Szent István University

Prediction of the potential planting area for woody ornamental plants based on potential natural vegetation models

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PREVIOUS RESEARCH AND AIMS

Although landscape architecture works at different scales and with different methods, its main building material are always the plants. Plants, that are closely linked to their environment, including climate. Therefore **correct plant application** is inextricably linked to the knowledge of the **characteristics of the climatic environment**. The climate is not constant; thus no final list of the ornamental plant taxa that can be applied in a certain place exist. Hence, it is particularly motivating to look for answers to the general question on plant application: where and when, what **can be planted**.

Nowadays, the accessible environmental data, the computing resources, and modelling methods enable to answer this question after the necessary restrictions (i.e. in time, in space, in study domain etc.) – even if not exactly but by **estimation** (**potential planting area**).

Although closely related to the modelling the potential distribution of native plant species both in logical and methodological terms, **modelling** the potential planting area raises a number of questions. Such a pivotal question is the choice of **input data** used for training the model. This complicates the use of the original modelling concept (i.e. we train a model based on the original distribution area) especially in case of exotic ornamental plants. Naturally, using maps that draw the **actual planting area** should be the most appropriate method (in terms of logic and error reduction as well) for training the model. It has, however, only one, but a very serious obstacle: these maps **do not exist**.

In my research, I gained input data for modelling the potential planting area by a method, that is seemingly simple and obvious, but to my knowledge has not been used by others. I **link** the ornamental taxa **to the natural vegetation**, and I predict the future potential planting area of the ornamental plants **based on predictions of potential future vegetation**.

My aims were during the research:

- training a predictive **ecological model** for climax and subclimax habitats of Hungary;
- studying the **potential impact** of the climate change of the 21^{st} century **on the habitats** by evaluating the model results;
- characterizing the **environmental demands** of the studied 31 important woody ornamental taxa based on their ability to be planted in the climax and subclimax habitats;
- modelling and analyzing the potential **impact of climate change on the planting area** of the selected ornamental taxa;
- assessment of the likely **changes in the application potential** of the selected taxa based on the results of the research.

Therefore, the main objective of the dissertation is to demonstrate the use of a **novel modeling approach** (framework) and to present the results on **maps**.

MATERIALS AND METHODS

My research has two main pillars: ecological modelling (**habitat modelling**) and **modelling the potential planting area** of ornamental plants. Although the second pillar is based on the first one, this is not true vice versa. The ecological modeling forms a separate unit, but the modelling of planting area can be interpreted only in conjunction with the former one.

The proposed modeling framework enables modelling the potential planting area of ornamental plants despite **training data is not available**. Applying the knowledge of 9 **experts**, i.e. 9 **habitat-ornamental matrices** were made supplemented by an aggregated one. Therefore, I had the opportunity of modelling the planting area of the 31 studied ornamental plants for the **five prediction targets** (reference period, and the two future periods according to the two climate models) in two ways.

I used the habitat predictions based on the environmental databases of the reference period and the future periods corresponding to the appropriate prediction target and the models of the 47 individual and 7 merged habitats. Habitat models were trained with **presence/absence** data of the habitats as **dependent variable**, and I used the following environmental data as **predictor variables**:

- 26 **edaphic** variables corresponding to pH, organic matter content, rooting depth, groundwater depth and texture classes;
- 9 **hydrological** variables (distances from water bodies);
- 6 **topographic** variables (terrain variability); and
- 27 **climatic** variables (bioclimatic and seasonal variables).

The derived variables that were used as predictors in the final models were calculated based on the following databases of different horizontal resolution:

- Digital, Optimized, Soil Related Maps and Information in Hungary (**DOSoReMI.hu**);
- digital terrain model from Shuttle Radar Topography Mission (**SRTM**);
- vector-type GIS layer of **lakes and rivers** courtesy of the Geological and Geophysical Institute of Hungary;
- **CarpatClim-Hu** database;
- **ALADIN**-Climate 4.5 and **RegCM** 3.1 regional climate models;
- Spatial Database of Habitats in Hungary (**MÉTA**).

The original climate variables (**monthly** mean, minimum and maximum **temperatures**, and **precipitations**) were **bias corrected** by Delta Change method. Then all these 48 variables and all for the five prediction targets were **downscaled by regression kriging** based on altitudinal, latitudinal and longitudinal auxiliary variables.

According to iterative expert variable selection, I selected **25 predictors** as **final predictor set** from the 68 potential (initial) predictors of the derived environmental database that have **pairwise correlations** and **multicollinearity** at an acceptable level. The ecological model I used in my research was '**Boosted Regression Trees**' (BRT). It found, for all the studied habitats, a function those domain is the 25 predictor vectors. The model is constructed as a combination of nearly 5,000 logical branching system of three levels. The function predicts a vector of values between 0 and 1 (codomain), that determine, for all spatial points, the **probability of potential presence**, if the constraints of colonization are excluded. The **maps displaying the potential distribution** of habitats were produced based on an appropriate rescaling (to a five-levels ordinal scale) of these results.

