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Assessing the potential distribution of invasive alien species *Amorpha fruticosa* (Mill.) in the Mureș Floodplain Natural Park (Romania) using GIS and logistic regression

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Abstract

The assessment of invasive terrestrial plant species in the Romanian protected areas is an important research direction, especially since the adventive species have become biological hazards with significant impacts on biodiversity. Due to limited resources being available for the control of the invasive plants, the modelling of the spatial potential distribution is particularly useful in order to find the best measures to eliminate them or prevent their introduction and spread, as well as including them in the management plans of protected areas. Thus, the present paper aims to assess one of the most disturbing invasive terrestrial plant species in Europe – *A. fruticosa* in one of the most important natural protected area in Romania, i.e. Mureş Floodplain Natural Park (V IUCN category and RAMSAR –Wetlands of International Importance). The current study is a geographical approach seeking to explain the spatial relationships between this invasive species and several explanatory factors (soil type, depth to water, vegetation cover, forest fragmentation and distance to near waters, roads and settlements) and to assess its potential distribution by integrating GIS and logistic regression into spatial simulation. The resultant probability map can be used by the park's administration in implementing the Management Plan in terms of identifying the areas with the highest occurrence potential of *A. fruticosa* according to the primary habitats and ecosystems and setting up actions for its eradication/limitation.

Keywords
A. fruticosa (Mill.), spatial assessment, GIS, logistic regression, Mureş Floodplain Natural Park, Romania

Introduction

Invasive species are acknowledged as economic, environmental or social threats (Charles and Dukes 2006; Bailey et al. 2007; Mcgeochm et al. 2010), becoming key components of global change (Shea and Chesson 2002; Arim et al. 2006) through their high adaptive capacity which enables them to penetrate natural geographic barriers or political boundaries (Richardson et al. 2000; Anastasiu and Negrean 2005; Anastasiu et al. 2008; Andreu and Vila 2010). As a result, invasive species are characterised by remarkable spatio-temporal dynamics, thus becoming successfully established and spread over extended areas in Europe, triggering significant environmental and socio-economic damages (Pyšek and Hume 2005; Lambdon et al. 2008). It is estimated that only 0.1% of the introduced species became invasive (Williamson 1996). However, at European level, in the last two centuries, an increasing number of species have become capable of spreading on an annual average of 6.2 neophytes (Lambdon et al. 2008, Pyšek et al. 2009). In protected areas, in particular, biological invasions are disturbing drivers for ecosystem functioning and structure, as well as for species, species communities or habitats (De Poorter et al. 2007). The site features that have been associated with invasibility include both environmental and anthropogenic factors such as disturbance (Almasi 2000; Silveri et al. 2001), proximity to roads (Harrison et al. 2002), soil nutrients, topographic position and forest fragmentation (Brothers and Spingarn 1992; Cadanasso and Pickett 2001, Mortensen et al. 2009).

A. fruticosa is considered one of the most invasive species, native to the south-eastern part of North America, widely introduced in North Asia and Europe (Weber and Gut 2004). In Romania, the species has been cultivated prior to the nineteenth century (Sîrbu and Oprea 2011; Sîrbu et al. 2012). Since 1975, it has become invasive and after 1985, it has spread over broader areas proving the high capacity for widening its habitat (Stănescu et al. 1997). However, it became adapted to different types of habitats such as: river banks (poplar or willow galleries, almond willow-osier scrubs), unvegetated or sparsely vegetated shores, water-fringing reed-beds, riverine and lake-shore scrubs (Anastasiu et al. 2008), as well as mesophyle and xeromesophyle meadows in western Romania (Sărăţeanu 2010). Recent studies consider that *A. fruticosa* is one of the worst invaders in wetland habitats (Doroftei 2009), a real competitor to native plant or riverine scrubs (Anastasiu and Negrean 2006) with high capacity to remove indigenous species (Sîrbu et al. 2016a).

Recent interdisciplinary studies conducted in the framework of FP7 enviroGRIDS project – *Building Capacity for a Black Sea Catchment Observation and Assessment supporting Sustainable Development* (WP5 – Impacts on Selected Societal Benefit; Subtask 5.6.2: *Terrestrial Invasive Plant Species in Romanian Protected Areas*) have identified and assessed *A. fruticosa* in the Danube Delta Biosphere Reserve, Comana and Mureş

Floodplain Natural Parks in relation to species preference for different natural and human-induced conditions (Dumitraşcu and Grigorescu 2016). Thus, large areas covered with *A. fruticosa* were spotted in wetlands, along forest roads, in arable lands, in the proximity of transport routes etc. (Anastasiu et al. 2008; Dumitraşcu et al. 2013; Dumitraşcu et al. 2014). In 2016, a first synthesis work, representing a geographical approach of the invasive terrestrial plant species in the Romanian protected areas, was elaborated. The volume includes various aspects connected with the *A. fruticosa* and its impact on the protected ecosystems, as well as relevant environmental and anthropogenic driving factors which influence its potential spread (Dumitraşcu and Grigorescu 2016). As a result, a first methodology, aiming to assess the spatial potential distribution of *A. fruticosa* in important wetland protected areas, was elaborated. Hence, based on the GIS spatial and statistical analysis, the frequency of the invasive species in relation to its natural and human-induced driving factors was calculated in order to identify different ecological requirements in various habitat types aimed at modelling the areas with different potential distribution (Kucsicsa et al. 2016).

Limited resources are available for the control of these plants (Goslee et al. 2006). Given this constraint, the mapping and assessment of invasive species' potential distribution can provide a useful tool for investigating its dynamics at different spatial scales. Thus, numerous studies use logistic regression to identify and quantify the strength of association between invasive plant presence and environmental and anthropogenic factors and to model their potential spread in new areas (e.g. Panetta and Dodd 1987; Franklin 1995; Higgins et al. 1999; Rouget et al. 2001; Dirnbock et al. 2003; Rew et al. 2005; Goslee et al. 2006; Fukasawa et al. 2009; Joly et al. 2011). In this respect, based on GIS spatial and statistical analysis, within the current research, two objectives have been achieved: (1) to identify which of the analysed explanatory driving factors better contribute to the explanation of *A. fruticosa* occurrence and (2) to generate a probability map in order to identify the areas with different potential for *A. fruticosa* spreading in the Mureș Floodplain Natural Park. The results of the current study might be useful for the administration of Mureș Floodplain Natural Park in terms of directing the management efforts towards monitoring the areas at high risk of being affected by invasive species and as support for thorough future research at finer spatial scales.

Materials and methods

The study-area

Mureş Floodplain Natural Park is located in the western part of Romania (20°53'E; 46°07'N) in the Panonic biogeographic region (Fig. 1). The study-area covers 17,455 ha and overlaps the lower part of the Mureş River (tributary of Tisa River), occupying the embanked enclosure of the river between the city of Arad and the state border with Hungary (Bălteanu et al. 2016).

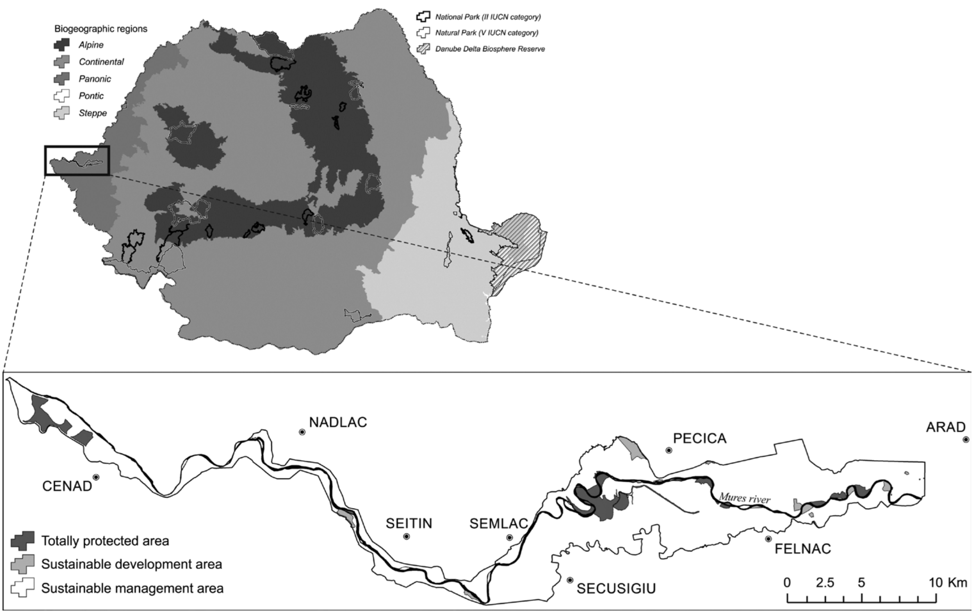

Figure 1. Location of the Mureş Floodplain Natural Park in Romania.

