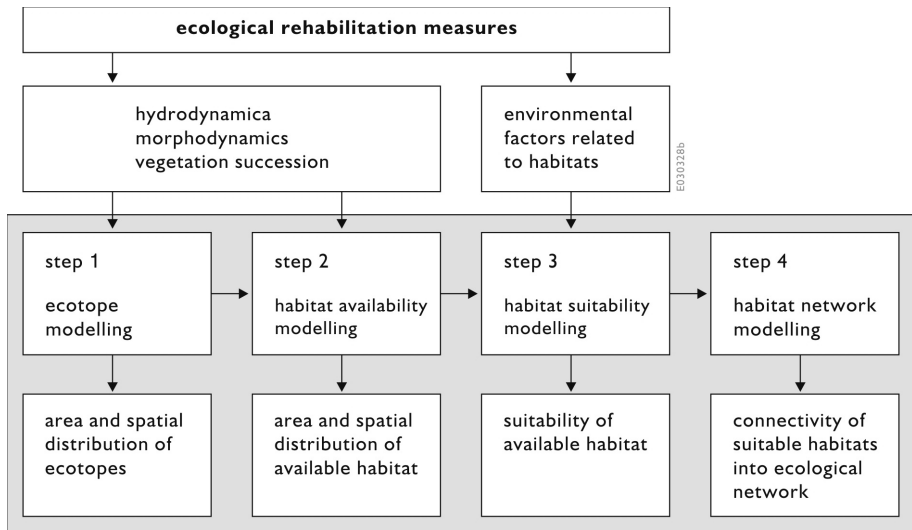
Figure 1. The Habitat Modelling Framework for Ecological Rehabilitation of Rivers and Lakes in the Netherlands.

history studies, field observation studies and statistical analysis of the characteristic environmental factors of the habitats used by species. The habitat suitability models produce numerical ratings, which represent the carrying capacity of the aquatic ecosystems reviewed. The habitat suitability is determined by the environmental factors limiting the carrying capacity (Duel *et al.*, 1995, 2000). Based on the assessment of the carrying capacity, potential population size of the species reviewed may be calculated. At present, habitat models are available for more than 100 target species: macrophytes, macro−invertebrates, fishes, amphibians, reptiles, waterfowl, wetland birds and mammals.

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 imply that species will settle and/or survive there. To support viable populations, it is important that habitats are large enough and sufficiently linked into ecological networks (Reijnen *et al.*, 1995). Key factors for the assessment of the viability of ecological networks for species are the size and configuration of habitat patches and the dispersal distances of species (Verboom *et al.*, 2001; Pouwels *et al.*, 2002).

ECOLOGICAL POTENTIAL FOR THE RIVER RHINE

Problem

The river Rhine is the largest river system in western Europe with a total length of 1,320 km and a catchment area of 185,000 km². The mean discharge to the North Sea is about 2,000 m³/s. Due to river regulations and the utilisation of floodplains

for agriculture and urbanisation in the past centuries, characteristic riverine and floodplain habitats were destroyed or fragmented and the quality of the remaining habitats deteriorated (Van Dijk and Marteijn, 1993). During recent decades, water pollution control and ecological rehabilitation as well as flood risk management of the river and its floodplains have become important issues in river management besides flood risk management. Although the historical situation can serve as a reference, rehabilitation of the river ecosystems does not imply restoring the pristine ecological values which were present in the rather undisturbed river many centuries ago (Milner, 1994; Pedroli and Dijkman, 1998). Societal and economical interests in the river catchment and climate change limit the restoration of the natural hydro– and morphodynamics of the river, and situations similar to those prevalent under almost pristine conditions are not possible or realistic (Duel *et al.*, 2001). Nevertheless, it is clear that the ecological quality of the river Rhine may improve by restoring the river dynamics to a certain extent (Van Dijk and Marteijn, 1993; Duel *et al.*, 1999). This implies that new ecological objectives (the ecological potential) for river rehabilitation must be defined.

