Predict potential risk of bark beetle disturbance
Applying Bayesian Belief Networks

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Introduction

The central Europe experienced loss in forest areas due to the bark beetle outbreaks [2]. These zones are characterized mainly by the dense density of Norway spruce species. Recent evidence suggests that the accelerated bark beetle spread was driven by the drought and high level of proportion share of Norway spruce factors. Decision makers and forest practitioners have to take the necessary measures to avoid future tree damages. Managing forest stands involved applying several steps in BBN.

Figure 1: Impact of bark beetle outbreaks in the Czech forest areas

The Bayesian decision system was used to perform the challenging tasks of decision maker through uncertainty and vaguely [1]. An effective and accurate approach was described for Czech forest practitioners through modeling, in order to optimize all available resources and to prevent further spread of bark beetles. The main purpose of this research is to define the possible high potential disturbed sites (Figure 1).

Main Objectives

1. Predicting bark beetle outbreaks in order to reduce future forest loss.
2. Identifying causal influence of the Bark beetle disturbance variable.
3. Quantifying the BBN bark beetle disturbance categories application for different ecological conditions.

Materials and Methods

Bayesian belief network is considered as one of the most Knowledge representation and reasoning, also decision making under uncertainty. The tool has been developed mainly for medical issues, the technique has been extended the practice to industrial and environmental sciences. A recent review of the literature describes the many emerging tools and practices developed for a BBN. In this research, in order to reduce the assessment burden of large discrete conditional probability distributions, the structural BBN methodology was applied following Wisse et al [3] and using Hugin researcher software. The experts were designed to build the network structure, identify the variable names and relation among the variable goal 'Bark beetle disturbance' (Figure 2), then were invited to elicit a subjective probabilities, in order to provide Conditional Probability Table (CPT).
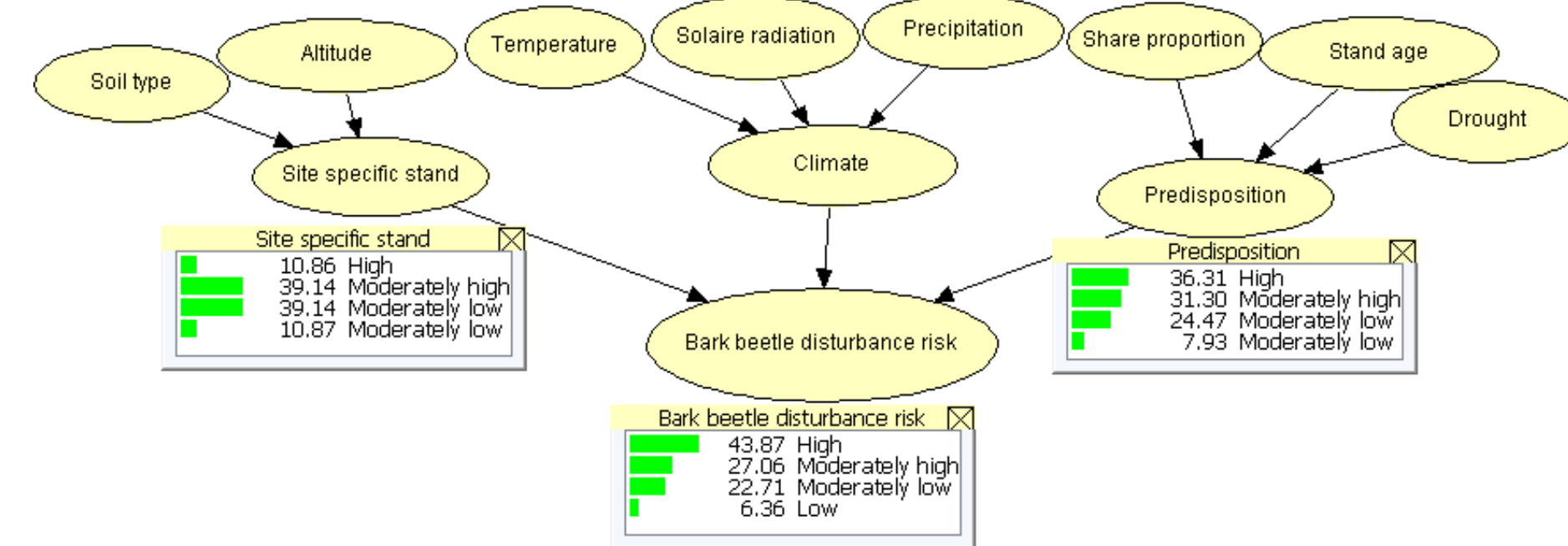