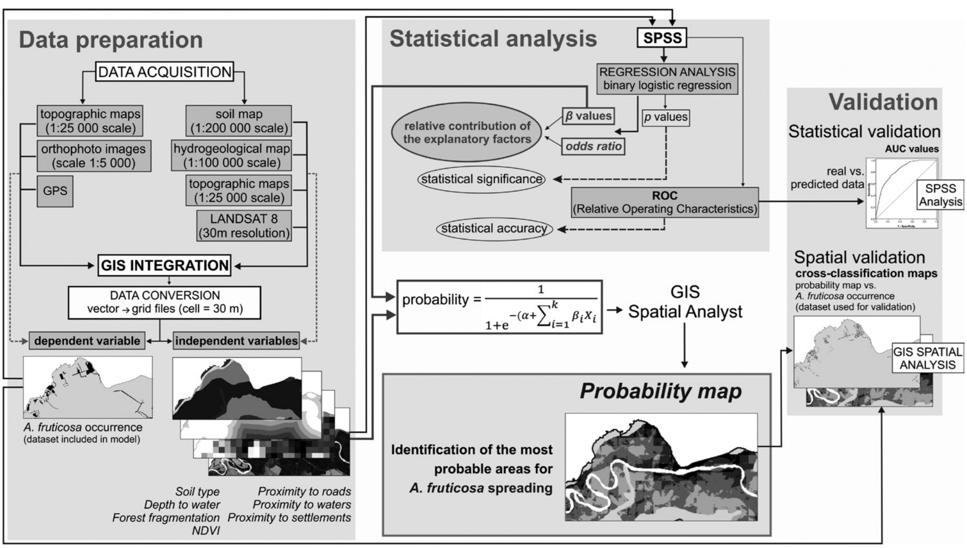

Figure 2. The flowchart showing the methodology used to assess *A. fruticosa* in Mureş Floodplain Natural Park.

The Mureş Floodplain Natural Park, established in 2004 through Government Decision no. 2151/2004, falls into *V IUCN category - Protected Landscape (Natural Park)* and Natura 2000 European Network, both *SPA – Special Protection Areas* and *SCI - Site of Community Importance*. Furthermore, since 2006, the area was included on the RAMSAR list as *Wetlands of International Importance*. The Park is a typical wetland area with running and still waters, alluvial forests, as well as an important place for nesting and passage for a large number of bird species of international importance (Dumitraşcu et al. 2013), hosting specific wetland habitats and species of conservation interest within four nature reserves: *Prundu Mare-Pecica, Igriş Isles, Insula Mare Cenad* and *Cenad Forest* (Bălteanu et al. 2016).

Generally, the area is a floodplain with altitudes decreasing from about 110 m (in east) to about 80 m (in west). The climate is temperate-continental with oceanic humid influences (Bogdan 2004), with almost 10–11 °C mean annual air temperature and 500–600 mm mean annual precipitation (Bogdan et al. 2016). Forests (in the eastern half) and agricultural land (mainly arable) represent the main land use/cover category of the Park.

According to the geographical distribution of habitats, the importance of the species and management, the Park is divided into three different zones: (1) the totally protected area (6%) which includes the most valuable natural elements, (2) the sustainable management area (92%), also called the buffer zone, which makes the transition between the totally protected area and (3) the sustainable development area (2%) which includes built-up areas or natural resources exploitation sites that existed prior to the designation of the protected area. Within the totally protected area, any form of use of natural resources, construction or investments which do not meet the sustainable management of the protected natural area and/or scientific research activities is forbidden. In the buffer zone, it is prohibited to build new constructions, except for those that strictly serve the protected natural area, the scientific research activities or those meant to ensure national safety or the prevention of natural disasters. Investments or development activities are accepted in the sustainable development area, priority being given to tourism, albeit respecting the sustainable use of natural resources and the prevention of any significant negative effects on biodiversity (Mureş Floodplain Natural Park Administration 2016).

Methodology

The current study aims to explain the relationships between *A. fruticosa* occurrence and its explanatory driving forces, on one hand and to model the probability of the potential distribution using spatial analysis and binary logistic regression (BLR), on the other. The methodology, used in the present study, includes three main stages: the extraction of the geospatial datasets, the spatial analysis using GIS and the statistical analysis using SPSS (Statistical Package for the Social Sciences) software package. Synthetically, Figure 2 describes the methodology applied to calibrate, simulate and validate the model in order to assess the potential distribution of *A. fruticosa* in Mureş Floodplain Natural Park.

Data and data processing

Based on field research findings, as well as on data availability, eight spatial datasets representing the dependent and the independent variables (Fig. 3) were employed to model

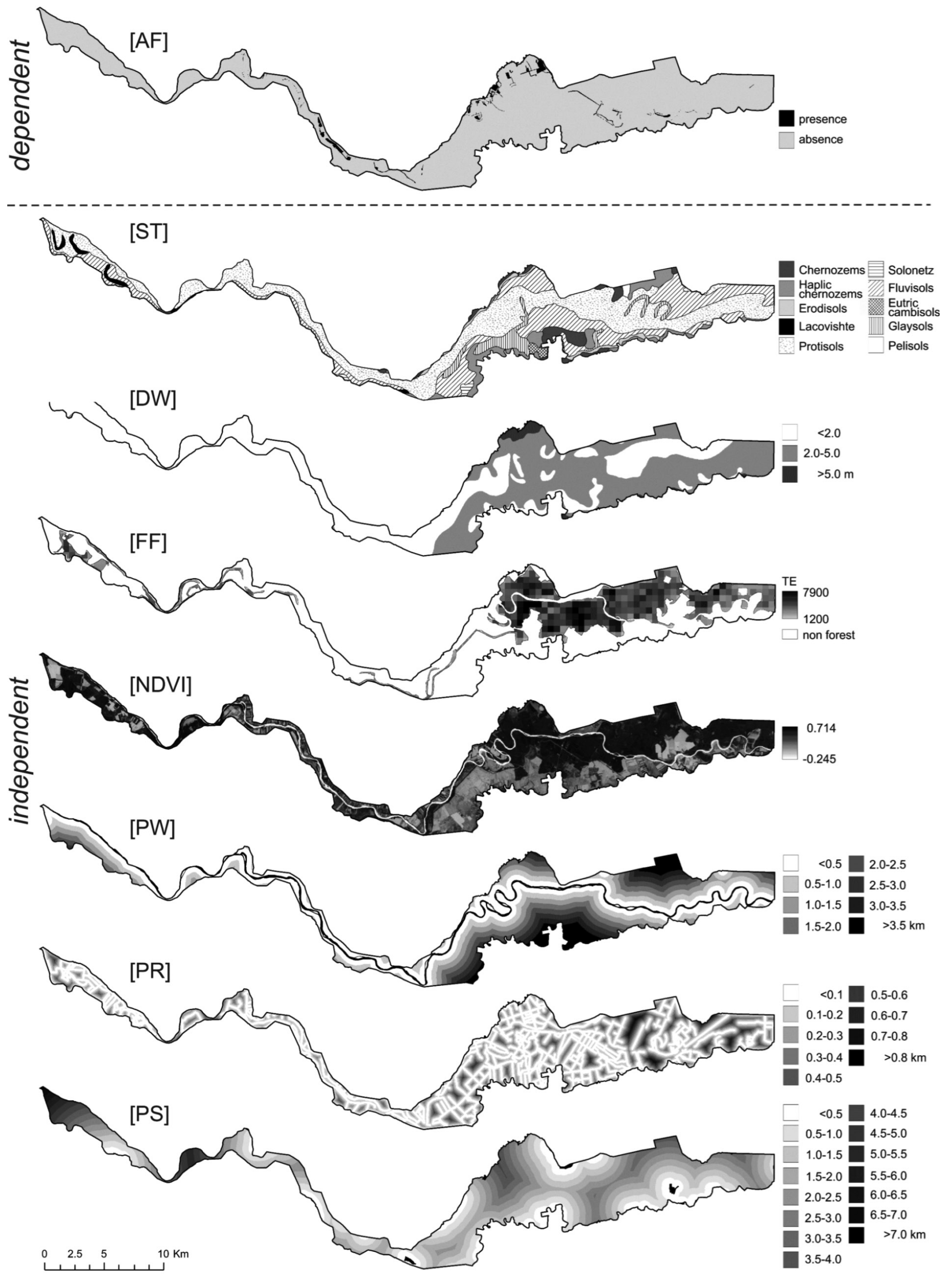

Figure 3. Raster layers representing the dependent and independent variables.

the probability of *A. fruticosa*'s potential distribution: *A. fruticosa* presence/absence (AF), soil type (ST), depth to water (DW), proximity to water (PW), Normalised Difference Vegetation Index (NDVI), proximity to near roads (PR), forest fragmentation (FF) and proximity to near settlements (PS). Due to the relative homogenous topographical characteristics with rather insignificant altitudinal difference (about 30 m), as well as to its longitudinal and latitudinal low extension (00°47' and 00°07', respectively), the explanatory factors related to climate and relief were not considered. Moreover, the scale of the study area, coupled with the particular local environmental features, makes this research a valuable local-scale approach, allowing a better understanding of the environmental issues and an increased potential for being included into the decision-making process. Thus, we consider that such an approach can be replicated to other geographical areas with similar environmental conditions or extrapolated from local to regional scales.

