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To cite this article: M. Haasnoot & K. E. van de Wolfshaar (2009) Combining a conceptual framework and a spatial analysis tool, HABITAT, to support the implementation of river basin management plans, International Journal of River Basin Management, 7:4, 295-311, DOI: 10.1080/15715124.2009.9635390

To link to this article: http://dx.doi.org/10.1080/15715124.2009.9635390

Published online: 23 Aug 2010.

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Combining a conceptual framework and a spatial analysis tool, HABITAT, to support the implementation of river basin management plans

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ABSTRACT

Since the Ramsar meeting in 1971 many plans and agreements are developed to conserve and improve the quality of wetlands throughout the world. Within the European Union for example legislation has been developed in four Directives which require that water managers test activities on ecological effects. Moreover, in most areas measures have to be taken and included in river basin management plans in order to achieve ecological objectives in terms of occurrence of species and habitats set by EU Directives. To improve quality and conserve areas it is needed to assess the effects of current land use and autonomous developments and to identify the effectiveness of measures. Different studies have already addressed the need for models to quantify these effects. We developed a conceptual framework to analyse the cause-effect chain from management to new environmental conditions and to the potential occurrence and quality of species and habitats using response curves. To our knowledge, this is the first framework presented that has the ecological assessments embedded within the structure, which allows for ecological assessments within the development of management plans rather than at the end of the development. For this purpose a spatial analysis tool is used (HABITAT), which is developed for a broad spectrum of users, from ecologists to managers, and purposes, from ecological assessments to flood risk assessments. The framework is applicable on an (inter) national scale and can promote the dialog between politicians, managers and ecologists. In this paper we demonstrate that the conceptual HABITAT framework for ecological impact assessment is able to support the development and implementation of ecologically sound management plans and illustrate this with a case study for the lake Markermeer in The Netherlands.

Keywords: Ecological impact assessment; habitat suitability analysis; model; GIS; water framework directive; habitats directive; birds directive; flood directive

1 Introduction

Nowadays ecological restoration and rehabilitation of wetlands receive increasing attention. Worldwide action plans were invoked starting with the Ramsar meeting in 1971, the Conference of the Contracting Parties to the Convention on Wetlands, on national and international scale. In Europe this attention is amplified by the enforcement of three major ecologically related European Union Directives [1–3]. Member States have to take the requisite measures to meet the ecological objectives, while taking into account human health, economic, cultural and recreational requirements. Furthermore protection areas were designated for nature conservation because of their uniqueness or importance for species, species groups or habitats on a national or European level. These areas form the Natura 2000 network (which is a coherent European ecological network of species areas of conservation) for which Member States of the European Union have to establish the necessary river basin management plans and conservation measures, and take other appropriate steps to avoid deterioration and disturbance. Any plan or project not related to the river basin management plan, but which is likely to have a significant effect thereon, should be assessed on its implications for the site in view of the site’s conservation objectives. Recently, another water management related EU-directive came into force, namely the Directive on the assessment and management of flood risks, often referred to as simply ‘Flood Directive’ [4]. This directive aims to reduce flood risk, while taking into account the impact on the environment.

1Birds Directive (1979, 79/409/EEC) was set up to conserve the naturally occurring birds in Europe by protecting the birds, nests and preserve, maintain or re-establish a sufficient diversity and area of habitats; Habitat Directive (1992, 92/43/EEC) ensures biodiversity through the conservation of natural habitats and of wild fauna and flora; Water Framework Directive (WFD, 2000, 2000/60/EC) aims at preventing further deterioration, and protecting and enhancing the status of aquatic ecosystems and water related nature.

2Flood Directive (2007/60/EC): aims to map and subsequently reduce flood risk, which is defined as “the combination of the probability of a flood event and of the potential adverse consequences for human health, environment, cultural heritage and economic activity associated with a floods event. Considering the adverse effects on the environment includes potential effects on relevant Natura 2000 sites, the environmental objectives of the Water Framework Directive and nature conservation.

Received on April 29, 2008. Accepted on August 8, 2008.
The development of the necessary river basin management plans requires a strong ecological impact assessment, including a quantification of the impact, to detect the causes of failing and remedies to reach ecological objectives in the current and future situation and to assess whether effects may be significant. Furthermore, assessing ecological status and perspectives calls for an ecology-based approach. Wasson et al. [5] already pointed out the necessity of a shift from classical biogeochemical modelling towards ecological modelling. From a management perspective the cost-effectiveness is also an important factor in the decision making process; hence any approach should be able to provide an analysis on this level as well. These European Directives show the need of a boundary transcending approach on wetland conservation including management issues such as safety and cost-effectiveness, which can be compared with any other boundary exceeding management plan on state, national or international level.