Figure 2: Computation of BBN in Hugin researcher software

Mathematical Section

The calculus of $P(X_c = x_c)$ (CPT) was estimated applying the EBBN method (an elicitation method for BBNs), it consists of several steps, the piecewise linear functions were constructed $f_{x_c} : [0,1] \rightarrow [0,1]$, through the points $(i_{joint}(a_{x_c}), P(X_c = x_c | a_{x_c}))$, the EBBN method is shown below:

$$P(X_c | pa(X_c) = a) = \sum_{k:X_k | pa(X_c)} w_i * \frac{\int_{i_{min,k}}^{i_{max,k}} f(i) * di}{i_{max,k} - i_{min,k}} \quad (1)$$

where

$$\begin{aligned} i_{min,k} &= \min(i_k(x_k), i_{joint}(a)) \\ i_{max,k} &= \max(i_k(x_k), i_{joint}(a)) \\ f(i) &= (f_{xc,min}(i), ..., f_{xc,min}(i)) \end{aligned} \quad (2)$$

and the calculus of w_k which represent the weight for each parent X_{pi} is defined as:

$$w_i = \frac{1}{2} \frac{\delta_i^+}{\sum_{n:X_{pn} \in pa(X_c)} \delta_n^+} + \frac{1}{2} \frac{\delta_i^-}{\sum_{n:X_{pn} \in pa(X_c)} \delta_n^-} \quad (3)$$

where

$$\begin{aligned} \delta_i^+ &= P(X_c = x_c^{max} | a_{neg,p_i^+}) - P(X_c = x_c^{max} | a_{neg}) \\ \delta_i^- &= P(X_c = x_c^{min} | a_{neg}) - P(X_c = x_c^{min} | a_{neg,p_i^+}) \end{aligned} \quad (4)$$

The CPT algorithm was built and a program was launched in MATLAB software, then the results were incorporated in Hugin Researcher software.

Results

Let consider the hypothesis variable Bark beetle disturbance (H_{BBD}), and the initial set of evidence is $\{\varepsilon_T, \varepsilon_P, \varepsilon_{Sh}, \varepsilon_{St}\} = \{T = m.Low, P = Low, Sh = m.High, St = High\}$.
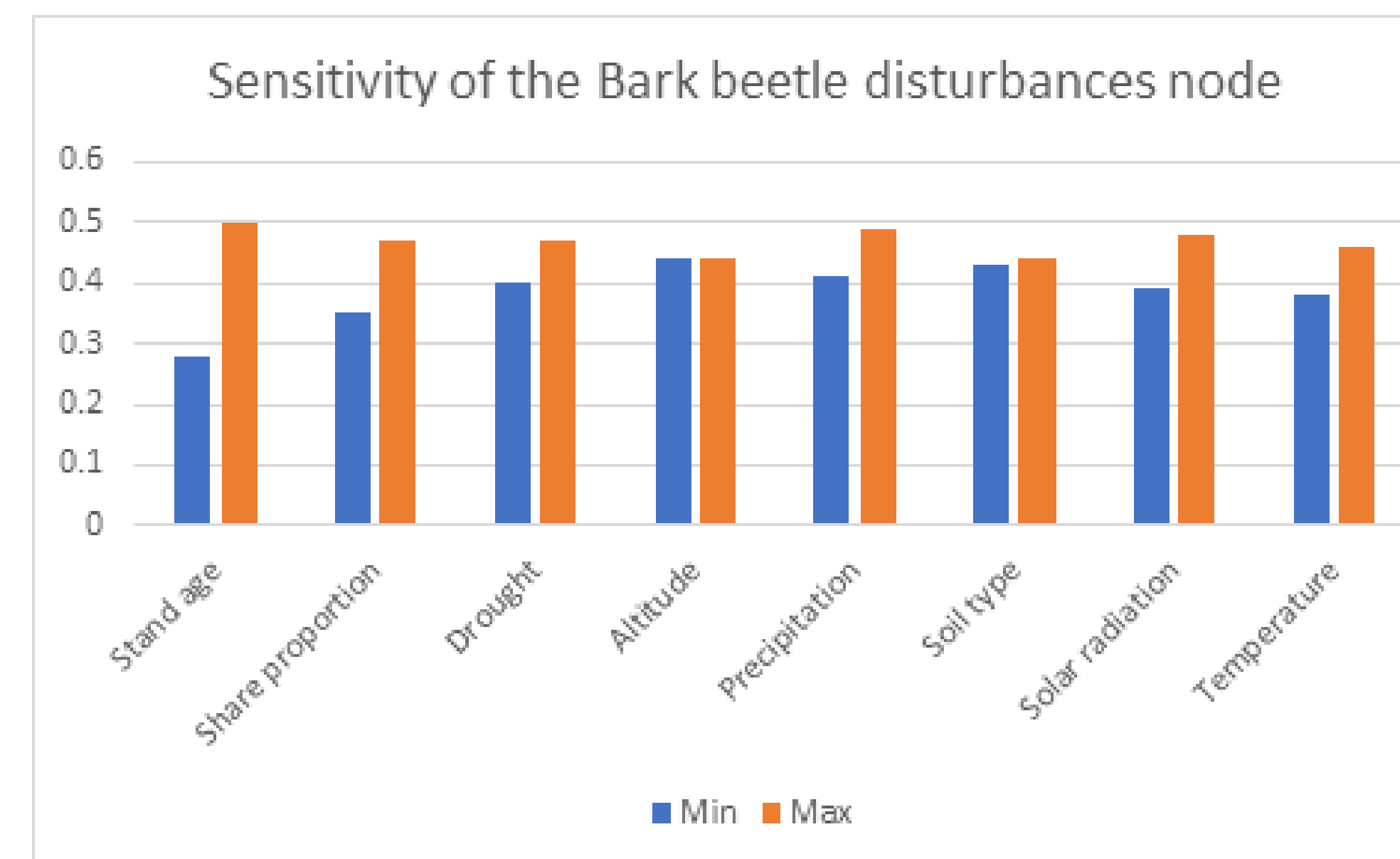