Approach

To determine the ecological objectives of the Rhine and Meuse Rivers, an assessment of the ecological potential has been carried out (Postma *et al.*, 1995). Historic maps were used to draw landscape units such as gravel and sandbanks, secondary channels, oxbow lakes, natural levees that are important to determine ecosystem patterns. To combine this with hydro– and morphodynamic criteria for ecotope classification, maps with the distribution of ecotopes were developed. Subsequently, an assessment of the potential carrying capacity for species was made based on the distribution of habitats (Figure 2). It was assumed that the water quality does not limit the habitat suitability in the ecological reference condition. Selected species are indicators for the ecological quality and ecological functioning of the rivers. For example for the river Waal, a branch of the river Rhine, more than 30 species were selected as indicator species.

Finally, the effectiveness of ecological rehabilitation strategies was analysed using river dynamic models, water quality models and habitat suitability index models (Duel and Laane, 1998). The results were compared with the ecological potential.

Results

The current ecological quality of the river Rhine in the Netherlands is very low compared to the ecological potential (Table 1). The ecological quality of the river can be greatly improved by rehabilitation of the river banks and secondary channels and by increasing the river dynamics in the floodplains (Duel and Laane, 1998; Duel *et al.*, 1999). For example, rehabilitation of the river banks provide nesting opportunities for bird species such as Little Ringed Plover (*Charadrius dubius*) and
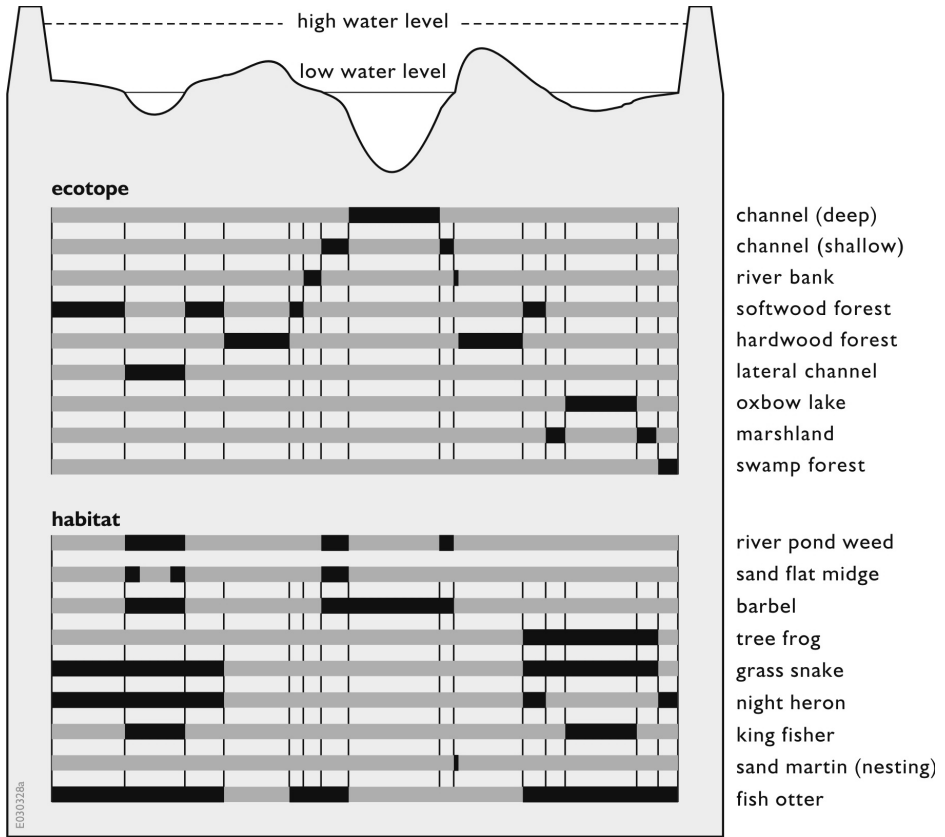
Figure 2. Illustration of the Distribution of Ecotopes and Habitats in a Cross–Section of the River System in the Netherlands.

Sand Martin (*Riparia riparia*). Improvement of the flow conditions in the secondary channels will increase the availability of habitats for rheophyllic macro–invertebrates and fish species which are seriously endangered along the river Rhine, such as may flies, caddish flies, dragonflies, Barbel (*Barbus barbus*), Ide (*Leuciscus idus*) and Dace (*L. cephalus*). Restoring river dynamic processes in floodplains is important for providing spawning and nursery habitat for fish species, such as Yellow Perch (*Perca fluviatilis*). Wetland birds like Night Heron (*Nycticorax nycticorax*) and Spotted Crake (*Porzana porzana*) will benefit from those dynamic conditions as well.