In this paper we introduce a conceptual framework which incorporates a spatial analysis tool called HABITAT and allows for a systematical approach on ecological impact assessments, which are obligatory within the ecological directives set by the European Union and needed for the development of cost-effective management plans for nature rehabilitation. The use of spatial information in habitat suitability models is not new [6], a quick search for literature published on this matter since 1998 results in more that 1400 hits, but the software used is often costly and/or requires advanced programming skills (Arc programs or Matlab for example) or is specially designed for one specific case. This often leads to the situation that the spatial ecological assessment is done at the end of the development of a management plan by specialists, rather than during the development. Would the assessment be done during the development of a management plan, the plan can still be adjusted if the assessment reveals that some measures do or do not work, resulting in a more tailor-made solution for the area of interest. The conceptual framework together with the HABITAT tool provide a transparent and trans-national approach which will aid to understand the pressures-impact relations and support the development of river basin management plans, by systematically analysing:

- cause-effect relations,
- feasibility of ecological objectives,
- effects of measures and autonomous developments,
- cost-effectiveness of measurements and set priorities.

The use of the conceptual framework with HABITAT will be illustrated with a case study concerning a management question of the Dutch government within the setting of EU legislation. The case study is situated in Lake Markermeer, The Netherlands.

2 Conceptual framework for ecological impact assessment

A well known conceptual framework for analysing and managing environmental problems is the DPSIR framework (Driving forces-Presses-State-Impacts-Responses) [7–9]. ‘Driving forces’ are socio-economic and socio-cultural drivers which determine human activities. These drivers enhance or mitigate pressures on the environment. ‘Pressures’ are stress related conditions for the environment caused by humans. ‘State’ is the condition of the environment. ‘Impacts’ are the effects of pressures on the environment. Finally, ‘responses’ refers to the reaction of society on the environment (‘state’). Rekolainen [10] identified some shortcomings on this concept and proposed to change ‘state’ and ‘impact’ into ‘chemical state’ and ‘ecological state’ to make it more appropriate for the implementation of the European Directives (referred to as the DPCER framework). We argue that the ‘ecological state’ should also be determined by aspects related to the water quantity and other characteristics, such as water depth and stream velocity. We therefore define the ‘state’ as the ‘environmental state’, which includes factors such as chemistry, morphology or bathymetry, which affect the ‘ecological state’ (Figure 1). The ‘ecological state’ is also influenced by ‘pressures’, which entail any anthropogenic action with a direct effect. Like the DPSIR and the DPCER we recognize ‘responses’ and ‘driving forces’ that only affect the ‘ecological state’ indirectly through the ‘pressures’ and ‘environmental state’. The framework as a whole consists of a description of human activities, environmental conditions, biological information of the species or community of interest and their preferred conditions and the interactions of these which can be practiced with HABITAT.

Step 1: Explore drivers, pressures, impacts and responses

The first step to implement this framework is to briefly go through all elements mentioned in Figure 1. The ‘driving forces’ have to be acknowledged and their influence on every other element in the framework should be explored (Figure 1). The next step is to determine what measures can be applied to reach the goals set by the ‘driving forces’. Also the ‘pressures’ corresponding with the ‘driving forces’ should be identified. In addition, the ecological objectives need to be determined. This can be done based on expected effects, presence/absence in the area, uniqueness, or on the presence of species on (endangered species) target lists. When considering the ecological objectives, the list of ‘pressures’ needs to be checked whether any pressures related to the objectives have to be added. The ‘pressures’ will result in a definition of the ‘environmental state’ determining which and how environmental characteristics will be influenced by suggested measures and developments. The relationship between species, species groups or habitats set in the ecological objectives with the environment will complete the list of environmental characteristics that need to be taken into account.

Step 2: Develop knowledge rules for habitat models

The second step is the development of rules that link the relevant aspects of an organism’s life to environmental characteristics in knowledge rules, information needed for a habitat suitability model. The rules defining habitat suitability are also known as response curves or cause-effect relations, and describe the
Combining a conceptual framework and a spatial analysis tool, HABITAT, to support the implementation of ecological impact assessment.

**Figure 1** Scheme of the ecological impact assessment framework, darker parts denote the parts where HABITAT is used. Drivers like demography or natural changes, influence the pressures, like water management and land use. This determines the environmental states in terms of water quantity and quality. The ecological state is influence by the pressures directly through for example disturbance by recreation, and indirectly through the environmental state. If the ecological state is not conform the ecological objectives, a human response will be needed.

**Figure 2** Example of a response curve for a macrophyte population and an environmental parameter.

A response of a species to environmental conditions. Besides a particular species also a group of species can be taken into account. This is maybe species with the same feeding habitat, an ecotope (a homogeneous ecological land unit, defined by abiotic (soil, climate, water availability and quality, and others) and biotic factors (vegetation structure)) or a habitat type (a plant and/or animal community used as characterising element of the biotic environment and abiotic factors). With HABITAT also rules on safety and costs can be used in a spatial setting, for example when maintenance costs per area or distance have to be considered.

Besides biotic and abiotic characteristics determining the environment of an individual, also direct effects of pressures by human activities influence the ‘ecological state’, and all can be described in rules. For example, the presence of submerged macrophytes is mainly determined by light availability at the soil surface. The light availability is influenced by algae concentration, suspended sediment, detritus, humus acids and water depth. Recreation can affect sediment resuspension and therefore can have a negative effect on macrophyte presence and abundance. Figure 2 gives an illustration of a knowledge rule for macrophytes that shows an optimum population density for an environmental parameter, such as water depth. Under optimum conditions the plant cover is high and plants are often also larger. Under stress conditions, plants are scarce and smaller.

