Development of a monitoring network to model the habitat suitability of macroinvertebrates in the Zwalm river basin (Flanders, Belgium)

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Abstract: Research indicated that habitat suitability models are efficient tools to predict macroinvertebrate taxa based on the physical-chemical and structural characteristics of a river basin. Although these habitat suitability models allow to make reliable predictions, adaptations are necessary to make practical simulations for river restoration management. In particular, spatial-temporal relations have to be included to simulate migration dynamics of the organisms in water, on land and in the air. Thus, not only models to predict the species habitat suitability are required, but also GIS systems are necessary to simulate the migration behavior of the macroinvertebrate taxa. This type of model development requires a different and more intensive monitoring approach compared to the traditional monitoring schemes that are set up to evaluate ecological river quality. Therefore, a part of the Zwalm river basin was selected that covered a total distance of about 12 km (Zwalm river and its tributaries) and a new monitoring network was set up according to the data and information requirements to develop a migration model. In this article, the set-up of this monitoring network will be discussed and evaluated based on the required simulations of the model to support decision making in river restoration management.

Keywords: *monitoring; modeling; habitat suitability; migration*

1. INTRODUCTION

Increased human activities and an intensive use of freshwater resources have resulted in concerns about the ecological quality of catchments and watercourses in Flanders. Watercourses with natural stream characteristics and vulnerable species are rare and quite often isolated headwaters (Schneiders et al., 1999). River engineering has disrupted ecological integrity with regard to the longitudinal continuity and the lateral interactions with the bordering riparian zones. To restore the variety of aquatic systems with their characteristic biotic communities, site-specific restoration and conservation programmes are required. But providing a suitable habitat for more vulnerable species does not guarantee that these species will quickly colonize these mitigated sites. This requires that these species can freely migrate between sites and that there is a incentive for specific species to inhabit the mitigated site. Therefore, restoration of migration routes that interconnect valuable fragments is as important as the development of new habitats. These programmes will eventually enlarge the possibility for settlement and survival of endangered species in the long term. Although best management practices provide a set of options, it is still difficult to judge the impact and effectiveness of a specific river management option (Pullar and Springer, 2000). A Decision Support System (DSS) is therefore being developed to compare several river management scenarios based on coupled habitat suitability and migration models.

2. THE ZWALM RIVER BASIN

The Zwalm river basin which is part of the hydrographical basin of the Upper-Scheldt (Carchon and De Pauw, 1997). It drains an area of about 11,650 ha and its total length is 22 km. Although Flanders is a rather flat region, the Zwalm river basin is characterized by a number of differences in altitude, making it quite a unique ecosystem within the Flemish region (Soresma, 2000). Since 1999, the water quality in the Zwalm river basin has considerably improved due to investments in sewerage and wastewater treatment plants during the preceding years (VMM, 2000). Nevertheless, some parts of the river are still polluted by untreated urban wastewater and by diffuse pollution originating from agricultural activities (Goethals and De Pauw, 2001). Besides, still numerous structural and morphological disturbances exist (e.g. weirs for water quantity control, artificial embankments, ...) (Carchon and De Pauw, 1997). An overview of main factors that determine the spatial and temporal diversity in the Zwalm river basin is given in Table 1 (Goethals and De Pauw, 2001)

Table 1. Description of the main factors responsible for the spatial and temporal diversity in the ecosystem in the Zwalm river basin (Goethals and De Pauw, 2001).

Natural dynamics
• Season: flow velocity due to rain, temperature, light, … • Space: substrate type, flow velocity due to height gradient, distance from source,… • Surrounding river basins
Human impacts
Physical-chemical disturbances: **1.1. Point sources:** • Effluent WWTP (urban and industrial) • Combined sewer overflows • Sewer systems • Accidents (fuel storage tanks) • Feeding of animals, fishing **1.2. Diffuse sources:** • Agriculture • Traffic • Scattered housings
Structural and morphological: • Water quantity management (weirs, artificial embankment) • Transport infrastructure • Physical pollution (wood debris, large wastes)
Direct biological ‘disturbances’: • Fishing • Rat traps • Sampling related to monitoring • Fish plantations (angling management, pond overflows) • Game (e.g. birds: ducks)

3. DATABASE SET-UP

To allow this model development study, a monitoring campaign was set up. Therefore, a part of the Zwalm river basin of about 12 km was selected which consists of the Verrebeek brook, the Dorenbosbeek brook and the upstream part of the Zwalm river itself. This part contained river sites characterised by structural and morphological disturbances (weirs for water quantity control, artificial embankments, watering places for the cattle, ...), while other sites nearly met reference conditions (forests with good meandering, hollow river beds, deep/shallow variation, …). The selected part of the river basin was located in a region with different types of land use (urban, agricultural and industrial regions).

