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PMAT: A Quantum GIS plug-in to support the use of Bayesian belief networks in ecosystem service delivery mapping

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Probabilistic Map Algebra Tool

Introduction

The ecosystem service concept embraces all products and services delivered by natural and semi-natural ecosystems. The importance and value of these ecosystem services (e.g. food production, wood production, climate regulation) has been demonstrated in many studies and has resulted in emerging scientific and political attention to assess ecosystem service delivery, mainly through modelling and mapping. In the past, several ecosystem service modelling and mapping tools have been developed ranging from simple proxy-based methods to complex process-based models (e.g. InVEST). Although predictions of these tools are generally uncertain, uncertainties are rarely quantified or mapped. A modelling approach that does account for uncertainties is Bayesian belief network modelling. Through a developed plug-in for Quantum GIS, we apply these probabilistic models spatially to model and map ecosystem service delivery on a regional scale.

Bayesian belief network models

Bayesian belief networks are probabilistic models that model a system based on the causal relations that exist among the system's variables. To quantify these relations, conditional probability distributions are used. Bayesian belief networks graphically represent the system by a directed graph wherein variables are represented by nodes and causal relations by arrows. Major advantages of this modelling technique are the ability to account for uncertainties and the ability to integrate multiple data types. In ecosystem service research, limited available empirical data frequently has to be complemented with expert knowledge. In case raster maps are available for the model's input variables, the model can be ran pixel-based to generate ecosystem service delivery maps. For each pixel, the model will provide a probability distribution over the states of the output node. Several metrics, derived from this probability distribution, can be mapped (Figure 1).

Output node	
1	20.0
2	30.0
3	50.0
4	0
5	0
2.3 ± 0.78	

Most probable state: $\arg\max_{x \in S} P(x) = 3$

Probability of most probable state: $\max_{x \in S} P(x) = 0.50$

Expected value: $\sum_{x \in S} (P(x).x) = 2.3$

Standard deviation: $\sqrt[2]{\sum_{x \in S} (E[X]-x)^2.P(x)} = 0.78$

Figure 1. Metrics that can be derived from a probability distribution, predicted by a Bayesian belief network model