The second pillar, the model of the planting area of **ornamental plants**, is based on the predictions of the ecological model, since that provides the **input**. The structure of the planting area model is much simpler than that of the previous one, since it is not trained algorithmically but relies on **expert decisions**. Algorithmic training would not have been possible because I had no response variable: there is no knowledge at enough spatial points if the studied ornamental plants can be safely planted. The model links the planting probability of ornamentals (as likelihood value) to the predicted probability of presence of habitats with an easily interpretable and demonstrative tool: the **habitat-ornamental matrix**. This matrix contains the ornamental plants in its rows and the habitats in its columns. Its cells give a **numeric value between 0 and 1**, and express if a certain ornamental plant can survive without special maintenance regime in a place, **where the given habitat is potentially present**. Several alternative methods might produce such a matrix. In my research, independent matrices were produced by experts (one matrix per one expert), and then aggregated to the final matrix. This can be used by the model in several ways. I show **two possible methods** in my dissertation. By applying the matrix, I present the potential planting area of the 31 studied ornamental taxa for all the five prediction targets.

RESULTS

The following intermediate and final results, data, and maps were produced during my research:

- **bias corrected** climate surfaces of the monthly mean, minimum and maximum temperatures, and monthly precipitations of the two climate models and two future prediction periods (i.e. a total of 192 data vectors), with a horizontal resolution of 0.1° (nearly 10 km); and surfaces of bias correction factors that are calculated multiplicatively in case of precipitation and additively in case of temperature;
- monthly mean, minimum and maximum temperatures, monthly precipitations of the two climate models and two future prediction periods, as well as the reference period (i.e. a total of 240 data vectors, five prediction targets), surfaces **downscaled** at the resolution of the MÉTA database (i.e. at a hexagonal grid with 734 m distance); and the statistical characteristics of the **regressions** and **semivariogram fittings** used in the downscaling; and the **fitted semivariogram models**;
- 26 edaphic, 9 hydrologic, 6 topographic, and 27-17 climate surfaces (for all of the prediction targets (**initial predictor set**) at the resolution of the MÉTA database;
- **correlation structure**, different measures of **multicollinearity** and **cluster analysis** of the initial predictor set for all the five prediction targets;
- **correlation structure**, different measures of **multicollinearity** and **cluster analysis** of the final predictor set containing 25 predictors for all the five prediction targets;

- 54 **habitat models**;
- **statistical characteristics** (number of trees, learning rate, dropped predictors, spatial sorting bias etc.) of the habitat models;
- goodness measures (four **AUC** values for all the models) and **ROC** curves of the habitat models that assist the evaluation;
- **predictions** for the five prediction targets based on the 54 habitat models (i.e. a total of 270 **maps of potential planting area** at the resolution of the MÉTA database);
- **experiences**, comments related to the filling of habitat-ornamental matrix;
- four **aggregations** (mean, minimum, maximum, standard deviation) of the expert **habitat-ornamental matrices**;
- row and column-wise (i.e. a total of 8) **cluster analysis** of the aggregated habitat-ornamental matrices;
- **potential planting area** of the 31 ornamental taxa for all the five prediction targets, according to two modeling methods ('based on matrix mean' and 'ensemble'); i.e. a total of **310 maps of potential planting area** at the resolution of MÉTA database;
- uncertainty of the estimation of potential planting area of the 31 ornamental taxa (i.e. a total of **155 uncertainty maps** at the resolution of MÉTA database);
- **habitats that determine** the potential planting area of the 31 ornamental taxa (i.e. a total of **155 maps** at the resolution of MÉTA database);
- **experiences**, comments related to the modeling framework.

NEW SCIENTIFIC RESULTS. THESES

I. thesis group – potential impacts

1. thesis – potential impact on habitats

Potential impact of climate change on the distribution of climax and subclimax habitats was demonstrated and these results broadly correspond to ecological expectations. The potential impact is unfavorable in case of most of the **woody habitats**, but favorable in case of some of the grasslands and other non-woody habitats according to the predictions. Among the woody habitats, **zonal mountain forests** are the most negatively affected ones. The models predict the most positive effect for some of the grasslands and other non-wooded habitats, mainly **halophytic** habitats, **reeds** and **closed steppes on loess**. Impact of climate change on most of the **habitats related to surface waters** is not significant.

2. thesis – potential impact on ornamental plants

I demonstrated that **planting possibilities** of some of the studied 31 ornamental plants **will be affected** positively **by climate change**. Others will be negatively affected. These findings were underpinned by the literature.

II. thesis group – reliability of the models

3. thesis – reliability of habitat models and predictions

I found that **habitat models and predictions are reliable** given that deficiencies or weaknesses are acknowledged. Predictor selections and maps produced **are consistent** with ecological expectations and literature. Based on all these I pointed out that the habitat models **can serve models of planting area well**.