The monitoring campaign consisted of two parts. First, an inventory of the structural and morphological characteristics along the selected part of the Zwalm river basin was made. The selected river parts were split up in stretches of 50 m, each marked with a code according to the AQEM consortium manual (AQEM consortium, 2002) (an upstream and downstream (X,Y) co-ordinate). An example is given in Figure 1. By walking along the river, information about a number of variables that could easily be noticed without the use of equipment was recorded of every 50 m stretch (Table 2).

Secondly, 60 sites were selected in the Verrebeek, the Dorenbosbeek and upstream part of the Zwalm river about every 250 m, depending on the change in characteristics that was inventoried during the first phase. At these 60 sites, macroinvertebrates were collected by means of a standard handnet during five minute kick sampling within a river stretch of 10 m (IBN, 1984) or by *in situ* exposure of artificial substrates (De Pauw et al., 1994). Also a number of physical-chemical, structural and morphological variables were measured at the selected sites (Table 3).

Table 2. Overview of the data that were gathered in every 50 m stretch

Data gathered in every 50 m stretch
• Distance to mouth • Stream order • River meandering (6 classes) • Hollow beds (6 classes) • River bank type (natural, wood, concrete, …) • Slope of river banks • Land use (forest, agricultural, industrial, …) • Buffer strip (type and distance to river) • Discharges (WWTP, domestic, agricultural, …)

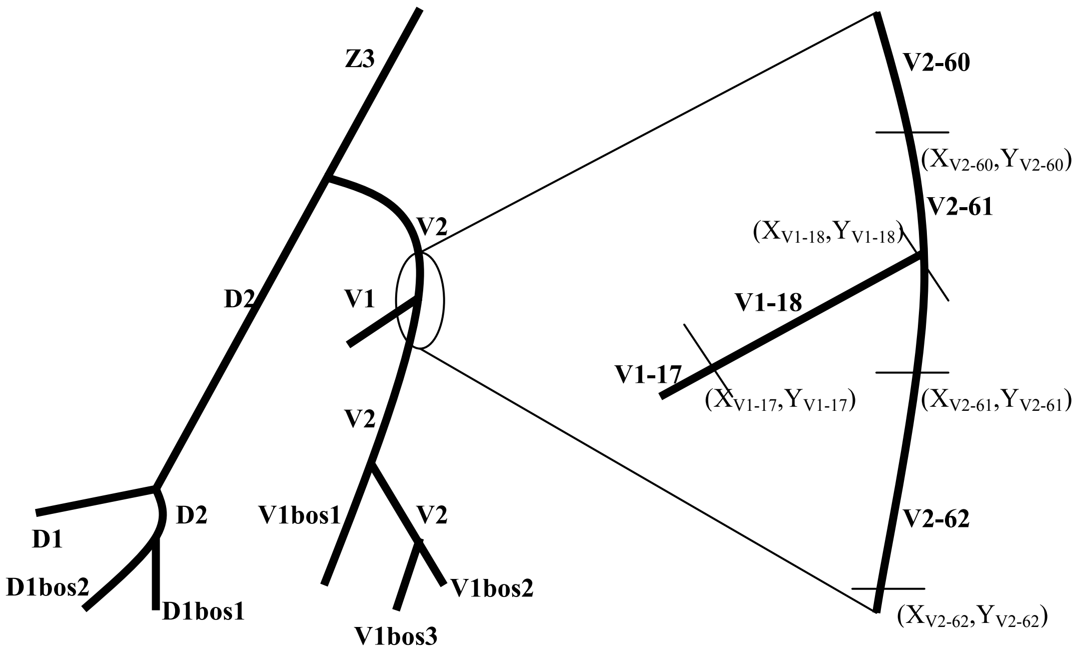

Figure 1. The Verrebeek brook (V), the Dorenbosbeek brook (D) and the upstream part of the Zwalm river (Z) are coded based on the system suggested by the AQEM consortium. All streams upstream of the first confluence are regarded as 1st order streams; two 1st order streams together form a 2nd order stream, two second order streams a 3rd order stream, … These rivers are split up in stretches of 50 m, each with an upstream and downstream (X,Y) co-ordinate.