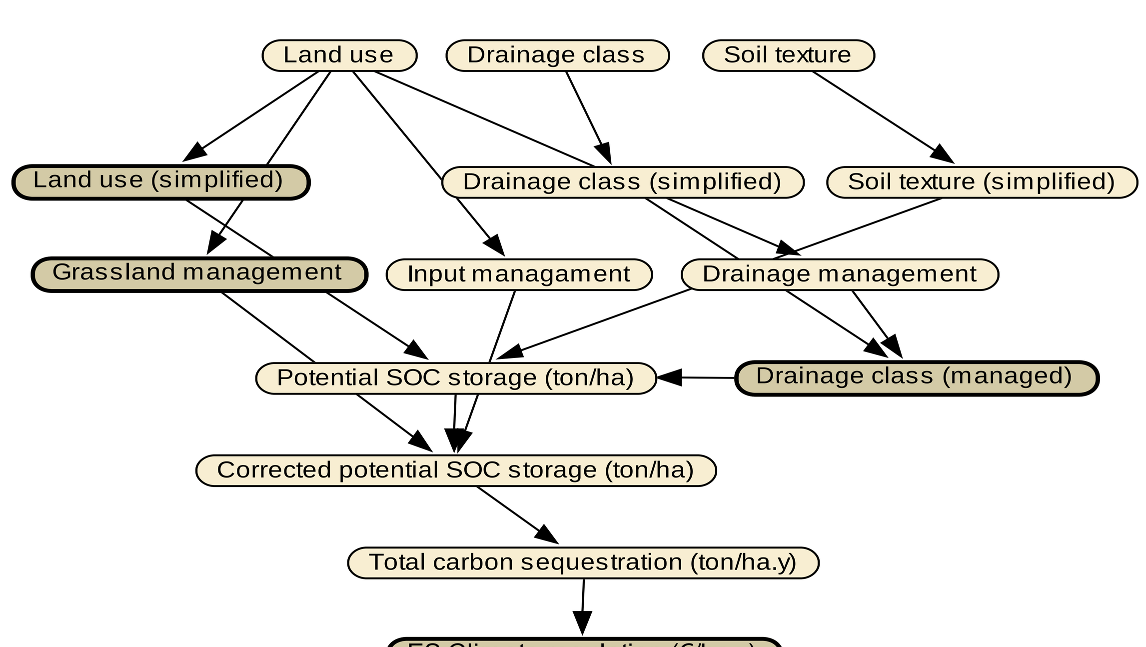

Figure 3. A Bayesian belief network model for pixel-based assessment of the ecosystem service climate regulation

Applying the plug-in

The PMAT plug-in is designed to run a Bayesian belief network model (developed in Netica) on a set of raster maps containing spatial data on the model's input variables.