When all information is gathered the knowledge rules and all corresponding information can be implemented in a tool such as HABITAT, thereby creating a spatial species (or group specific) habitat suitability index (HSI) model. This method has been developed by the US Fish and Wild Life Service in the 1980s [6] and has been used since then to determine the quantity and quality
of habitats for organisms [see for example 11–13]. HSI models calculate the potential occurrence of species often presented as a suitability index, based on the chosen set of environmental conditions limiting the density and fitness of species and a set of functions describing the response of species to these environmental conditions. The habitat suitability index ranges from 0 (low quality) to 1 (high quality). A high habitat suitability index value means that there is a higher chance of the occurrence of a species than with a low habitat suitability index value.

**Step 3: Verification**

The outcome of the developed knowledge rules can be evaluated with statistical methods, aiding the judgement of the results and consequently the management decisions on feasibility and costs. A verification is the assessment and quantification of the relationship between a matched set of forecasts and observations. HSI models are in general judged by the accuracy indicated by various measures like the number of correct answers, which can be either correct presence or correct absence forecasts, and the number of prediction errors. In some cases it may be an indication that an environmental factor is not included in the knowledge rules, for example when the model results indicate a high suitability but the species of interest is absent. An other explanation could be that ecological processes such as areas that are difficult to reach, hampering migration, species interactions or by different environmental conditions in the past [14].

To determine the accuracy the Signal Detection Theory, derived from medical science, is used [14–18]. This theory uses a presence/absence table which presents the number of correctly predicted positive cases (when both model and measurements indicate presence), the number of correctly predicted negative cases (when both model and measurements indicate absence), the number of falsely predicted presence (the model predicts presence but the species is actually absent, this is also known as false positive) and the incorrectly predicted absences (the model predicts absence but the species is actually present, this is also known as false negative). A commonly used measure is the Correct Classification Rate (CCR) indicating the percent of correct forecasts [14]. A disadvantage of this method that a species with a low occurrence may still have a high percentage of correct classified answers by forecasting the absence of the species.

As the habitat models result in a continuous variable a HSI threshold value is needed to classify the model results concerning the presence or absence of species. A method which measures the accuracy independent of the chosen threshold for the HSI is the relative operating characteristic plot, also known as the ROC curve [15]. This curve plots the ‘hit rate’ against the ‘false alarm rate’ for different thresholds (demonstrated in Figure 3). The hit rate is the number of correct presences divided by the total number of presences, while the false alarm rate is calculated through the number of falsely predicted presences divided by the total number of absences. It is of course most desirable that the hit rate is high and the false alarm rate is low, which means that the closer the curve is to the upper left hand corner, the better the prediction (Figure 3). The area under the ROC curve (AUC) is a measure for the overall accuracy [16]. When the false alarm rate equals or exceeds the hit rate (for AUC smaller or equal to 0.5) the prediction is useless, while the best prediction is given for AUC = 1 [19]. Additionally, a sensitivity analysis of the input data and the knowledge rules can aid in understanding the variance and response of the model to environmental conditions [20].

**Step 4: Ecological impact assessment**

After a satisfying verification of the knowledge rules, the effects of management scenarios or external developments can be studied by analysing these different scenarios with HABITAT. The important environmental conditions for the current situation, which were recognized in step one and two have to be quantified. Ideally this quantification can be derived from monitoring and/or modelling data. Model simulations can give spatially and temporarily detailed information on environmental conditions resulting from the river basin management plans or external factors changing the environment, such as climate change. In some cases HABITAT can be used for this purpose, which will be illustrated in the case described later on, but in other cases, like for hydraulic or 3-dimensional issues, it is better to use more sophisticated hydrological and/or chemical models. Otherwise, literature research might provide the necessary information. With the quantified environmental conditions the ecological impact (in terms of habitat suitability for the specific ecological objectives) can be assessed.

![Figure 3 Accuracy of the HSI models indicated with ROC plots. The area under the ROC curve is: 0.87 for macrophyte and benthos eating birds, 0.74 for zebra mussels (new), 0.71 for zebra mussels (old), 0.92 for the Chara (Habitat type 3140), and 0.82 for macrophytes. For the presence of Chara a threshold of 1% coverage was chosen in order to make the presence/absence table, meaning that if the observation show a coverage of < 1% it is classified as ‘absence’ and if the observation indication a coverage of 1 or higher it is classified as ‘presence’. For zebra mussels a biovolume of 10 ml/m² was chosen and for macrophytes a coverage of 5 %. The thin line in the diagonal denotes y = x.](image-url)
2.1 Framework use