Table 3. Overview of the extra data that were gathered at 60 selected sampling sites

Extra data gathered every 250 m
Biological sampling: macro-invertebrates
Physical-chemical measurements: • Water temperature (°C) • Dissolved oxygen (mg/l) (OXI 330/SET) • pH (Jenway 071) • conductivity (µS/cm) (WTW LF 90) • suspended solids (mg/l) (spectrophotometer) • COD (mg/l) (spectrophotometer) • NO_3^- (mg N/l), PO_4^{3-} (mg P/l), NH_4^+ (mg N/l), Total P (mg P/l) and Total N (mg N/l) (spectrophotometer)
Structural and morphological data : • River width and depth (with a measuring tape) • Water velocity (propeller) • Granulometric composition of river sediment (bolders, pebbles, sand, loam and clay) • Shadow (%) and water vegetation

4. MODEL DEVELOPMENT

To simulate habitat suitability and macroinvertebrate migration, habitat suitability and GIS models are being combined. First, models to predict the habitat suitability of the macroinvertebrates based on the abiotic characteristics of their aquatic environment are developed based on the variables in Table 2 and 3. Artificial Neural Networks (ANNs) and Decision Trees are implemented to predict this habitat suitability. The variables that were measured every 50m (Table 2) allow to make a reliable estimate of the abundance of a taxon in every 50m stretch. The difference between the abundance of the macroinvertebrates that was observed and predicted based on the habitat suitability models in every 50m stretch is considered as a 'tension'. This tension indicates how likely it is that species want to move to another site or want to stay or attract species from neighboring sites. The next step in the modeling process is to determine the possibility for migration of a species from or to a 50m stretch. Therefore a 'local potential of migration' is calculated based on the observed abundances, migration barriers (e.g. weirs, river impoundments,…), the migration distance, flow velocity and also based on existing ecological information. For example, the upstream and downstream movement of animals within and between habitats is of particular ecological significance. In running waters, the drift of benthic macroinvertebrates is a well-studied phenomenon. Active (upstream) movements by invertebrates have also been frequently observed. An overview of the factors affecting the movements of *Gammarus pulex* (Amphipoda) is given by Dedecker *et al.,* 2003. This migration potential upstream and downstream will also be calculated over land and in the air. Thus, four maps will show the migration potential of a certain macroinvertebrate taxon respectively through the air, over land and upstream and downstream through the water column (Figure 2). When an overlay of the four maps is made, the total migration potential for a macroinvertebrate taxon is known. In this way, the migration time from one stretch to another can be calculated.

The combination of these two types of models (habitat suitability and migration models) is finally wrapped up into a DSS environment. A set of habitat suitability models based on artificial neural networks (ANNs), decision trees and fuzzy logic are linked to a GIS that allows the user to (Figure 3):

(1) evaluate the habitat suitability of river stretches for different aquatic taxa based on the important river system drivers and their interactions;
(2) simulate management activities that modify river characteristics, landscape features,…;
(3) obtain results from simulated activities in terms of changes in species distribution and the associated management costs.

The complementarities of the different types of habitat suitability models enables to perform reliable simulations at different spatial and temporal scales. Decision trees extract simple rules from large quantities of data, while ANNs are able to establish patterns and characteristics in situations where rules are not known. Fuzzy logic on the other hand allows to work with unreliability and inaccuracy of data and brings in expert knowledge.
Not only optimizing the performance of the modeling results is necessary but also a lot of effort is needed to select the appropriate models, modeling strategy, data and/or expert rules for the problem at hand. To know when, how and in what sequences to use the models and data in combination to solve specific problems is essential. This involves knowledge of how to perform spatial modeling and how to use a set of tools in combination for particular analytical purposes.

5. DISCUSSION

This monitoring network was constructed in the Zwalm river basin because the monitoring approach currently adopted in Flanders is not adjusted to the needs of the DSS. The Flemish Environment Agency (VMM) has selects specific sampling sites to meet their requirements: reveal effects of pollution and monitor long term trends in water quality. In this way, sites are selected which are expected to be influenced by agricultural or industrial activities. Also sites near wastewater treatment plants are selected. The general trend is to monitor sites with an expected degradation in water quality. Biological as well as physical-chemical samples are analyzed.