Table 1. The carrying capacity of the river Waal for a range of target species in water and nature management in current situation and after ecological rehabilitation measures compared with the ecological potential.

Species		Current Situation	Rehabilitation Measures	Ecological Potential
Meadow Fleabane *(Inula britannica)*	vegetation cover (ha)	123	244	560
Long Leaf Pondweed *(Potamogeton nodosus)*	vegetation cover (ha)	21	69	210
Bluebell Nursery *(Eryngium campestre)*	vegetation cover (ha)	100	1714	1580
Oak *(Quercus robur)*	vegetation cover (ha)	9	707	730
Dragonfly *Gomphus flavipes*	numbers of individuals (*1000)	1030	1285	2915
Barbel *(Barbus barbus)*	biomass (kg)	81,384	129,080	182,160
Ide *(Leuciscus idus)*	biomass (kg)	14,386	21,532	26,635
Tree frog *(Hyla arborea)*	number of individuals	200	2470	2680
Night heron *(Nycticorax nycticorax)*	breeding pairs	32	39	75
Corncrake *(Crex crex)*	breeding pairs	40	1075	1590
Sand Martin *(Riparia riparia)*	breeding pairs	1370	5349	5500
Reed Bunting *(Emberiza schoeniclus)*	breeding pairs	280	1103	1610

FLOOD RISK MANAGEMENT AND ECOLOGICAL REHABILITATION OF RIVERS

Problem

In the last decades of the 20th century, there have been frequent problems with high river water discharges along the Rhine River. Reinforcement of the existing embankments and levees is no longer an option in the Netherlands, because this would result in a considerable loss of natural values and cultural heritage, and is not a long–term sustainable strategy. The river management authorities emphasized the need for a sustainable water management strategy based on increasing the conveyance capacity on the one hand and improving the quality of the physical environment, river ecosystems and landscape on the other hand (IKSR, 1997; Smits *et al.*, 2000). This resulted in a new flood protection concept "Room for the River" for the Dutch river system: (Smits *et al.*, 2000; Silva *et al.*, 2001; Van Stokkom and Smits, 2002). In this concept of water management, a wide variety of measures are available:

- widening the main channel in combination with a reconstruction of the river banks, including removal of the groynes;
- excavating parts of the floodplain which are rarely or irregularly flooded;
- (re)constructing lateral channels and floodplain lakes;
- removing artificial levees in the floodplains;
- enlarging floodplains by relocating the existing dykes.

Floodplain lowering and reconstruction of lateral channels will result in an important reduction of the water levels at high river discharges (Silva *et al.*, 2001). Moreover, those measures create large areas with opportunities for ecological rehabilitation of floodplains as well, especially for the floodplains that are currently used for agricultural production (Simons *et al.,* 2001; Raat, 2001; Buijse *et al.*, 2002). However, there are still uncertainties regarding the sustainability of floodplain lowering and reconstruction of secondary channels, as the conditions will alter within time due to natural morphological and ecological processes. Due to vegetation succession, the hydraulic roughness of the floodplains will increase over time and as a consequence, the discharge capacity of the river will decrease and the water levels during high discharges will increase. An analysis was carried out of the morphological and ecological development of flood reduction measures in the floodplains (Duel *et al.,* 2001, 2002).

Approach

Ecotope modelling is used in order to assess the effects of changed vegetation structures in the floodplains on the safety requirements against flooding risk (Van der Lee *et al.*, 2001) and on the morphodynamics of lateral channels (Baptist and

Mosselman, 2002). A case–study was carried out for an 80–km stretch of the Waal branch of the river Rhine. Ecotope modelling was used in iteration with a hydrological and a morphological model.

The morphological development and the vegetation succession in the floodplains were analysed for time steps of five years using a morphological and an ecotope model. After that, the expected water levels based on vegetation roughness and elevation maps were calculated. When the maximum water levels were exceeded as a result of increased vegetation roughness and elevation of the floodplains due to sedimentation, measures were implemented to counteract those effects.