Dependent variable: *A. fruticosa* occurrence

The layer of *A. fruticosa* presence/absence in the Mureş Floodplain Natural Park was derived from the data collected during the field surveys which were carried out between 2012 and 2016. The mapping was realised using topographic maps (1:25000 scale) and, for more accuracy, using orthophoto images (scale 1:5000) and GPS measurements. The species was identified in various habitat types where field relevés with over 20% coverage (according to Braun – Blanquet scale) and frequency (according to Raunkiaer scale) were taken into consideration (Grigorescu et al. 2014). Thus, the total mapped area covers a surface of 363 ha, including polygons with different coverage of *A. fruticosa.*

With respect to the dataset used to model the probability map, a binary raster with the categories "presence" (coded with 1) and "absence" (coded with 0) was generated (Fig. 3), in order to discriminate the cells with *A. fruticosa* occurrence from the non-occurrence.

Explanatory factors

After processing different maps (topographic, soil and hydrogeological) and orthophoto images, six thematic layers were extracted and analysed: soil characteristics, piezometric level, surface waters, forests, built-up areas and roads from where soil type, depth to water, forest fragmentation, distance to roads, distance to waters and distance to settlements were derived.

In order to assess the occurrence of *A. fruticosa* within the dominant vegetation cover, the NDVI *(Normalised Difference Vegetation Index)* was used. This index was calculated using the Landsat 8 OLI_TIRS (Operational Land Imager_Thermal Infrared Sensor, accessed July 18, 2017) acquired from the United States Geological Survey – USGS (portal available at http://www.usgs.gov/). This index, developed by Rouse et al. in 1974 and widely used for the remote sensing of vegetation, is a measure of surface reflectance and gives a quantitative estimation of vegetation growth and biomass (Hall et al. 1995). The NDVI values were obtained by employing the following formula:

$$NDVI = \frac{NIR - RED}{NIR + RED}, \qquad \text{(Eq.1)}$$

where *NIR* = reflectance in the near infrared band; *RED* = reflectance in the red (visible) band.

Table 1. The input independents variables used to assess *A. fruticosa* potential occurrence.

Data layer	Meaning	Source	Data type	Assumption
Soil type (ST)	chernozems; haplic chernozems; erodisols; lacovishte; protisols; solonetz; fluvisols; eutric cambisols; glaysols; pelisols	National Research & Development Institute for Pedology, Agrochemistry and Environment Protection) (scale 1:200 000)	categorical	specific characteristics (e.g. soil moisture, nutrient availability, microorganisms, humus quality and quantity, pH) which play an important role in the occurrence of the invasive species
Depth to water (DW)	low piezometric level (<2 m); medium piezometric level (2–5 m) high piezometric level (>5 m)	Hydrogeological map (Geological Institute of Romania) (scale 1:100 000)	categorical	lower piezometric levels are assumed to be more suitable for invasive species occurrence due to the better connectivity to groundwater
Forest fragmentation (FF)	slightly fragmented forests (TE <2000 m) moderate fragmented forests (TE 2000–5000 m) highly fragmented forests (TE >5000 m)	derived from orthophoto images (scale 1: 5 000)	categorical	forest fragmentation could increase ecosystems' vulnerability to invasive species
Normalised Difference Vegetation Index (NDVI)	no vegetation areas (NDVI <0) crop lands (NDVI = 0–0.25) grasslands (NDVI = 0.25–0.40) transitional woodland-scrub (NDVI = 0.40–0.55) forests (NDVI = >0.55)	derived from LANDSAT 8 satellite image (30 m resolution)	categorical	vegetation cover can lead to spatial heterogeneity in invasive species distribution
Proximity to roads (PR)	distance to nearest roads (buffer = 0.1 km)	derived from topographic map (scale 1:25 000)	continuous	influence of roads in ecosystems fragmentation role of roads in facilitating the movement of the invasive species road traffic can favour invasive species' expansion (tolerance to polluting environments)
Proximity to settlements (PS)	distance to nearest settlements (buffer = 0.5 km)	derived from topographic map (scale 1:25 000)	continuous	the invasive species could be facilitated by human activities (e.g. plantation as ornamental species, natural habitat disturbance)
Proximity to waters (PW)	distance to nearest waters (buffer = 0.5 km)	derived from topographic map (scale 1:25 000)	continuous	water is considered as one of the main vectors for invasive species dissemination fluvial processes can generate natural disturbances that create suitable sites for invasive species expansion water can generate a microclimate with potential influence on the invasive species expansion

The resultant NDVI values ranged between –0.245 and 0.714. After the visual interpretation of orthophoto images, the NDVI values were considered as representing: no vegetation areas (aquatic surface, bare soils, built-up areas, recent riverbed deposits) (NDVI <0); agricultural crops (NDVI = 0…0.25); herbaceous vegetation (NDVI = 0.25…0.4); transitional woodland-scrub (0.40…0.55); forest vegetation (NDVI >0.55).

Total edge (TE), calculated as the sum of the lengths (m) of all edge segments in a class or landscape (McGarigal and Marks 1995) was used to quantify the forest fragmentation. In this case, the TE was calculated just for the forested class, in a 25 ha window size, using Patch Analyst (Rempel et al. 2012), a GIS tool developed to analyse spatial landscape patches and model the attributes associated with patches, according to numerous statistical metrics. The resultant values were categorised in: slightly fragmented forests (TE <2000 m); moderate fragmented forests (TE = 2000…5000 m); highly fragmented forests (TE >5000 m). Moreover, based on the *Euclidean multiple ring* buffers, maps depicting the distance to roads (buffer = 0.1 km), waters (buffer = 0.5 km) and settlements (buffer = 0.5 km) were created. Twenty-one binary rasters were generated to distinguish the ten soil type classes, three piezometric levels, three forest fragmentation classes and five NDVI classes. Finally, twenty-four categorical and continuous independent variables were prepared and homogenised as raster with 30×30 m cell (equivalent to the spatial resolution of the Landsat image used to derive NDVI) for further spatial and statistical analyses (Table 1). For these variables, several assumptions related to location suitability were presumed in order to explore the relationship between the invasive species and its explanatory factors.

Statistical analysis

In the present study, to assess the relationships of the site characteristics and *A. fruticosa* presence/absence, BLR was applied. This method is the most commonly used parametric model aimed at determining the empirical relationships between a dependent and several independent variables (McCullagh and Nelder 1989), where the dependent variable is a binary presence (1) or absence event (0) and the independent variables are categorical and/or continuous variables. If binary values 1 and 0 are used to represent *A. fruticosa* occurrence and no occurrence, respectively, the probability of the presence of the species for any specific grid cell was calculated using the logistic curve as described by the logistic function (Kleinbaum 1994):

$$f(z) = \frac{1}{1+e^{-z}}, \qquad \text{(Eq.2)}$$

then the probability of occurrence can be estimated with the following logistic regression model:

$$P(Y = 1|X_1, X_2, \ldots, X_i) = \frac{1}{1+e^{-(\alpha+\sum_{i=1}^{k}\beta_i X_i)}}, \qquad \text{(Eq.3)}$$

where $P(Y=1|X_1, X_2, ..., X_i)$ is the probability of the dependent variable Y being 1 given ($X_1, X_2, ..., X_i$), i.e. the probability of a cell of being invaded by invasive species; X_i is an independent variable representing the explanatory factors of *A. fruticosa* and β_i is the coefficient for variable X_i.

The response of these regression functions is visualised into the raster probability map based on the location suitability, given the probability of the occurrence of *A. fruticosa* in each resultant raster cell.

In order to reduce the effects of multi-collinearity, before the logistic regression analysis, *Pearson* correlations between each pair of independent variables were conducted and examined. In case of strong correlations (min. ±0.7), the better predictor variable (in univariate trials) was retained. Furthermore, to verify the explanatory power of the variables included in the sub-model, the *Cramer's V* statistics tool was used. *Cramer's V* is a statistic that transforms chi-square (for a contingency table larger than two rows by two columns) to a range of 0–1, where unit value indicates complete agreement between the two nominal variables (Liebetrau 1983). The test procedure is based on contingency table analysis which can test the strength of the association between the dependent variable and both continuous and categorical independent variables.

Model calibration and assessment of potential distribution

The BLR was performed using the backward stepwise method in SPSS in order to obtain the best-fit combination for predictors. Thus, the variables, which collectively best explain *A. fruticosa* occurrence, were adopted by the regression model. To indicate the effectiveness of the each sets, a Nagelkerke pseudo R square (Nagelkerke 1991) was determined. Furthermore, ROC/AUC (Relative Operating Characteristic/Area Under Curve) was used to test the "goodness of fit" (Pontius and Schneider 2001). In the standard ROC approach, the predictive probability map is compared with the map of the true binary event in order to assess the spatial coincidence between the event and the probability values (Mas et al. 2013). This graph displays the predictive accuracy of the logistic model, which can be evaluated using the area under the ROC curve (AUC). A completely random model gives a ROC value of 0.5, while a perfect fit results in a ROC value of 1.0. For the best-fit combination for resultant predictors, the maximum likelihood estimator (Hosmer and Lemeshow 1989) was determined. In the BLR, the model is considered to fit if the value of the Hosmer-Lemeshow test shows a value higher than *p*-value (0.05).