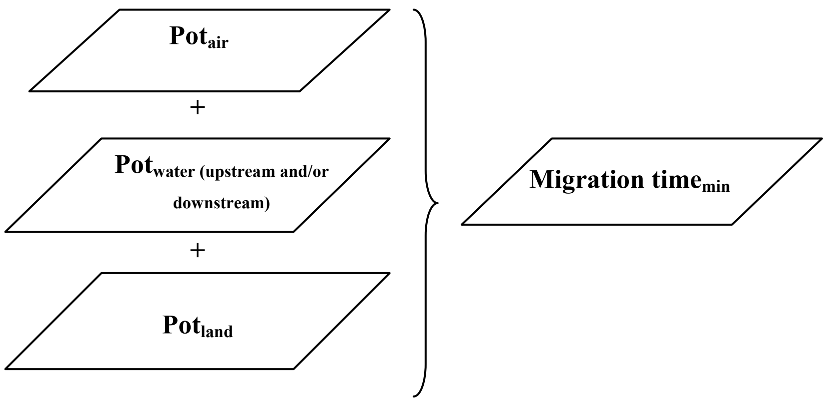

Figure 2. A migration model includes four layers, each representing one migration medium. The four maps show the migration potential (Pot) of a certain macroinvertebrate taxon respectively through the air, over land and upstream and downstream through the water column. When an overlay of the four maps is made, the minimum migration time between two sites for a macroinvertebrate taxon can be calculated.