Once the framework is set up, it can be used to study different management questions by taking different routes or parts of the framework (Figure 1). It is possible to set ecological objectives and locate suitable areas by applying the response curves for a particular study area on the available environmental conditions and human conditions, and assess the suitability for the species or habitat types. Once this appears not sufficient it is possible to identify causes of failure by searching for the limiting environmental factor(s) which decrease the ecological quality. This aids the process of formulating adequate rehabilitation measures. The effectiveness of these measures can be analysed with the response curves by a direct change of the habitat variable (environmental factor or human activity) or indirect through results of e.g. hydrological or water quality models. The maximum feasible objective through all possible measures, useful for heavily modified modified water bodies indicated for the WFD, can be determined by implementing them all in the framework and assessing the effect on the ecological status. Examples of the use of the HABITAT framework are the assessment of the effects of a different water level management on ecology (this article), the effects of climate change on riverine ecotopes [21], and the assessment of possibility to combine flood detention with nature development [22].

2.2 HABITAT

HABITAT is a tool to support the development of river basin management plans. It is especially designed for ecological assessments to analyse the availability and quality of habitats for individual or groups of species. Its applicability is not restricted to ecological purposes, it can be used for any spatial analyses where grid operations are needed such as flood risk maps or damages to agriculture or urban areas in case of floods and droughts. The tool has been built around PCRaster, a software package for map-calculations [23], and is developed by WL | Delft Hydraulics and Ministry of Transport, Public works and Water management, The Netherlands. The main characteristic of HABITAT is that it provides a platform for grid operations without highly advanced programming skills from the user via the user interface (Figure 2), which makes it usable for a broad audience. The top graph of Figure 4 shows an example of the user interface on which a knowledge rule can be entered, which will be presented as a table and as a graph. The bottom graph shows a model result for the habitat suitability of zebra mussels based on silt content. The spatial representation allows for a quick recognition of suitable areas. HABITAT helps the user to systematically follow cause-effect chains and simulate each step in knowledge rules, which may be based on monitoring results and/or expert knowledge. By making the knowledge explicit the impact assessment method becomes transparent and re-usable. Combined relations and effects can be analysed by using knowledge rules for different environmental factors and measures. Basic statistical functions can be used to summarise the results. The systematic approach allows for an easy comparison of different strategies and a better understanding the ecosystem and its relevant steering variables. The tool applies knowledge rules to maps (grid cells) (Figure 2, bottom graph), using data in different data layers and/or a number of adjoining cells. As the analysis is performed on maps, the heterogeneity of areas and consequently the diversity of the environment can be taken into account.

Within HABITAT knowledge rules developed for specific studies can be stored in a knowledge database, re-used and adapted for other studies possibly in other areas. In The Netherlands already a start was made to set up such a database with knowledge rules and documentation for all species and species groups defined in the European Directives that occur in The Netherlands. The Canadian National Wetlands Research Center has adopted the same approach providing a literature database on habitat suitability studies concerning species of their interest. A database could easily be expanded with knowledge rules for other purposes such as costs and risk assessments. Delft Hydraulics has adopted the principle ‘Dare to Share’ [24] in order to enhance knowledge exchange through a wiki page and thereby improve the quality of studies done with HABITAT. HABITAT is freely available for users which are willing to share their developed knowledge rules as part of the ‘Dare to Share’ principle. The use of a common framework, knowledge base and tool can promote the sharing of knowledge and experiences on a level that transcends country boundaries and disciplines.

3 Case study of Lake Markermeer, The Netherlands

Step 1: Explore drivers, pressures, impacts and response

The central question in this study was: “To what degree can seasonality in the water level increase the value of nature in order to meet or approach the ecological objectives according to the European Directives, taking into account the prerequisites that both safety, shipping and water supply in the area can be guaranteed?”. The Lake IJsselmeer area (previously called Zuiderzee before building the Afsluitdijk) exists of three water management units: Lake IJsselmeer, Lake Markermeer and the Veluwe lakes. The main water fluxes into the area are the inflow of the river IJssel and the outflow through gravity at low tide through sluices in the Afsluitdijk to the Wadden sea. The current water levels of these water management units are unnatural and are aimed at a higher water level in the summer than in the winter period. A more naturally fluctuating water level would be in correspondence with the variability in discharge of the river IJssel and the precipitation surplus, resulting in a higher water level in winter than in summer (Figure 5, ‘environmental state’). Without a large investment in embankments a real natural water level fluctuation is not feasible. For that reason the government is investigating the concept of a seasonal water level fluctuation to enhance the ‘ecological state’, which is based on the principle that during the most crucial

3 http://habitat.deltares.nl
Figure 4  Top graph: screenshot of HABITAT and the knowledge rule of zebra mussel and silt content as an example of a rule defined in classes. The values in the classification table are immediately visualized in a graph on the right of the table. On the left the tree-like structure of the case is visible, with name of the study as highest level (Natura2000 Markermeer), followed by the scenario (Current Water Level), the environmental state definition (water levels, water quality parameters and wind fetch (‘expositie’)), the species of interest (macrophytes, zebra mussel, birds, fish) and the knowledge rules at the lowest level (Natura2000 Markermeer – Current water level – zebra mussel – silt content). Besides the presented knowledge rule type, it is also possible to enter extensive formulas with several maps as input and output, broken linear functions, and a classification table with multiple maps as input. Bottom graph: similar to top but now with the resulting suitability map for zebra mussels and concerning silt content for Lake Markermeer.
Combining a conceptual framework and a spatial analysis tool, HABITAT, to support the implementation