Based on the corresponding coefficients of the best fit predictor set, the relative contribution of the explanatory variables of the *A. fruticosa* occurrence was assessed and the potential distribution probability map was generated. To categorise the resultant map, five classes were used to classify the probability values: very high, high, medium, low and very low probability. The classification was performed by *Natural breaks (Jenks)*, a method that seeks to reduce the variance within classes and to maximise the variance between classes (Jenks 1967), commonly used in GIS techniques for grouping spatial values that are not evenly distributed.

Spatial validation

Usually, in the analysis and modelling of spatial data, real datasets are used to validate the performance using different techniques. A typical procedure is splitting data into two parts (Kanevski and Maignan 2004): training set (used to develop the model) and validation set (used to estimate the ability of the model). The proportions of data included in each dataset are somewhat arbitrary and dependent on the total mapped area available, 70% for calibration and 30% for validation being commonly used (Pearson 2010). According to the available datasets representing *A. fruticosa* occurrence (mapped) and to build the model with a significant percent for the training set, in the present study a 70%/30% training/validation split was considered. Furthermore, to eliminate sampling biases and associated subjectivism, the random-partition was used to extract the data for validation. Then, based on the cross-classification technique, the analysis between validation dataset and probability map was achieved and the frequency of the *A. fruticosa* occurrence was identified and quantified for each probability class.

Results

The occurrence of *A. fruticosa* in relation to the analysed explanatory variables

In terms of the analysed explanatory factors, *A. fruticosa* distribution across the park has a relative spatial heterogeneity. The frequency analysis (Fig. 4) shows that *A. fruticosa* occurs in various conditions but with differences mainly according to the soil type, vegetation cover and distance to roads. In relation to soil type, *A. fruticosa* overlaps largely protisols and fluvisols (92% of the total mapped area). Similar to the soil particularities, the roads appear to have the most important role in facilitating the establishment of *A. fruticosa*. In detail, the frequency of species related to distance to nearest roads, calculated for 0.1 km buffer rings, shows that 68% of the mapped area is identified in the first 0.1 km and 91% in the first 0.2 km. In relation to the depth to water, the most significant areas with *A. fruticosa* (58%) were mapped in the high floodplain, the sand banks and floodplain terraces where the aquifer level is situated at 2.0–5.0 m depth. In relation to the forest fragmentation, *A. fruticosa* was mainly found (69%) in the moderate fragmented forests (TE = 2000–5000 m/25 ha). Related to NDVI values, the large occurrence of *A. fruticoasa* (46%) is mainly related to values ranging between 0.40 and 0.55, thus indicating a preference of the invasive species for transitional woodland-scrub. Furthermore, the notable occurrence (25%), in relation to the highest NDVI values (>0.55) and 17% in relation to the medium positive NDVI values (0.25–0.40), indicate also a preference for forest vegetation and grasslands. In relation to the water's vicinity, 55% of the total mapped areas with *A. fruticosa* are situated close to the Mureș River, within the first 0.5 km buffer ring. The

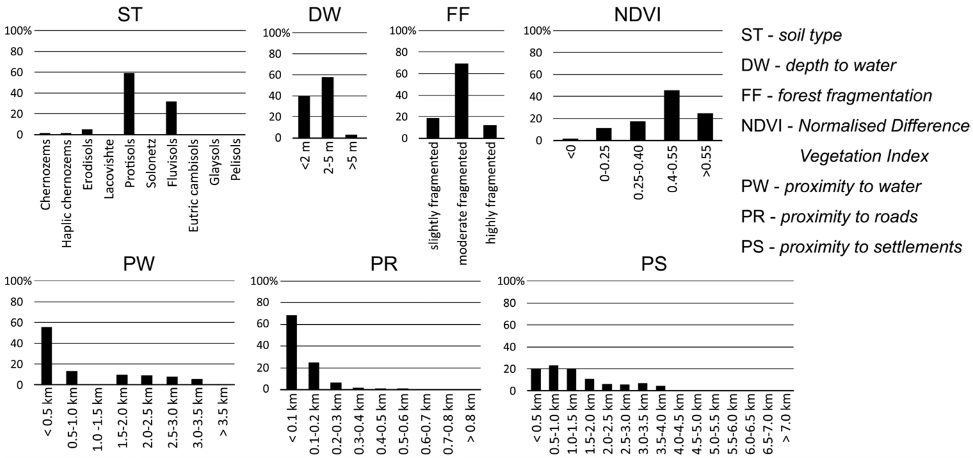

Figure 4. The distribution of *A. fruticosa* (mapped) in relation to the analysed explanatory factors.

frequency distribution of *A. fruticosa* indicates also an increasing occurrence in relation to the distance to settlements. Thus, 43% of the total mapped areas are distributed in the first 1 km and 73% in the first 2 km buffer rings.

Correlation analysis amongst the explanatory variables

The *Pearson* correlation analysis between the independent variables showed that the variables were not highly inter-correlated (max. ±0.30), which suggests the absence of multicollinearity. The highest values were found between NDVI (>0.55) and slightly fragmented forests (0.298), depth to water (<2 m) and protisols (0.255). The lowest coefficients (0.001) were found between slightly fragmented forests and chernozems soil type, moderate fragmented forests and depth to water (>5 m), NDVI (0–0.25) and lacovishte soil type.

Association between dependent variable and explanatory variables using *Cramer's V* test

The explanatory power of the independents' variables was tested based on the *Cramer's V* statistics. According to this method, the analysed explanatory factors were not strongly associated with *A. fruticosa* occurrence. Overall, continuous and few categorical variables were found to have better association with *A. fruticosa* occurrence with *Cramer's V* values between 1.5 and 2.3: proximity to roads (V = 0.224), proximity to settlements (V = 0.221), proximity to waters (V = 0.193), piezometric level <2 m (V = 0.151), moderate forest fragmentation (V = 0.161) and NDVI values between 0 and 0.25 (V = 0.152). Furthermore, except for erodisols (V = 0.143), protisols (V = 0.122), fluvisols (V = 0.113), piezometric level between 2 and 5 m (V = 0.114), highly fragmented forests (V = 0.105) and NDVI values between 0.25 and 0.40 (V = 0.11), remaining variables have values less than 0.1, indicating a weakly association with the *A. fruticosa* occurrence.

Logistic regression modelling

Setting the backward stepwise in the BLR, eight steps for the best predictor sets resulted (Table 2). Variables that were not statistically significant, associated with *A. fruticosa* occurrence within the 95% confidence interval, were identified and automatically excluded by the model. Thus, the best-fit combination for predictors was found in step eight, which includes seventeen explanatory factors (Table 3).

Table 2. Regression coefficients, indicating the effectiveness of eight sets of predictors, resulted after setting the backward method in BLR.

set	Nagelkerke R^2	AUC
1	0.161	0.648
2	0.195	0.743
3	0.220	0.769
4	0.228	0.777
5	0.237	0.790
6	0.241	0.794
7	0.242	0.797
8	0.243	0.798

Table 3. Estimated coefficients for the logistic regression model.

Independents' variables	*β*	*p*	*Odds ratio (OR)*
Erodisols (soil type)	2.923	0.000	18.588
Protisols (soil type)	2.101	0.000	8.171
Fluvisols (soil type)	1.940	0.000	6.961
Depth to water (0–2 m)	1.587	0.000	4.891
Depth to water (2–5 m)	0.867	0.000	2.381
Depth to water (>5 m)	–1.065	0.000	0.345
Forest fragmentation (low)	0.193	0.000	1.213
Forest fragmentation (medium)	0.672	0.000	1.959
Forest fragmentation (high)	1.167	0.000	3.211
NDVI (< 0)	0.202	0.035	1.224
NDVI (0–0.25)	0.415	0.032	1.515
NDVI (0.25–0.40)	0.872	0.039	2.392
NDVI (0.40–0.55)	0.833	0.049	2.301
NDVI (>0.55)	0.326	0.043	1.385
Proximity to roads	–0.694	0.000	0.500
Proximity to settlements	–0.155	0.000	0.857
Proximity to waters	0.006	0.018	1.006
Constant	–13.056	0.074	

For set-8, the regression "goodness of fit" measured by the Nagelkerke R^2 is -0.243 which, according to Clark and Hosking (1986), indicates that the model is a good fit for the data. Therewith, Hensher and Johnson (1981) also stated that pseudo R^2 value between 0.2 and 0.4 can be considered as an extremely good fit. The predictor set-8 also attained the highest accuracy (AUC=0.798) showing a prediction ability of 79.8% of the model. Furthermore, the Hosmer-Lemeshow significance test resulted in Chi-square = 13.39 and p = 0.063 (>0.05), indicating a good fit of the model.