Figure 3: Min and Max beliefs for each node for Bark beetle disturbance variable given the evidence $\varepsilon_T, \varepsilon_P, \varepsilon_{Sh}, \varepsilon_{St}$

Figure 3 shows the posterior probability distribution of Bark beetle disturbance variable given the entire set of evidence, as well as the minimum, current, and maximum values for the posterior probability over each selected information variable.

Table 1: Normalized likelihood of hypothesis $H_{BBD} = High$ given all subsets of the evidence ε'

ε'				Normalized likelihood
-	-	-	-	1
-	-	-	ε_{St}	1.02
-	-	ε_{Sh}	-	0.94
-	-	ε_{Sh}	ε_{St}	0.9
-	ε_P	-	-	0.92
-	ε_P	-	ε_{St}	0.94
-	ε_P	ε_{Sh}	-	0.88
-	ε_P	ε_{Sh}	ε_{St}	0.9
ε_T	-	-	-	1.14
ε_T	-	-	ε_{St}	1.18
ε_T	-	ε_{Sh}	-	1.08
ε_T	-	ε_{Sh}	ε_{St}	1.12
ε_T	ε_P	-	-	1.06
ε_T	ε_P	-	-	1.1
ε_T	ε_P	ε_{Sh}	-	1.02
ε_T	ε_P	ε_{Sh}	-	1.06

The precipitation and stand age nodes showed the highest sensitivities, and were the most influential for all connected nodes. The table 1 showed the normalized likelihood of the hypothesis $H_{BBD} = High$ given the evidence $\varepsilon_T, \varepsilon_P, \varepsilon_{Sh}, \varepsilon_{St}$, It is clear that the finding $\varepsilon_T = Temperature$ and $\varepsilon_{St} = Standage$ act in favor of the hypothesis $H_{BBD} = High$, this suggests that evidence supports the hypothesis that the outbreak disturbance is originate from share proportion, temperature and stand age (Table 2).

Table 2: Results of proposed BBN application in three Czech forest stands

	Stand A	Stand B	Stand C
Stand age	High	Low	High
Share proportion	Moderately high	Moderately low	Moderately High
Drought	Moderately high	Moderately high	Low
Precipitation	Low	Low	Moderately high
Temperature	Moderately high	Moderately high	Low
Disturbance risk estimation			

Conclusions

- The BBN model proposes a rapid solution for solving complex decision problems, it could be reused in other worldwide similar study areas
- An efficiency strategic decision solutions to deal with forest stakeholders and practitioners.
- Focus the investigation on share proportion of Norway spruce and stand age parameters, in order to protect the healthy standing forest lands.

References

[1] Uffe B. Kjærulff and Anders L. Madsen. *Bayesian Networks and Influence Diagrams: A Guide to Construction and Analysis*. Information Science and Statistics. Springer-Verlag, New York, 2008.

[2] Alfred Radl, Manfred J. Lexer, and Harald Vacik. A Bayesian Belief Network Approach to Predict Damages Caused by Disturbance Agents. *Forests*, 9(1):15, January 2018.

[3] B. W. Wisse, S. P. van Gosliga, N. P. van Elst, A. I. Barros, and TNO Defensie en Veiligheid. Relieving the elicitation burden of Bayesian Belief Networks, January 2008.

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