Driving forces

- wish society for more natural conditions, WFD, HD, BD

Responses

- additional measures needed

Pressures

- safety, shipping, water management

Environmental state

- waterlevel, depth, light, fetch, soil type

Ecological state

- macrophytes, fish and bird species

Figure 5  Similar to Figure 1, but now the assessment framework is specified for the Lake Markermeer case study. The European Directives urged the Dutch government to increase the ecological state (driving force) through a new water management (pressure). The proposed water level dynamics changes the environmental state in terms of water depth, wind fetch and the amount of light which can reach the lake bottom. If the identified ecological state after the proposed measure does not meet the ecological objective additional measures are needed.

periods for ecology (the growing season) the water level follows a more natural situation and that during winter safety has priority in determining the water level. Taking into account the ecological objectives and ensuring safety in the area (Figure 5, ‘pressures’) a more natural water level should follow the following regime: a low water level in winter to be able to cope with events as storms and high river discharges, a high water level in early spring and a low water level at the end of the summer. In this case study only the Lake Markermeer is presented as an example, the analysis for the other parts of the Lake IJsselmeer area was done similarly. Lake Markermeer covers 750 km$^2$ which is around 37% of the total IJsselmeer area (2025 km$^2$).

Based on the ecological objectives for the European Directives an ecological assessment for the Lake IJsselmeer area was done for 5 water level scenarios [25], of which three will be presented here. Figure 6 shows the current water level throughout a year in Lake Markermeer and two potential water levels that are evaluated in this study. In the current situation Lake Markermeer shows little seasonal variation in water level. Especially a rise in spring due to a naturally occurring flow of rain and melting water lacks in this situation which is one feature that the Dutch government wants to change in a future scenario. Scenario 1 denotes the maximum allowable change in water level with regard to safety and shipping. Additional to the spring rise in water level in this scenario the winter level is kept high to allow boats to pass the lake. Scenario 2 is added to the study to get a better understanding of the effect of changing water levels. Compared to scenario 1 it allows for a more moderate decrease in water level during summer and a lower water level in winter (Figure 6).

Figure 6  Current water level (averaged over 20 years) and water level scenarios for Lake Markermeer given in meters difference relative to Dutch Standard level (NAP).
HABITAT was used to quantify the water level fluctuations in different periods during a year, and the effect thereof on macrophytes, fish species, birds, bivalves and different habitat types. The whole process-effect chain followed in the study is given in Figure 7. First the water depth and flood duration are calculated using the water level dynamics induced by the proposed water management measure. These influence habitats for vegetation types, macrophytes, bird, fish and zebra mussels. Vegetation management, like mowing, has an effect on the vegetation types as well. Wind may cause disturbance and turbidity resulting in a lower habitat suitability for macrophytes. Fish use the macrophytes to find shelter and as feeding place. Zebra mussels grow in shallow to intermediate deep areas with a relatively hard soil to grow on, and serve as food for birds. Mussels in shallow water are easier to reach then mussels in deeper water.

In order to determine the habitat suitability for the tufted duck an analysis for zebra mussels was done first since they are the primary food source for these ducks (Figure 7). For the response curves for zebra mussels salinity, sediment type, silt content and summer water temperature are used [27-29]. For the tufted duck a suitability equal to or larger than 0.7 for the zebra mussels was defined as suitable, based on expert judgement. Also water depth was taken into account for determining the suitability [25].