The relative contribution of the explanatory factors was evaluated using the corresponding coefficients in the BLR (Table 3). Based on the coefficients' values, all the explanatory variables were ranked. Thus, amongst all variables, erodisols, protisols and luvisols were found as the most significant predictors for *A. fruticosa* occurrence in the study area. All values of OR are greater than one, indicating a higher probability of *A. fruticosa* occurrence in those areas comparing to other soil type classes. The probability of *A. fruticosa* occurrence in areas with erodisols is larger than the probability in areas covered with protisols. The areas with protisols present more suitability for *A. fruticosa* occurrence than areas with luvisols. This can be seen from the odds ratio values of 18.59, 8.17 and 6.96 in a decreasing order for erodisols, protisols and luvisols, respectively.

The regression model showed a positive relationship between *A. fruticosa* occurrence and depth to water for piezometric level less than 2 m and between 2 and 5 m and negative relation with respect to a piezometric level higher than 5 m. This means that, with the increase in depth to water, the *A. fruticosa* occurrence decreases due to less connectivity to groundwater. This can be seen in the odds ratio values (4.89, 2.38 and 0.35) in a decreasing order for the piezometric level. Furthermore, the positive values of β and OR show that *A. fruticosa* tends to spread in moderate and mainly highly fragmented forests. However, the positive values of β (0.19) and the value of OR greater than one (1.21) for slightly fragmented forests also demonstrate that the species can spread in rather compacted afforested areas.

The model also demonstrates that *A. fruticosa* is in relation to vegetation cover, the positive β coefficients and OR values for NDVI values >0.25 showing the tendency of species to spread in areas with grasslands, transitional woodland-scrub and afforested areas. The estimated β value (–0.694) and OR (0.50) for the proximity to roads indicates that the probability of *A. fruticosa* occurrence further away from roads is less expected. Specifically, the probability of species occurrence would decrease 2 times if distance to roads increases by 0.1 km. The model demonstrates that *A. fruticosa* occurrence is not significantly controlled by the proximity to settlements, however the negative value of β (–0.16) indicates that, with the increase in distance to settlements, the probability of this invasive terrestrial species to occur decreases. Thus, the odds of *A. fruticosa* occurrence in an area 0.5 km closer to settlements is estimated to be 1.17 as large as that in areas further away from settlements.

The regression results for proximity to waters (β = 0.006; OR = 1.006) revealed that they have no significant influence on *A. fruticosa* occurrence.

The probability map of *A. fruticosa* occurrence

The probability of *A. fruticosa* occurrence was assessed by plugging the β coefficients of the logistic regression model containing the 17 significant predictors (Table 3) into Eq. (3). Thus, the probability map (Fig. 5) indicated that 24.9% of the grid cells have high and very high suitability for *A. fruticosa* occurrence, largely in the eastern half of the Park, close to Felnac, Pecica and Semlac localities. Here, the suitability is mainly characterised by the favourable soil type, the presence of numerous agricultural and forestry roads and the large extension of the pastures and transitional woodland-scrub vegetation. On the other hand, the lowest probability values are in the western (near Cenad locality), north-eastern and southern parts of the protected area (near Arad and Secusigiu localities) where the unsuitable soil type classes and piezometric level ranking between 2 and 5 m or arable lands and compacted forests are predominant.

In order to conduct the spatial validation of the model, the map of *A. fruticosa* occurrence probability, computed using the logistic regression model, was compared with the actual *A. fruticosa* occurrence (reference datasets used for validation). Thus, the cross-classification map reveals a relatively good spatial fit between the observed data and the predicted data (Fig. 6). Both very high and high probability classes include 69.9% of total cells, representing the real *A. fruticosa* location used as the validation dataset. Furthermore, only 10% of the total pixels, representing the real *A. fruticosa* used as the validation dataset, overlap the very low and low probability classes.

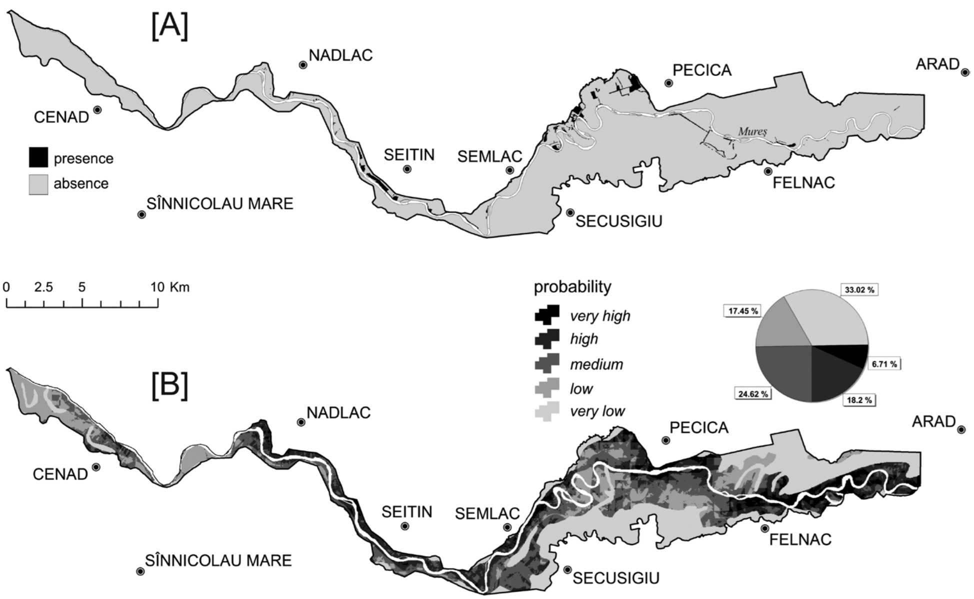

Figure 5. The mapped areas (**A**) and the probability of *A. fruticosa* occurrence, based on the BLR (**B**).

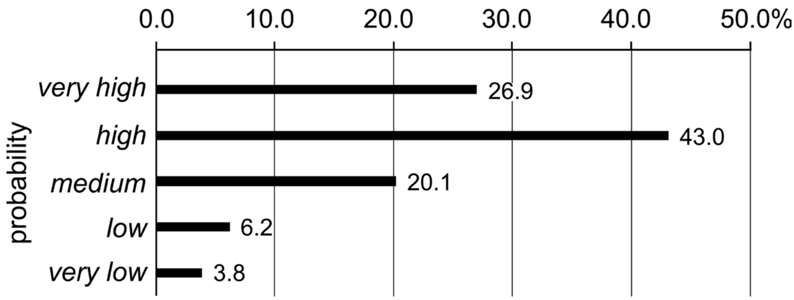

Figure 6. The frequency of *A. fruticosa* occurrence (datasets used for validation) in the probability classes.

Discussion

A. fruticosa location in the Mureș Floodplain Natural Park

The field surveys in the Mureș Floodplain Natural Park have shown *A. fruticosa* occurrence in different ecosystems and habitats, significantly affecting the native vegetation. The species were identified mainly along the forest roads edges and forest glades (especially north to Mureș River), as well as along the edges of arable lands (mainly abandoned, unused) with a tendency to invade them in the west and north-west of Felnac locality. The largest area was identified in the western part of Pecica locality and north-west of Fenlac, along the forest roads and at the contact between forested areas and pastures or arable lands. Therewith, the species has a significant spread south-west of Şeitin locality on arable lands and along Mureş River (Fig. 7). Selected biological indices (coverage, frequency, abundance) computed in six representative sites during the field research, indicate a preference mainly for the riparian habitats (with *Salix alba* and *Populus alba*), alluvial forest (with *Alnus glutinosa* and *Fraxinus excelsior*), riparian mixed forests (with *Quercus robur*, *Ulmus laevis*, *U. minor*, *Fraxinus excelsior*, *F. angustifolia*) and muddy banks (with *Chenopodium rubri* pp and *Bidention* vegetation).

In relation to park zoning, out of the total mapped surface, 1.7% is located in the totally protected area (Felnac, Libus), 13.6% in the sustainable development area (largely in Pecica locality), while the remainder (84.7%) is in the sustainable management area, mainly spreading along the left bank of Mureş River.