4. thesis – reliability of habitat-ornamental matrix

I found that **cluster analysis** done on the columns of habitat-ornamental matrix (**habitats**) classify, according to their planting possibilities, the studied ornamental taxa similarly to that of the expectations **based on environmental characteristics**. Also it was pointed out that the results of the cluster analysis done row-wise (**ornamental plants**) are largely **consistent with statements in the literature.**

III. thesis group – modeling framework

5. thesis – habitat-ornamental matrix as the tool of modeling the planting probability

It was shown that the **habitat-ornamental matrix has the potential of becoming an appropriate tool** that enables predicting potential planting area of ornamental plants **without training data of actual planting area**, since it can link planting possibilities of ornamental plants to potential distribution of habitats. Also it was found that the recommended **modeling framework is able to estimate the planting probability** of ornamental taxa.

6. thesis – estimation of planting probability and its spatial evaluation

I showed two methods of estimation of potential planting area ('**based on matrix mean**' and '**ensemble**') and two visualization techniques that assist the spatial evaluation of the model results (**uncertainty of the ensemble estimation** and **displaying the selected habitat**).

7. thesis – maps of potential planting area

I concluded that **maps of potential planting area can**, if the errors of the generating models are well explored and correctly acknowledged, **spatially display** the estimation of planting probability. Furthermore they **show the potential impact of climate change** on the planting probability of these taxa to dendrologists, landscape architects, ornamental plant appliers.

8. thesis – use of the modeling method by landscape architects

Finally it was demonstrated that **predictive ecological modeling** is a technique the tools and results of which may be used not only in the field of **ecology** and **regional landscape planning**, but also in **garden and open space design,** as well as in dendrology of garden design.

Conclusions

My ecological and landscape architectural conclusions and my recommendations connected to research and landscape architecture are formulated in the PhD dissertation. I summarize the most important ones as follow:

– according to my results, **maintenance of closed forests** in our country might be difficult, and more open habitats of the **forest-steppe zone** will be more sustainable;
– I find very important that, beyond the point of view of the forestry, **ecological viewpoint** should prevail in achieving a positive future ecological status of Hungary. For that, the **interdisciplinarity nature of landscape architecture can provide a basis**;
– it is a rather optimistic conclusion made based on my results that the studied habitats (and those unstudied ones that are situated to the south of the country) will, theoretically, be able to fill entire Hungary without gaps. We can assume that in some previously unknown (non-existent) sites **habitats might develop** that we cannot imagine today;
– the model results suggest that the **invasion potential** of *Ulmus pumila* var. *arborea*, which is already treated as invasive plant, might greatly increase in the future. It cannot be rejected that some studied taxa that are not yet invasive or established in the country might **turn into invasive plants**;
– by using my predictions as inputs one can calculate **vulnerability**, by which **conservation biology** may gain useful hints about what and where might, should, and will be economical to preserve;

- my results point to environmental characteristics of some parts of our country being potentially more favorable for some ornamental plants, and therefore they might be planted more safely and **maintained cheaply** in the future;
- climate change might significantly affect the ornamental plant application in Hungary. Changes might concern both **garden and open space design**, and **regional landscape planning**. Moreover, it might affect both the planting and the maintenance of ornamental plants;
- based on my results, one may draw conclusions about the potential **planting area** not only of the studied ornamental taxa but of **other ornamental plants** that have similar ecological demands;
- beyond that it is the central element of the modeling framework, the **habitat-ornamental matrix** provides possibility of drawing useful conclusions not related to the modeling. By analyzing it, one can determine which habitats have the potential of planting some of the ornamental plants according to the experts. Hence we get a **new kind of description of the ecological demands** of these taxa. Although this description is not essentially more detailed, neither is it more indirect than the traditional one that enlists the particular environmental factors;
- the modeling framework might, after an appropriate transformation, be able to predict the **potentially invaded area** for those ornamental taxa that have invasion potential;
- every broad-scale **landscape plan** or decision, that affect natural vegetation or its potential, might benefit from the maps displaying potential distribution of habitats when taking a responsible decision. The most evident examples are those works that connect to planning **ecological network and green infrastructure**, but much more general works, connected to **landscape evaluation, and landscape and spatial planning** can use the predictions shown in my dissertation in several ways. Significance of it may increase when landscape development leads to restauration or nature protection interventions;

– one should pay more attention to the **invasion potential of ornamental taxa**, since there is a concern that changed climatic environment opens niches that might be filled with exotic ornamental plants instead of the native species. In the long term, this may result in the significant and irreversible degradation of the ecological conditions of our country;
– it is expected that **landscape architecture gains much more influence** in forming the built human environment, since the role of vegetation and urban green infrastructure in achieving **livability** and appropriate **open space comfort** may significantly increase.

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ALL PUBLICATIONS

The PhD candidate wrote 23 scientific articles including those 13 that were published in journals with impact factor. He is author or editor of 4 books or chapters, and author of 19 full papers and 20 abstracts. 9 is independent from his 26 citations. All of his scientific publications are available from the following link: vm.mtmt.hu/search/slist.php?AuthorID=10029831