For the spined loach water depth, salinity and macrophyte presence are important habitat characteristics [30-32]. For this species a distinction was made between egg-larval stage and juvenile-adult stage because the environmental requirements of these stages differ. For the juvenile-adult stage water depths between 0.1 and 1.5 m are considered suitable, while the eggs and larvae are present at more shallow parts [30-32]. The spined loach occurs in fresh and more brackish waters with a salinity of 0.01 to 2.7 gCl/L [30-32]. This parameter was not taken into account in this study as it is not relevant in this freshwater lake.
extinction, soil and substrate type and orthophosphate). The water depth originated from a digital bathymetry map and the wind fetch was calculated (see appendix A), whereas the input for the other parameters was derived from time series of observed water quality parameters. In order to carry out a quantitative analysis of the accuracy of the habitat models, a verification conform the Signal Detection Theory was carried out with the statistical program R [33]. The data used for the verification was derived from several monitoring programs (Figure 8, left pictures). The macrophytes monitoring was done only in the western part of the lake since they are virtually absent in the rest of the area (personal communication M. Platteeuw). The zebra mussels were monitored throughout the lake following a grid which is presented with the dots in Figure 8. The bird inventory was conducted from an airplane along the shore of the lake as the birds aggregated there. The AUC’s for the different HSI models range from 0.71 to 0.92 and direct to the upper left corner indicating that the models are able to discriminate between the presence and absence of species and that the hit rate is larger than the false alarm rate (Figure 3). The amount of correct forecasts (CCR) was 86% for the macrophytes model (thresholds 0.6 for the HSI and 1% for the observed coverage), meaning that in 86% of the cases the model resulted in the correct answer. For Habitat type 3140 (Chara) the CCR is 88% at thresholds 0.6 and 1% for respectively HSI and observed plant cover. A visual inspection of the zebra mussel model result and the field data reveal a mismatch especially in the eastern part of the area (Figure 8). The occurrence of old sea shells in the soil which they use to grow on was missed as parameter. With this improvement the AUC increased from 0.71 to 0.74 and the CCR from 57% to 72%. The models for birds were mainly qualitatively compared with monitoring results as each monitoring location was representative for a large area and because the birds not always using the area for feeding but also for resting. Also, the studied birds are not strictly feeding on macrophytes or benthos. The tufted duck for example feeds mainly on macrophytes and benthos. The effects of a different water level regime depend on the change in water level in both time and space, and on the morphology of the area. With a raising relative water level the surface area of shallow wet regions decreases (‘environmental state’, Figure 5). This is due to the bathymetry of the lake, which has very steep slopes that are not over flown by small changes in water level. For the effects on the presented ecological parameters the mean and minimum water levels in the period from March to September are used. For the current situation these levels are respectively −0.2 and −0.22 m below the Dutch standard level. For scenario 1 the mean summer water level decreases with −0.6 m to −0.26 m and the minimum water level is this period is −0.3 m. For scenario 2 the average water level is the same as in the current situation and the minimum water level is −0.3 m.

**Step 4b: Ecological impact assessment: quantifying ecological state**

In Table 1 the relative differences between the scenarios 1 and 2 and the current situation are shown (scenario 3 will be explained later). The surface of suitable area is calculated for each species and each scenario. An area is defined as suitable if the HSI is larger then 0.7. The differences between the scenarios and the current situation are expressed as percentage change and can be compared with the amount of hectares in the current situation (Table 1 and Figure 8). For submerged macrophytes scenario 1 has a positive effect on the suitability of the area (4.9% increase). This is because the decrease in water level results in an increase of areas with a water depth between 1 to 3.5 m which are not too shallow and not too deep resulting in enough light for plants to grow, especially in the south-west part of the lake (Figure 8, top row). Scenario 1 results in an increase of 8.3 % of suitable habitat for Chara species. For the common pochard scenario 1 has a positive effect on the available habitat at a water depth between 0.2 and 1 meter (18.5 % increase) mainly in the southern part of the area (Figure 8), while for depths between 0 and 0.2 meter no effect occurs (Table 1). A small negative effect is observed for the suitability for zebra mussels (0.9% decrease). Due to the lower average summer water level the area with preferred water depth values decreases somewhat. For the tufted duck the total suitable area decreases with 151 ha, but in the remaining habitat the benthos are in shallower areas, which makes it easier for the duck to reach it’s food (increase of 8% of areas with a depth of 1 to 3 m). For spined loach the most increase in suitable habitat is found for the egg and larval stage (25.5%). The area suitable for the juvenile and adult stage also increases but to a lesser extend (9.2%) (Table 1).

Scenario 2 has no effect on the suitability for all ecological objectives (Table 1), as a result of an identical average summer water level, and too little difference in minimum water level for a significant effect. A larger change of water levels is not possible because of the boundary conditions given by safety reasons and shipping (‘pressures’, Figure 7).

**Step 5: Evaluation and statistics**

The overall result is that scenario 2 has hardly any effect on the ecological parameters studied and that scenario 1 results in more suitable habitat compared to the current situation. However, the relative increase is not high with an average increase of 6% (but note the exception of a 25.5% increase for spined loach egg and larval stage (Table 1)). Given the expected cost of the measures the ecological profit is not high enough, hence additional measures are considered to improve the ecological benefit, which was one of the ‘driving forces’. This means that the steps...
Figure 8  Field data, model results for the current situation and changes in habitat suitability for scenarios 1 and 3. For the zebra mussels the results of both the non- and the adapted model are given, while the results for scenario 2 are left out as they do not differ much from the current situation. For spined loach no field data are available.
in the framework presented in Figure 5 are repeated. The steep slope of the lake is the reason for the little increase in suitable area with increasing water levels in summer. Especially shallow parts provide suitable habitat for a large number of species, hence most improvement is expected when manipulating this parameter.

Step 6: Additional measures
To increase the amount of shallow parts, an artificial island can be made that can have the same effect as more gentle slopes, along with under water dams to reduce effects of wind. Since scenario 2 had little or no effect, the additional island will be combined with scenario 1, which is within bounds of safety and shipping, to a third scenario.