The main explanatory factors of *A. fruticosa* occurrence. Expected invasion

The driving factors of *A. fruticosa* occurrence may vary from place to place. Many factors can affect the establishment and spread of invasive species (Underwood et al. 2004). They include the interaction of multiple environmental variables, such as elevation, precipitation and soil type, which constitute the species' fundamental niche (Hutchinson 1957; Pysek et al. 2003). Invasive species have also been associated with areas of distur-

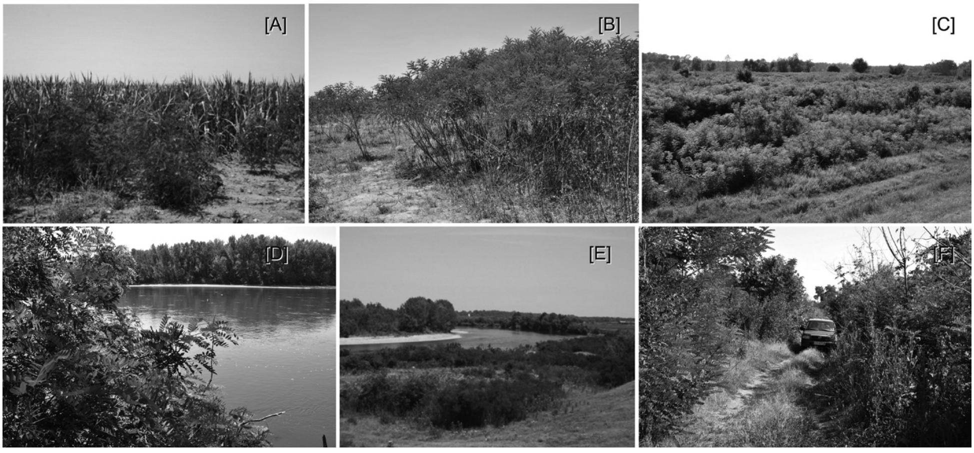

Figure 7. *A. fruticosa* invading: **A** crop lands **B** grasslands **C** abandoned agricultural land west of Pecica locality **D, E** Mureș River riverbed **F** forest roads.

bance, either natural (e.g. fire or floods; Rejmánek 1989; Mack and D'Antonio 1998) or human related (Macdonald et al. 1988; Cowie and Werner 1993) and influenced by abiotic factors, such as historical land use and management (Mack et al. 2000).

In the present study, the selected explanatory variables encompass a significant share of the driving factors. Many studies have indicated that most of the analysed factors were also found to be important in other protected wetland areas in Romania (Dumitraşcu et al. 2011, Dumitraşcu et al. 2013, Kucsicsa et al. 2013; Dumitraşcu et al. 2014; Grigorescu et al. 2014), as well as in the other European countries (Blagojević et al. 2015; Radovanović et al. 2017; Delai et al. 2018). In the present study, the model shows that *A. fruticosa* is mainly controlled by the soil, groundwater's availability, predominant vegetation type in the invaded areas and human-induced disturbance (forest fragmentation, roads extension). Specifically, amongst all analysed explanatory factors, erodisols, protisols and luvisols were found as the most significant categorical predictors for *A. fruticosa* occurrence in the Mureş Floodplain Natural Park. It should be noted that, in the study area, these classes of soil types cover about 80% of the total area, thus indicating a significant potential for *A. fruticosa* to spread in large areas of the park. The model also proved a significant relationship between the piezometric level and *A. fruticosa* distribution indicating species' requirements for water availability in the soil.

A. fruticosa is considered a weak competitor in forests because it is usually excluded by tree species (Magyar 1960), but due to its fast growth, shading and probably its allelopathic effects (Elakowich and Wooten 1995) and nitrogen-fixing ability (Wang et al. 1999), it is a superior transformer in grasslands (Szigetvári 2002). In the present study, the model confirms the strong adaptability of *A. fruticosa* in grasslands areas. However, it can be noticed that the regression coefficients for highest values of NDVI also show the tendency of *A. fruticosa* to spread in the transitional woodland-scrub and afforested areas. This can indicate the adaptation capacity to any terrestrial ecosystems and, consequently, a tolerance for semi-shade. Furthermore, the model indicates the preference of *A. fruticosa* for fragmented forests, confirming that forest fragmentation could increase the ecosystems' vulnerability to invasive species and habitat decline (Turner 1989).

It is widely known that roads can serve as corridors for the movement of invasive species (Christen and Matlack 2006), as well as for providing main habitats for establishment (Mortensen et al. 2009). In other Romanian protected areas, large areas covered by *A. fruticosa* were spotted in wetlands, along the forest roads (Dumitraşcu et al. 2013; Dumitraşcu et al. 2014). This can be explained by their influence in ecosystems fragmentation through creating suitable areas for invasive species growth. For the present-study, the regression results indicate that the proximity to roads was the predictor that has the most important contribution for *A. fruticosa* occurrence amongst the continuous driving factors. On the other hand, the continuity and the patterns of *A. fruticosa* occurrence along the roads show the very important role of roads in facilitating the movement of this invasive plant. Moreover, the road traffic close to the Park's border can favour species' expansion, having been known for its tolerance to polluting environments (Seo et al. 2008; Marian et al. 2010; Xiang et al. 2011). The development of the invasive species on contaminated areas was confirmed within another protected area of Romania (Comana Natural Park), where the large spread of *A. fruticosa* along the main roads and non-electrified railroad was observed (Dumitraşcu et al. 2011). The model does not demonstrate that *A. fruticosa* occurrence is significantly controlled by the proximity to settlements. However, the negative value of regression coefficients shows that the presence of the invasive plant species could be facilitated by human activities, indicating that the disturbed habitats inside and close to the settlements are easier to invade. This study also revealed that the proximity of aquatic surfaces has no significant influence on *A. fruticosa* occurrence. However, the positive regression coefficients, as well as the mapped areas with *A. fruticosa* (59%) within the first 500 m distance to Mureş River, could be explained through the favourable specific microclimate or fluvial processes within the riverbed which can favour the growth of invasive species to the detriment of riparian vegetation. In addition, the occurrence of *A. fruticosa* along the riverbed could be also explained by the fact that rivers are regularly considered natural vectors for invasive species dissemination (Fenesi et al. 2009).

In this respect, the authors consider that the more ecosystems and habitats are affected by disturbance, the more likely they become invaded by *A. fruticosa*. Thus, future forest fragmentation and clearing, the extension of the transportation network and the abandonment of the agricultural lands will increase the potential spread of *A. fruticosa*. Furthermore, planting *A. fruticosa* for different purposes (on the degraded lands, protection of dams or roads) will facilitate species' invasion within the important habitats and ecosystems of the Park.

Importance of the study. Perspectives

Invasive species may cause cascading effects in communities and/or affect both biotic and abiotic components of ecosystems (Charles and Dukes 2006) bringing in substantial costs to agriculture, forest and human health (Sîrbu et al. 2016b), as well as to ecosystem services, affecting ecosystem structure and function (Charles and Dukes 2006), loss of biodiversity or unique habitats. Invasive plants may decrease the suitability of soil for native species (Callaway and Ridenour 2004), disturbing soil formation, nutrient components or altering microbial communities. As a result, detailed knowledge of species' ecological and geographic distribution is critical for effective conservation planning and modelling of its potential spread. However, data about most of species occurrence is sparse, resulting in incomplete information about species distribution, which leads to its difficult control and monitoring in sensitive areas (e.g. protected areas, wetlands). Hence, species distribution models attempt to provide detailed spatial data by relating presence of species to environmental predictors (Guisan and Thuiller 2005; Elith et al. 2006; Václavík and Meentemeyer 2009). In the current study, in order to identify and inventory *A. fruticosa,* as well as to develop a potential distribution model for the entire protected area, integrating GIS and logistic regression have been performed, given that we consider that the resultant map would provide the necessary information for the effective management of native ecosystems in the study area. Since the river systems are considered as main transport corridors for the invasive plants (Gallé et al. 1995), characterised by natural disturbances that create suitable sites for invasive species (Rood et al. 2010), it can be appreciated that *A. fruticosa* expansion could represent an important trans-border ecological issue given that Mureş River represents an important tributary of the Tisa River in the Danube Basin area. More than that, this can be critical given that the Danube is considered one of the most important routes for spreading invasive species, owing to its long distance, fluctuating water level and long-time anthropogenic presence, which facilitate these invasions (Pedashenko et al. 2012). Due to the resultant map indicating a significant susceptibility to invasion, we consider that, without careful management, the important habitats and essential ecosystem processes in large fluvial areas in the Mureş Floodplain Natural Park could be seriously disturbed in a relatively short time. Hence, the resultant outcomes could become important tools for the park's administration to adopt appropriate planning strategies for the eradication/limitation of *A. fruticosa* in view of conserving the biodiversity of native flora and, finally, to provide the sustainable development of this protected area. On the other hand, the database containing the spatial distribution of *A. fruticosa* can serve the park's administration and research as useful information about the location of the invasive species in order to monitor and carry out an assessment of the quantitative rates of dispersal in different habitats and ecosystems within the protected area, but also cross-boundary, knowing the relative continuity of the environmental conditions which provides suitable habitats for potential expansion. Furthermore, the results might be also used in other similar sites where *A. fruticosa* occurs in order to identify the areas that can be potentially invaded by this terrestrial invasive plant species. Given that this invasive plant is strongly associated with some landscape features such as soil type, depth to water, vegetation cover or roads, it is also essential to incorporate this knowledge into the assessment of potential spreading of other invasive terrestrial plant species in other sites. In addition, the probability map generated in this study can provide the basis for scenario analysis where independent variables can be improved and modified according to the specific biophysical and anthropogenic changes in an area.