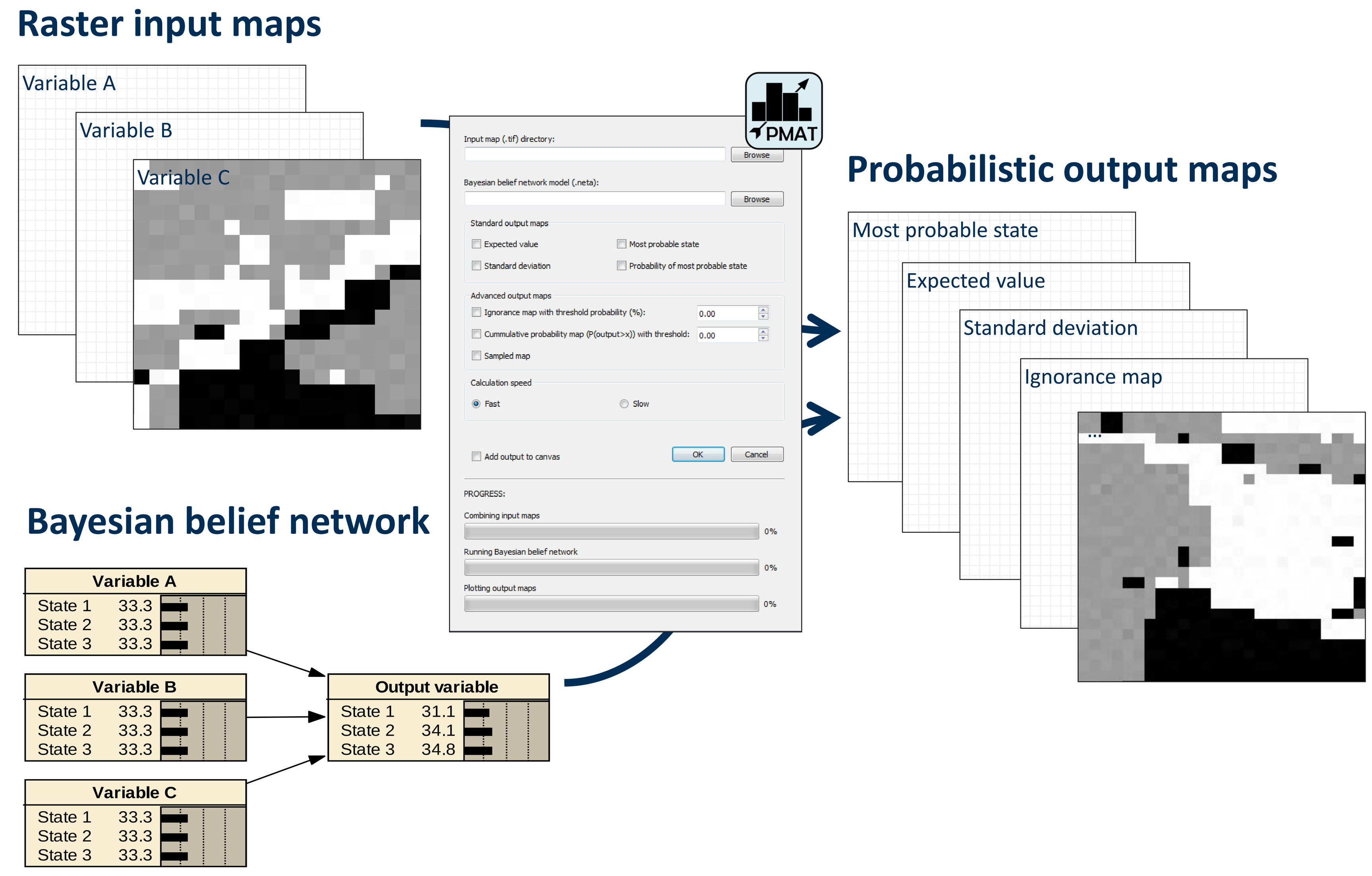

Figure 2. Schematic representation of the proposed workflow

Results of a case study

To illustrate the main functionalities of the plug-in, we applied it on a land dune region, located in the northeast of Belgium. A Bayesian belief network, to model the ecosystem service climate regulation, was developed by integrating different knowledge sources (e.g. expert knowledge, literature data, existing models) (Figure 3). By applying the plug-in, using spatial data on land use and soil type, we obtained several probabilistic maps that represent the spatial delivery of the ecosystem service climate regulation in the study area (Figure 4, from left to right: a probability map (of the most probable state), an expected value map, a cumulative probability map and an ignorance map). Not all delivered maps may be useful. The decision on which type of uncertainty map to use for decision support depends on different factors. Clearly, no one-fits-all visualization approach exists. Depending on whether the output variable is qualitatively or quantitatively defined, the cognitive capacity of the map reader and the questions that need to be answered, different visualization approaches are needed.

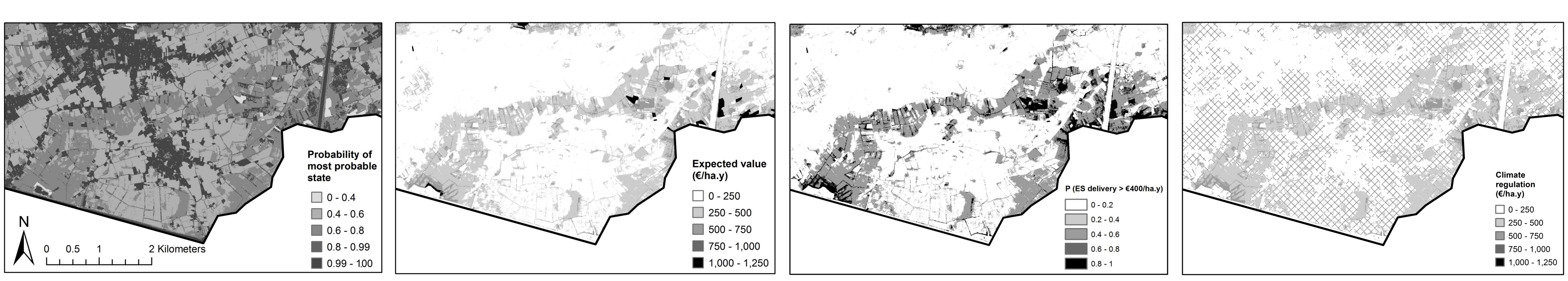

Figure 4. Probabilistic maps representing spatial delivery of the ecosystem service climate regulation

Software availability

Name	PMAT(Probabilistic Map Algebra Tool)
Developer	Dries Landuyt dries.landuyt@vito.be
Software requirement	Quantum GIS 1.8.0 'Lisboa' Netica
Availability	https://github.com/DriesLanduyt/PMAT

Conclusions

The developed plug-in promotes the use of Bayesian belief networks to model and map ecosystem service delivery. Bayesian belief networks can add value to current ecosystem service mapping research as they enable the integration of uncertainties and expert knowledge in spatial accounting studies. In management domains that predominantly rely on expert opinion for decision making (as no other information is available), this tool can be extremely useful.

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