Step 7: Quantifying environmental change due to action
The artificial island will affect the water depth and the wind fetch locally ('environmental state', Figure 5). Any effect of the island on increased water turbidity due to a smaller wind fetch is not taken into account here. This will underestimation the positive effects on the habitat suitability, which should be taken into account when evaluating the results.
The combination of the seasonal water level fluctuations with the sheltered areas behind the dams. With respect to pochard, the availability of suitable habitat nearly triples compared to the effect of scenario 1, which is due to the increase in the area with macrophytes (Figure 8). Especially for depths between 0.2 to 0.5 meters the increase is high, 30% compared to the current situation, while for water depths between 0.5 and 1.0 meter the increase is 24% (Table 1). For the zebra mussel and the tufted duck, the addition of an island has little effect as they prefer deeper waters.

### Step 9: Evaluation

The combination of the seasonal water level fluctuations with spatial planning measures, such as the development of shallow parts, wetlands and islands, *i.e.* changing the ‘environmental state’ improved the ‘ecological state’ of Lake Markermeer in this habitat suitability analysis. Without the island, or other measures to increase more shallow parts and shore line, the goals set by the government and the ‘driving forces’ will not be reached. Additionally, this measure does not conflict with the boundaries set by safety and shipping (‘pressures’).

### 4 Conclusions and discussion

Several frameworks have been proposed [5, 10] to aid the process of developing and managing measures to improve or protect ecology. Wasson et al. [5] pointed out the current shift from modelling as to extend knowledge to modelling as to integrate biotic and abiotic elements and human and social elements. The conceptual framework presented here, the HABITAT-framework, illustrates this shift and the advantage of a combined approach where a spatial analysis tool is embedded within the theoretical framework. Furthermore, we have extended the cause-effect relationships mentioned in the framework of Rekolainen et al. [10] with the environmental state, including the water quality (chemical state) and water quantity and its effects on the ecological state. With this framework and the HABITAT tool we attempt to promote the dialog between managers and policymakers on the one hand and ecologists and naturalists on the other.

The HABITAT Framework provides water managers a step-wise approach for ecological impact assessments, which are at least needed for ecologically related European Directives and useful for any other management plan with the same intent. By going through the framework the relation between human intervention, land, water and ecosystem are analysed systematically, which helps to understand the working of the system and above all to identify steering variables. Moreover, the sensitivity of the ecological objectives for these steering variables can be analysed in order to get an idea of possible measures for river basin management plans. The analysis of the process-effect chain from human intervention to environmental state and finally to the ecological state with a computer tool instead of invoking only expert judgement, makes it easier to analyse combined relations, compare strategies and quantify results. The use of a spatial analysis tool appeared to be essential in the case of the study on the Lake Markermeer. It showed the small ecological impact of the seasonal water levels in an area with low spatial diversity in the morphology of the water body. Without a spatial analysis tool the heterogeneity of the area and the diversity of the environment cannot be taken into account, while this is very important for analysing the ecological state.

Despite the availability of several habitat computer tools, we chose to use HABITAT as it easy to implement and adjust knowledge rules to make them case-specific. Furthermore, HABITAT shows the knowledge rules through the interface, which makes it transparent.

Both the conceptual framework and the HABITAT tool support water managers (1) to assess ecological impacts, (2) understand cause-effect relations, (3) identify relevant steering variables, (4) quantify effectiveness of measures (5) analyse

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**Table 1: Effects of the different scenarios relative to the current situation for macrophytes, common pochard, tufted duck, and spined loach in Lake Markermeer given as percentage change in surface area.** Negative effects are shown in italics.

<table>
<thead>
<tr>
<th>Habitat Type</th>
<th>Current Situation</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
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</tr>
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<td>1–2 m</td>
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<tr>
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<td>−1.0</td>
</tr>
<tr>
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<td>8.0</td>
<td>0.0</td>
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<td></td>
<td>1–3 m with</td>
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feasibility of ecological objectives in order to meet (inter)national obligations, such as set in the European Directives.

By using response curves based on the biology of species, species groups or habitat types and their requirements more realism is added to the evaluation process. It allows for a better unravelling of what could be the factors limiting ecological parameters. The fact that the relationships are based on the biology of species is at the same time a potential pitfall because they should be used with some notion of what is biologically realistic. For example, adaptation of rules that were developed in a certain situation cannot be implemented without a good look on the ‘environmental state’ and how the ecology of the species or groups functions in a different location. Most species are present throughout a wide geographical range and will have local adaptations, which have to be considered. One also has to take into account that the accuracy of the model outcome, the predictive maps, depends on the quality of the input data, being the response curves on one side and the input maps with environmental parameters on the other [20]. van de Lee et al. [20] found that the uncertainty in model results is largest for intermediate suitability values. Knowing this helps to interpret habitat model results. Model results can differ from the actual occurrence when for example not all important environmental conditions or seasonal changes are recognized. Of course the actual occurrence can depend on historical events [14], unforeseen (human) activity or conditions in areas neighboring the area of interest which were not considered. At this point a reevaluation of the environmental parameters taken into account may be helpful to identify any missing parameters. HSI models are often static prediction models, i.e. they rarely include temporal phenomena, such as resilience, adaptation and population dynamics [14]. However, dynamics can be included by analysing different time-steps with adapted knowledge rules. In principle, habitat suitability models predict a potential ‘end-result’ under a given scenario of environmental factors, but do not provide information on the time period that it will take for a species to have reached such a state. It is not guaranteed that the species or groups will actually respond in the manner expected from the model results. For example, a species may not return to a site after measures simply because it cannot reach the area. Still, one can use the results to understand the system and explain to managers and politicians whether they have explored all possibilities to achieve the ecological objectives; if the areas are expected to be suitable than failing of the objectives could be out of their hands. Of course, monitoring of the ecological states will always be necessary, as models can only be used to support the implementation of management plan. In addition, monitoring is also essential for the quality of the input data and the verification of the results.