Limitation of the results

Uncertainty is an inevitable component of invasion forecasts (Yemshanov et al. 2015) and modelling will always contain a level of errors resulting from a wide range of factors (Pearce et al. 2003), including insufficient sample size, measurements errors in the biological survey data or insufficient spatial resolution in the mapped environmental variables and impossibility or difficulty in integrating critical habitat variables and others factors (e.g. competition, dispersion). Hence, the resultant probability map should be used as a preliminary data on the potential distribution of *A. fruticosa* in order to identify regions with different probability and, consequently, to spot the areas that require more or less intensive monitoring of this invasive terrestrial plant species. Thus, important limitations and assumptions in the calibration of the model and generating the probability map have to be considered. The first is related to the *A. fruticosa* occurrence inventory dataset. In the present paper, we assume that all areas covered with *A. fruticosa* occurrence were not included in the analysis. However, several inconvenient factors (e.g. large extension of the area or inaccessibility in different sites) limited the mapping of all areas covered by *A. fruticosa*. We consider that the available datasets used to model the probability map were not sufficient to assess with the highest accuracy the potential occurrence *of A. fruticosa*. Thus, the estimated coefficients in the logistic regression models have associated estimation errors, the uncertainty decreasing by mapping more plant occurrence data and predictors (Horssen et al. 2002; Elith et al. 2006).

Another limitation refers to the unavailable datasets for the independent variables. Thus, the resulted pseudo R^2 values indicate that only 24.3% of *A. fruticosa* occurrence in the Mureş Floodplain Natural Park can be influenced by the analysed explanatory factors and the remaining percentage was influenced by other factors. Thus, in order to allow a better and realistic modelling of species' spreading potential in the future at a much finer scale, more information on the spatial distribution of *A. fruticosa* combined with other predictors (e.g. soil nutrients and heavy metals content, past land-use changes, existing plant community) must be integrated. Moreover, the coarse resolution of the available soils and depth to water data have also restricted the accuracy of the model. One more limitation is related to the final probability map which does not reflect its temporal probability. As it is difficult or impossible to model seed dispersal at a regional scale (Goslee et al. 2006), the current results only display the spatial distribution potential of *A. fruticosa* depending on the analysed explanatory factors, without considering the seed dispersal vectors. In addition, environmentally suitable sites within the native distributional area may remain free from invasion because of biotic interactions, dispersal limitations or historical constraints (Ricklefs and Schluter 1993; Pulliam 2000). On the other hand, these restrictive factors may, at least in theory, differ or even be lacking in invaded areas (Jiménez-Valverde et al. 2011). As a consequence, it can be appreciated that, in the future, the spread might affect more or less other areas indicated by the current research.

Conclusions

The present study is a geographical approach to assess spatial potential spreading of one of the most disturbing invasive terrestrial plant species in Europe *(A. fruticosa)* in one of the most important natural protected area in Romania (Mureş Floodplain Natural Park). Cross-referencing the scientific findings on the assessment of invasive species in Romania, revealed that the present study is one of the first attempts to explain the spatial relationships between this invasive terrestrial plant species and its explanatory factors and to assess potential distribution, integrating GIS and logistic regression into spatial simulation. Thus, the model shows that the explanatory factors of *A. fruticosa* occurrence are varied and have different influences, confirming previous findings of scientific literature and other current research on the increased tolerance and high adaptation capacity of this invasive species to a variety of conditions. The probability map, resulting from plugging the β coefficients of the logistic regression, indicates that spreading of *A. fruticosa* is expected to continue mainly in the areas where significant parcels were mapped (close to Pecica, Semlac and Seitin localities), but with extension into the eastern and central part of the Park, close to Arad, Felnac, Secusigiu and Nadlac localities. This could indicate a future strong adaptation capacity of *A. fruticosa* to many terrestrial ecosystems and, consequently, a serious threat for the native terrestrial plant species, requiring the inclusion of specific measures in the park's management plan.

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References

Almasi KN (2000) A non-native perennial invades a native forest. Biological Invasions 2(2): 219–230. https://doi.org/10.1023/A:1010009123469

Anastasiu P, Negrean G (2005) Alien plants in Romania. Analele ştiinţifice ale Universităţii "Alexandru Ioan Cuza" Iaşi Biologie vegetală, LI, 87–96.

Anastasiu P, Negrean G (2006) Alien vascular plants in Dobrogea (Romania) and their impact on different types of habitats. Plant, Fungal and Habitat Diversity Investigation and Conservation, Proceedings IV, BBC, Sofia, 590–596.

Anastasiu P, Negrean G, Bas C, Sîrbu C, Oprea A (2008) A preliminary study on the neophytes of wetlands in Romania. In: Rabitsch W, Essl F, Klingenstein F (Eds) Biological Invasions – from Ecology to Conservation. Neobiota 7: 181–192.

Andreu J, Vila M (2010) Risk analysis of potential invasive plants in Spain. Journal for Nature Conservation 18(1): 34–44. https://doi.org/10.1016/j.jnc.2009.02.002

Arim M, Abades SR, Neill PE, Lima M, Marquet PA (2006) Spread dynamics of invasive species. PNAS 103(2): 374–378. https://doi.org/10.1073/pnas.0504272102

Bailey J, Bimova K, Mandak B (2007) The potential role of polyploidy and hybridisation in the further evolution of the highly invasive *Fallopia* taxa in Europe. Ecological Research 22(6): 920–928. https://doi.org/10.1007/s11284-007-0419-3

Bălteanu D, Dumitraşcu M, Geacu S, Ciupitu D (2016) Ariile naturale protejate. In: Romania. Space, Society, Environment. Romanian Academy, Bucharest, 542-563.

Blagojević M, Konstantinović B, Samardžić N, Kurjakov A, Orlović S (2015) Seed Bank of Amorpha fruticosa L. on Some Ruderal Sites in Serbia. Journal of Agricultural Science and Technology B 5(2): 122–128. https://doi.org/10.17265/2161-6264/2015.02B.006

Bogdan O (2004) Regionarea climatică în: România. In: Calitatea solurilor şi reţeaua electrică de transport. Atlas geographic. Romanian Academy Publishing House, 6.

Bogdan O, Dragotă C, Micu D (2016) Potențialul climatic. In: In: Romania. Space, Society, Environment. Romanian Academy, Bucharest, 102–130.

Brothers TS, Spingarn A (1992) Forest fragmentation and alien plant invasion of central Indiana old-growth forests. Conservation Biology 6(1): 91–100. https://doi.org/10.1046/j.1523-1739.1992.610091.x

Cadanasso ML, Pickett ST (2001) Effect of edge structure on the flux of species into forest interiors. Conservation Biology 15(1): 91–97. https://doi.org/10.1111/j.1523-1739.2001.99309.x

Callaway RM, Ridenour WM (2004) Novel weapons: Invasive success and the evolution of increased competitive ability. Frontiers in Ecology and the Environment 2(8): 436–443. https://doi.org/10.1890/1540-9295(2004)002[0436:NWISAT]2.0.CO;2

Charles H, Dukes JS (2006) Impacts of Invasive Species on Ecosystem Services in Ecological Studies. Biological Invasions 193: 9–15.

Christen D, Matlack G (2006) The role of roadsides in plant invasions: A demographic approach. Conservation Biology 20(2): 385–391. https://doi.org/10.1111/j.1523-1739.2006.00315.x

Clark WAV, Hosking PL (1986) Statistical Methods for Geographers. Wiley, New York.

Cowie ID, Werner PA (1993) Non-native plant species invasive in Kakadu National Park, tropical northern Australia. Biological Conservation 63(2): 127–135. https://doi.org/10.1016/0006-3207(93)90500-Z

Delai F, Kiss T, Nagy J (2018) Field-based estimates of floodplain roughness along the Tisza River (Hungary): The role of invasive *Amorpha fruticosa.* Applied Geography (Sevenoaks, England) 90: 96–105. https://doi.org/10.1016/j.apgeog.2017.11.006

De Poorter M, Pagad S, Ullah MI (2007) Invasive alien species and protected areas. A scoping report. Part I. Scoping the scale and nature of invasive alien species. Threats to protected areas, impediments to IAS. Management and means to address those impediments. Produced for the World Bank as a contribution to the Global Invasive Species programme (GISP). http://www.issg.org/pdf/publications/gisp/resources/ias_protectedareas_scoping_i.pdf

Dirnbock T, Greimler J, Lopez PS, Stuessy TF (2003) Predicting Future Threats to the Native Vegetation of Robinson Crusoe Island, Juan Fernandez Archipelago, Chile. Conservation Biology 17(6): 1650–1659. https://doi.org/10.1111/j.1523-1739.2003.00173.x

Doroftei M (2009) Chorology of *Amorpha fruticosa* in Danube Delta. Romanian Journal of Plant Biology 54(1): 61–67.

Dumitraşcu M, Grigorescu I, Kucsicsa G, Dragotă C, Năstase M (2011) Non-native and native invasive terrestrial plant species in Comana Natural Park. Case-studies: *Amorpha fruticosa* and *Crataegus monogyna*. Rev. Roum. Géogr. Rom. Journ. Geogr. 55(2): 81–89.