Results

The results of the study indicated that nature development in the floodplain area is increasing the vegetation roughness of the floodplain, and thus affects the conveyance capacity. Figure 3 represents the changes in water levels during high river discharges over a period of 50 years and Figure 4 represents the development of floodplain forests in the same area. The two figures illustrate the effects of increasing areas of floodplain forest cover to the risk for flooding. In a few areas, the amount of forest increased to such an extent that measures had to be taken to prevent the risk of flooding (indicated with the square boxes). Different types of measures were defined, such as floodplain lowering, dredging of the silted–up lateral channels and removal of the floodplain forests. The analysis showed that, although nature development is possible along the river Waal, measures must be taken on a large scale to meet the requirements of flood risk management.

As a result of the morphological changes and vegetation succession the habitat availability and suitability for target species of water and nature management may change considerably over the years. An assessment carried out by Baptist *et al.* (2002) showed that the habitat availability and suitability for fish species in lateral channels will change significantly over time, mainly due to morphological changes. At present, a comprehensive analysis of the impact of the flood reduction measures on the availability and suitability of habitats for target species for water and management is carried out.

UNCERTAINTIES IN HABITAT MODELLING

Problem

Although habitat models have been generally accepted to assess the ecological impact of rehabilitation measures of rivers and lakes, the reliability of those models is often unknown. For a general application of habitat models it is essential to assess this reliability. Therefore, sensitivity of the model outcomes for input data and model parameters must be specified, uncertainty in the model prediction must be explored and the domain over which the model is applicable (e.g. temporal and
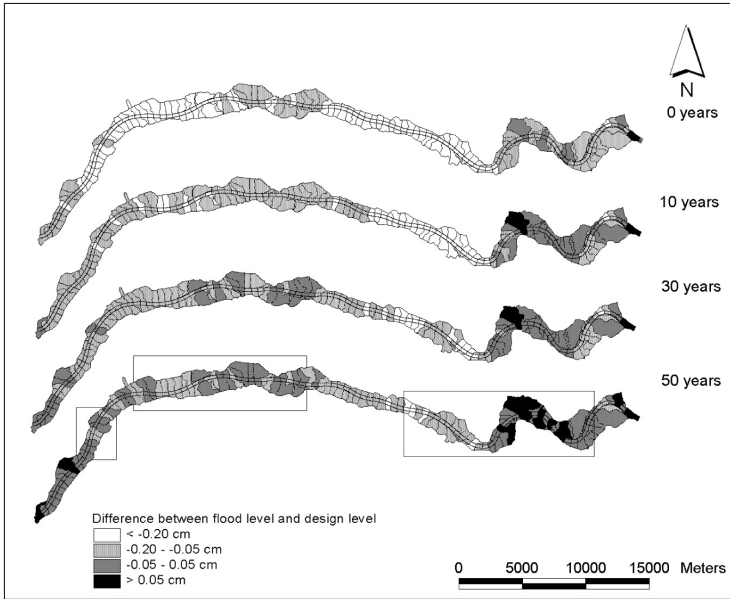
Figure 3. Difference Between Flood Level and Design Level for Floodplain Sections of the Waal River, the Netherlands. The sections indicated with square boxes are areas where floodplain forest had to be removed to remain within the safety standards for flooding.
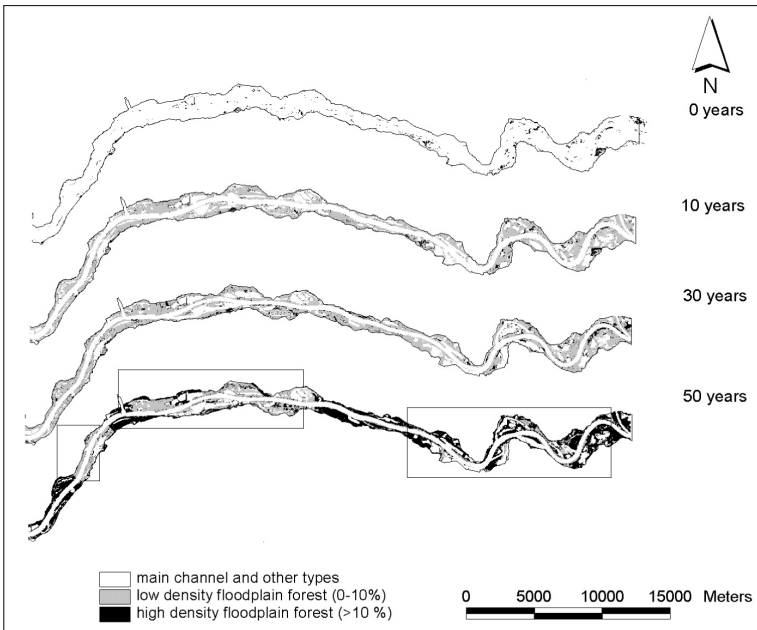