One of the advantages of the HABITAT-framework and the incorporation of biology-based response curves is that it is not limited to country boundaries. Donald et al. [34] show that the international approach has been successful for the bird species targeted for in the European Birds Directive: “…The data are therefore consistent with the hypothesis that the Birds Directive has brought demonstrable benefits to birds populations in the EU and that international policy intervention can be effective in addressing conservation issues over large geographical areas…” Using a spatial analysis tool can aid the international approach further by following natural boundaries or areas between countries. It also supports the assessment of spatial coherence of within and between nature areas, for example for an assessment of the strength of the Natura2000 network. At this moment the legislation is transcending boundaries, but there is much to gain when measures to improve the ‘ecological state’ also transcend the barriers between countries, governments and policymakers. Sharing the knowledge gained by individual ecological impact assessments on a international scale and constantly expanding the knowledge base will increase knowledge on the relation of water and ecology and aid the conservation and restoration of valuable areas and helps to identify possible knowledge gaps. Review of knowledge rules and references to peer reviewed papers can indicate the quality of the rules. Together, HABITAT and a shared knowledge database can provide consistency within approaches and a potential reduction of overlooking important ecological and environmental characteristics that determine the presence or absence of species.

Acknowledgments

The authors are grateful to RIZA and WL | Delft Hydraulics who financed the studies used as case in this paper. The authors like to thank Maarten Plateeuw, Jan Kranenburg and Rolf van Buren for their contribution to the case study. Furthermore, we thank Erik de Rooij, Onno van Loghem and Gennadi Donchys for their cooperation on the development of the HABITAT tool.

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5. WASSON, J., TUSSAUX-VUILLEMIN, M., ANDRÉASSIAN, V., PERRIN, C., FAURE, J., BARRETTEAU, O., BOUSQUET M.,
Combining a conceptual framework and a spatial analysis tool, HABITAT, to support the implementation


Appendix A

The knowledge rules for the ecological parameters used in the example of Lake Markermeer.

Macrophytes

For macrophytes average summer water depth (Wa), wind fetch (Fe) and light extinction (LE) are taken into account. The relationship between the suitability $P_m$ and these parameters is given by the following equation:

$$
P_m = \exp(4.47 - 0.018 \times Wa - 1.1 \times LE + 0.005 \times Wa \times LE + 0.000051 \times Wa \times FE + 0.0003 \times LE \times FE - 0.0000047 \times Wa \times LE \times FE).
$$

The probability of occurrence of macrophytes is then:

$$
P = \frac{P_m}{1 + P_m} \text{[26].}
$$

The results are only valid between a water depth of 0.2 and 3.5 m and in areas which remain under water during the whole summer.

The light extinction was calculated using the following equation [35]:

$$
LE = 0.81 + 0.016 \text{chlorophyll-a} + 0.46/\text{Secchi depth}
$$

where chlorophyll-a and Secchi depth were calculated from monitoring results.

The wind fetch was calculated as a weighted average of the fetch of eight directions and their relative occurrence, based on meteorology measurements [36]:

$$
\text{Wind Fetch} = \text{fetch_north} \times 0.1475 + \text{fetch_northeast} \times 0.2275 + \text{fetch_east} \times 0.1775 + \text{fetch_southeast} \times 0.1075 + \text{fetch_south} \times 0.0875 + \text{fetch_southwest} \times 0.0875 + \text{fetch_west} \times 0.0975 + \text{fetch_northwest} \times 0.0675
$$

Figure 1 Response curve for light availability at the bottom and water depth and 3140 [26].

Pochard

Figure 2 Response curve for macrophytes suitability (left) and depth (right) and the suitability for pochard [25].
Figure 3  Response curve for water depth, soil type, silt content, orthophosphate concentration and shell cover of the bottom surface and the suitability for the zebra mussel [27–29].

Figure 4  Response curve for zebra mussel suitability and depth and the suitability for the tufted duck [25].
Combining a conceptual framework and a spatial analysis tool, HABITAT, to support the implementation

Figure 5  Response curve for water depth and the suitability for spined loach eggs and larvae (solid line) and juveniles and adults (dashed line), for substrate types (1: sand; 2: loam, clay, or silt; 3: fine sand; 4: coarse sand; 5: pebbles and other) and macrophyte suitability (egg and larval stage) [30–32].