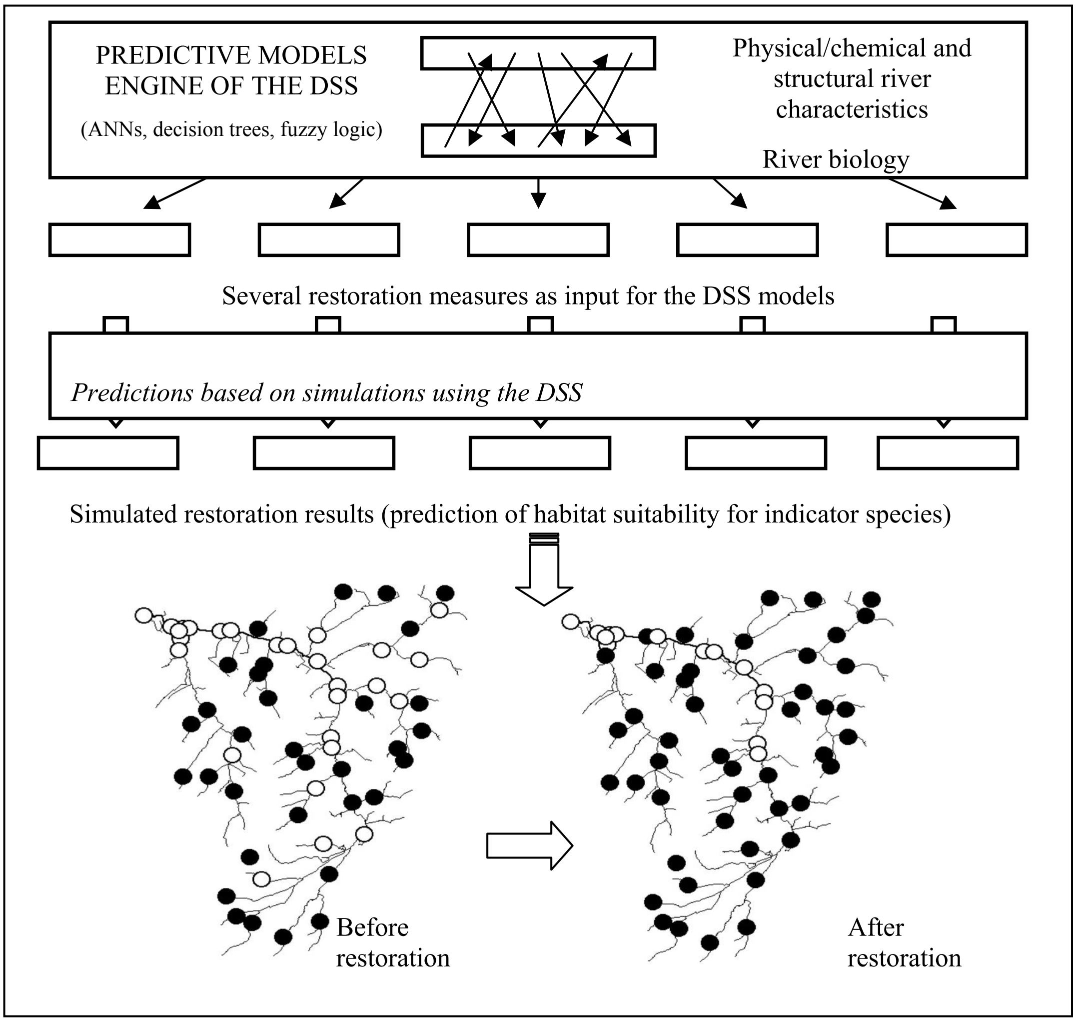

Figure 3. Decision Support System for integrated ecological river management with GIS-visualization (o = absent; • = present)

Reference sites are sampled by the Institute of Nature Conservation where attention is paid to biodiversity. Assessment of the structural characteristics of Flemish rivers is based on three characteristics that can easily be observed in the field: meandering, pools & riffle development and natural shelters (cavities in banks). Although a lot of data have been gathered in Flanders on the river systems, there are still some gaps to fill before these data meet the requirements for our modeling objectives. First of all, the data are scattered over different institutes in Flanders using various format types, other co-ordinate systems, etc. A database of the Zwalm river basin has been developed to be implemented in a GIS as an exercise. Data of several institutes was integrated, but it was never used in practice (Carchon and De Pauw, 1997). This methodology was based on the use of charts in which coloured lines and symbols gave information on the ecological quality, types of disturbances, their causes and also on potential solutions. The river quality lines represented the most recent data on the physical and chemical, biological and structural and morphological status of the river. But to meet our modeling requirements, also information about the river between sampling sites is necessary. Thus, an inventory based on visual characteristics of the river was conducted in 2002. Based on this inventory, sampling sites were selected which could be considered relevant for several 50 m stretches. With these data, it was possible to extrapolate the biological communities between the sampling sites (split up into 50 m stretches) by comparing the characteristics of the sampling sites presented in Table 2 with the characteristics in between. In the upper reaches, a distance of about 250 m between two sampling sites seems appropriate because the habitat features of these near-natural reference conditions are more diverse in different river sections. In the Zwalm river itself, this 250 m distance seems to be too small in some river sections because of the more uniform habitat characteristics. For example, the macroinvertebrate community in a river section of about 1 km with gabions does not change considerably. This is way the distance between sampling sites will be reviewed before the next sampling campaign. This systematic sampling design based on an inventory of visual river characteristics is considered as the optimal approach for our objectives. Hirzel and Guisan (2002) proposed following considerations to improve the sampling strategy for habitat suitability modeling:

(1) increase sample size;
(2) prefer systematic to random sampling;
(3) include environmental information in the design of the sampling strategy.

To be efficient, a sampling strategy needs to be based on those gradients that are believed to exercise major control over the distribution of species. These gradients should be considered primarily to sampling, because otherwise vital information will limit model accuracy. Random sampling could lead to truncated response curves for some species if the extremities of the main environmental gradients are under-sampled. Stratifying along these gradients and sampling the extremities can assure an efficient sampling of these outer limits (Hirzel and Guisan, 2002). This is why it is important not only to sample sites which are degraded to identify point-sources and disperse pollution sources based on physical-chemical or structural characteristics as the Environment Agency does. Also the more pristine sites in the upper reaches should be sampled. These sites reveal what is feasible from an ecological point of view. That is way a lot of effort was put in to also sample more reference-like sites in the upper reaches of the Zwalm.

6. CONCLUSIONS

Modeling the effect of restoration actions on a river basin scale based on habitat suitability models and a migration model looks promising, but it requires a high monitoring effort. A systematic sampling design based on environmental information is needed to build up large databases. In Flanders, it will be necessary that the different institutes involved gear their methodologies for monitoring and database set-up to one another.

7. ACKNOWLEDGEMENTS

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