Figure 4. Increase in Floodplain Forests along the River Waal over a Period of 50 Years. The sections indicated with square boxes are areas where floodplain forest had to be removed to remain within the safety standards for flooding.

spatial resolution) must be determined. An analysis was carried out to specifically address the uncertainty in the ecological optimum functions in habitat–suitability models (Van der Lee *et al.*, 2002).

Approach

Sensitivity and uncertainty analyses were carried out for different habitat models in a case study of Lake IJssel in the Netherlands. Lake IJssel is a fresh water lake, 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. With respect to biodiversity, Lake IJssel is an area of international importance. Due to large fish biomass and a high density of fresh water molluscs large numbers of piscivorous and molluscivorous bird species are present in the area, especially during wintertime (Wolff, 1989).

The sensitivity and uncertainty analyses were performed using the following approach. Firstly, a sensitivity analysis was performed with the available field data on habitat factors to identify all potential limiting habitat factors in the study area, such as water quality, water depth, substrate, etc. Secondly, a panel of experts was asked to estimate the uncertainty range of the parameters of the ecological optimum functions used in the various habitat models. In general, the expert panel consisted of three to six experts per species model. Thirdly, uncertainty analyses were carried out using Monte Carlo simulation tests to quantify the uncertainty in predicted habitat suitability. Fourthly, the sensitivity in the sustainability of habitat networks was estimated for the calculated uncertainty in habitat suitability.

Results

Results of the sensitivity analyses show that the habitat suitability is determined mostly by only two to four factors for each species, although models sometimes contain up to ten factors. Which factors are spatially limiting varies according to variations in environmental factors such as water quality, substrate and vegetation types, that occur in the Lake IJssel area. The uncertainty ranges in the parameters of the ecological optimum functions were at a maximum at intermediate values of suitability (0.4–0.6) and were at a minimum at indices approaching either 0 (unsuitable habitat) or 1 (optimal habitat). Moreover, the uncertainty ranges varied per species and between different habitat factors for one species.

The resulting uncertainty in the calculated habitat suitability, determined by the limiting factors, was quantified by the standard deviation. The standard deviation ranges from 0–0.2 and is mostly less than an index value of ±0.1. For example, Figure 5 shows the average habitat suitability and standard deviation in habitat suitability for the Zebra mussel (*Dreissena polymorpha*). Clearly, the average and standard deviation vary spatially due to changing limiting factors (depth, phosphate concentration and substrate).
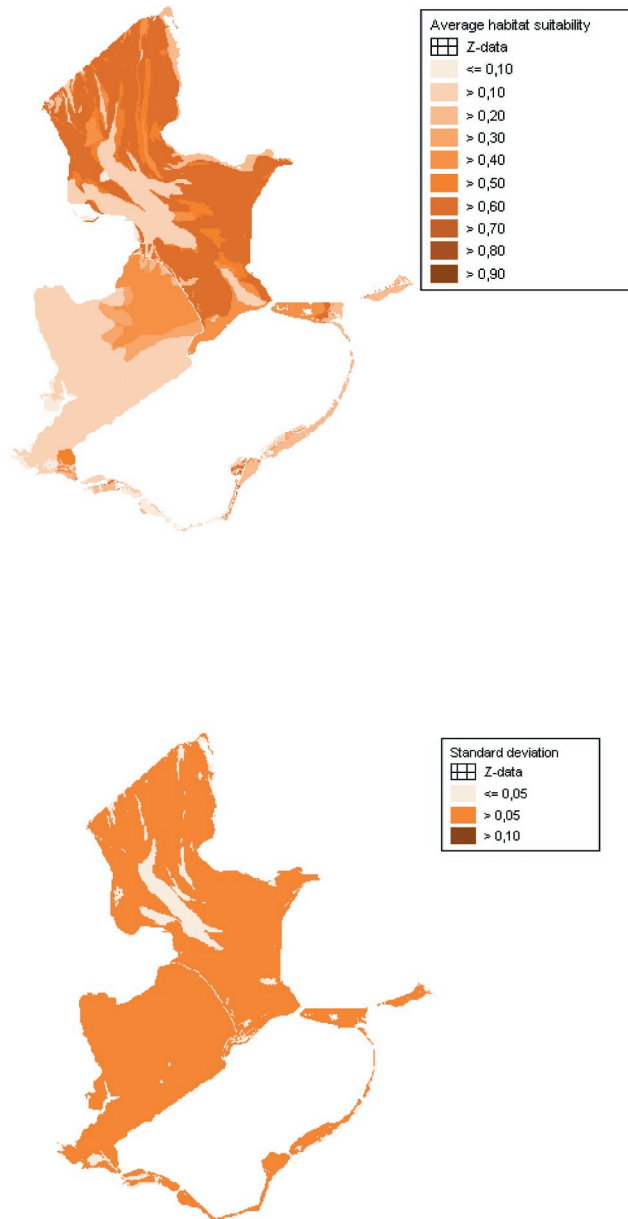
Average habitat suitability

⊞	Z-data
	<= 0,10
	> 0,10
	> 0,20
	> 0,30
	> 0,40
	> 0,50
	> 0,60
	> 0,70
	> 0,80
	> 0,90

Standard deviation

⊞	Z-data
	<= 0,05
	> 0,05
	> 0,10

Figure 5. The Average Habitat Suitability for the Zebra Mussel *(Dreissena Polymorpha)* in Lake IJsselmeer and the Model Uncertainty Expressed as Standard Deviation of the Average Habitat Suitability.

The uncertainty in habitat network sustainability increased proportionately, except when the key population threshold value (minimal population size needed to survive in the long term) was reached. In those cases, the network sustainability was increasingly sensitive to the uncertainties in the habitat suitability.

From the above results it was concluded that in most cases the resulting uncertainty in habitat suitability due to uncertainty in expert knowledge was acceptable for water managers. On the whole, the applied techniques of sensitivity and uncertainty analysis were found to be satisfactory and important to state the credibility of habitat models with.

RESEARCH AND DEVELOPMENT

To anticipate the future role of habitat modelling in river and lake management, existing habitat modelling tools in the Netherlands are currently merged into one generic modelling framework. This framework will be GIS–based and contains ecological databases with habitat requirements or preferences of species that are indicators for the ecological quality of wetlands, lakes, rivers and transitional waters. However, to assist water managers successfully, new developments (knowledge, methods, tools) must be implemented in this modelling framework as soon as possible. At present, research and development in habitat modelling in the Netherlands is focused on the following issues:

(a) habitat modelling on levels of (sub)basin, upscaling and downscaling techniques;
(b) habitat connectivity and configuration;
(c) relationships between morphodynamics and instream habitats for macro–invertebrates and fish species;
(d) interaction between river dynamics and vegetation development and succession in floodplains;
(e) uncertainty analysis methods of habitat models;
(f) validation of habitat models.

CONCLUSIONS

The case studies presented in this paper are an illustration of the importance of habitat modelling in the assessment of ecological rehabilitation projects and water management strategies in the Netherlands. The significance of habitat modelling as a tool for decision support in river and lake management will increase in the near future due to EU regulations and policies on water and nature management. To assess the ecological potential and the effectiveness of rehabilitation measures, habitat evaluation should be based on an ecosystem approach. For that reason, habitat evaluation of rivers and lakes is not focusing only on aquatic habitats, but

adjacent wetlands are considered as a part of the riverine or lacustrine ecosystem as well, and the species selected are indicators for ecosystem quality and functioning. To assess the reliability of habitat models, uncertainty analysis has proven to be a very useful method.

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