Dumitraşcu M, Grigorescu I, Doroftei M, Kucsicsa G, Mierlă M, Dragotă C, Năstase M (2013) *Amorpha fruticosa* in three wetland areas: Danube Delta Biosphere Reserve, Comana and Mureş Floodplain Natural Parks, The 13th International Multidisciplinary Scientific GeoConference SGEM, 16–22 iunie, 2013, Albena, Bulgaria, Ecology, Economics, Education and Legislation Conference Proceedings 1: 113–124. http://sgem.org/sgemlib/spip.php?article3268

Dumitraşcu M, Grigorescu I, Kuscicsa G, Doroftei M, Năstase M, Dragotă C (2014) Invasive terrestrial plant species in the Romanian protected areas. A geographical approach. Rev. Roum. Géogr. Rom. Journ. Geogr. 58(2): 145–160.

Elakowich SD, Wooten JW (1995) Allelopathyc woody plants I. *Abies alba* through *Lyonia lucida.* Allelopathy Journal 2: 117–146.

Elith J, Graham CH, Anderson RP, Dudík M, Ferrier S, Guisan A, et al. (2006) Novel methods improve prediction of species' distributions from occurrence data. Ecography 29(2): 129–151. https://doi.org/10.1111/j.2006.0906-7590.04596.x

Fenesi A, Ruprecht EK, Vincze E (2009) Aggressively spreading exotic plant species in Romania. Neobiota din Romania. Presa Universitara Clujeana.

Franklin J (1995) Predictive vegetation mapping: Geographic modelling of biospatial patterns in relation to environmental gradients. Progress in Physical Geography 19(4): 474–499. https://doi.org/10.1177/030913339501900403

Fukasawa K, Koike F, Tanaka N, Otsu K (2009) Predicting future invasion of an invasive alien tree in a Japanese oceanic island by process-based statistical models using recent distribution maps. Ecological Research 24(5): 965–975. https://doi.org/10.1007/s11284-009-0595-4

Gallé L, Margóczy K, Kovács E, Gyrffy G, Körmöczy L, Németh L (1995) River valleys: Are they ecological corridors? Tiscia 29: 53–58.

Goslee SC, Debra PC, Peters DPC, Beck GK (2006) Spatial prediction of invasion success across heterogeneous landscapes using an individual-based model. Biological Invasions 8(2): 193–200. https://doi.org/10.1007/s10530-004-2954-y

Grigorescu I, Dumitrascu M, Kucsicsa G, Doroftei M, Dragotă C, Năstase M (2014) Assessing Invasive Terrestrial Plant Species in the Mureş Floodplain Natural Park. Romania. The 14th International Multidisciplinary Scientific GeoConference SGEM, 17–26 iunie, 2014, Albena, Bulgaria, 1, Ecology & Environmental Protection, 51–58. https://doi.org/10.5593/SGEM2014/B51/S20.008

Guisan A, Thuiller W (2005) Predicting species distribution: Offering more than simple habitat models. Ecology Letters 8(9): 993–1009. https://doi.org/10.1111/j.1461-0248.2005.00792.x

Hall FG, Towhshend JR, Engman ET (1995) Status of remote sensing algorithms for estimation of land surface state parameters. Remote Sensing of Environment 51(1): 138–156. https://doi.org/10.1016/0034-4257(94)00071-T

Harrison S, Hohn C, Ratay S (2002) Distribution of exotic plants along roads in a peninsular nature reserve. Biological Invasions 4(4): 425–430. https://doi.org/10.1023/A:1023646016326

Hensher DA, Johnson LW (1981) Applied Discrete Choice Modeling. Croom Helm, London.

Higgins SI, Richardson DM, Cowling RM, Trinder Smith TH (1999) Predicting the landscape-scale distribution of alien plants and their threat to plant diversity. Conservation Biology 13(2): 303–313. https://doi.org/10.1046/j.1523-1739.1999.013002303.x

Hosmer DW, Lemeshow S (1989) Applied logistic regression. Wiley, New York.

Horssen PW, Pebesma EJ, Schot PP (2002) Uncertainties in spatially aggregated predictions from a logistic regression model. Ecological Modelling 154(1–2): 93–101. https://doi.org/10.1016/S0304-3800(02)00060-1

Hutchinson GE (1957) Concluding remarks. Cold Spring Harbor Symposia on Quantitative Biology 22(0): 415–427. https://doi.org/10.1101/SQB.1957.022.01.039

Jenks GF (1967) The Data Model Concept in Statistical Mapping. International Yearbook of Cartography 7: 186–190.

Jiménez-Valverde J, Peterson AT, Soberón J, Overton JM, Aragón P, Lobo JM (2011) Use of niche models in invasive species risk assessments. Biological Invasions 13(12): 2785–2797. https://doi.org/10.1007/s10530-011-9963-4

Joly M, Bertrand P, White MC, Lavoie C, Gbangou RY, Dube J (2011) Paving the Way for Invasive Species: Road Type and the Spread of Common Ragweed (*Ambrosia artemisiifolia*). Environmental Management 48(3): 514–522. https://doi.org/10.1007/s00267-011-9711-7

Kanevski M, Maignan M (2004) Analysis and modelling of spatial environmental data. EPFL Press, 300 pp.

Kucsicsa G, Grigorescu I, Dumitraşcu M (2013) Integrated methodology for the assessment of Invasive Terrestrial Plant Species potential distribution in the Romanian Protected Areas. A GIS-based approach. Proceedings of 9th WSEAS International Conference on Energy, Environment, Ecosystems and Sustainable Development, Recent Advances in Environmental Science, 150–155.

Kucsicsa G, Grigorescu I, Dumitrascu M (2016) Integrated methodology and Data. In: Invasive Terrestrial Plant Species in the Romanian Protected Areas. A geographical approach. Romanian Academy Publishing House, 37–46.

Lambdon P, Pyšek P, Basnou C, Hejda M, Arianoutsou M, Essl F, Andriopoulos P (2008) Alien flora of Europe: Species diversity, temporal trends, geographical patterns and research needs. Preslia 80(2): 101–149.

Macdonald IAW, Graber DM, DeBenedetti S, Groves RH, Fuentes ER (1988) Introduced species in nature reserves in Mediterranean-type climatic regions of the world. Biological Conservation 44(1–2): 37–66. https://doi.org/10.1016/0006-3207(88)90004-3

Mack MC, D'Antonio CM (1998) Impacts of biological invasions on disturbance regimes. Trends in Ecology & Evolution 13(5): 195–198. https://doi.org/10.1016/S0169-5347(97)01286-X

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M, Bazzaz FA (2000) Biotic invasions: Causes, epidemiology, global consequences, and control. Ecological Applications 10(3): 689–710. https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2

Magyar P (1960) Afforestation in Great Hungarian Plain. Akadémiai Kiadó, Budapest. [in Hungarian]

McGarigal K, Marks BJ (1995) FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351.U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 122 pp.

Mcgeochm MA, Stuart HM, Spear D, Marais E, Kleynhans EJ, Symes A, Chanson J, Hoffmann M (2010) Global indicators of biological invasion: Species numbers, biodiversity impact and policy responses. Diversity & Distributions 16(1): 95–108. http://www.cbd.int/sp/. https://doi.org/10.1111/j.1472-4642.2009.00633.x

Mortensen DA, Emily SJ, Rauschert ESJ, Nord AN, Jones BP (2009) Forest Roads Facilitate the Spread of Invasive Plants. Invasive Plant Science and Management 2(03): 191–199. https://doi.org/10.1614/IPSM-08-125.1

Mureş Floodplain Natural Park Administration (2016) Mureş Floodplain Natural Park Management Plan, National Forest Administration ROMSILVA, 193 pp.

Panetta FD, Dodd J (1987) Bioclimatic prediction of the potential distribution of skeleton weed *Chondrilla juncea* L. in Western Australia. Journal of the Australian Institute of Agricultural Science 53: 11–16.

Pearce JL, Venier LA, Ferrier S, McKenney DW (2003) Measuring prediction uncertainty in models of species distribution. Predicting Species Occurrences: Issues of Accuracy and Scale. The Auk 120(4): 1199–1200. https://doi.org/10.1642/0004-8038(2003)120[1199:PSOIOA]2.0.CO;2

Pearson RG (2010) Species' Distribution Modeling for Conservation Educators and Practitioners. Lessons in Conservation 3: 54–89.

Pedashenko HP, Apostolova II, Kiril V, Vassilev KV (2012) *Amorpha fruticosa* invasibility of different habitats in lower Danube. Phytologia Balcanica 18(3): 285–291.

Pulliam HR (2000) On the relationship between niche and distribution. Ecology Letters 33: 49–361. https://doi.org/10.1046/j.1461-0248.2000.00143.x

Pyšek P, Hume PE (2005) Spatio-temporal dynamics of plant invasions: Linking pattern to process. Ecoscience 12(3): 302–315. https://doi.org/10.2980/i1195-6860-12-3-302.1

Pyšek P, Jarošík V, Pergl J, Randall R, Chytrý M, Kühn I, Tichý L, Danihelka J, Chrtek jun J, Sádlo J (2009) The global invasion success of Central European plants is related to distribution characteristics in their native range and species traits. Diversity & Distributions 15(5): 891–903. https://doi.org/10.1111/j.1472-4642.2009.00602.x

Pysek P, Jarosik V, Kucera T (2003) Inclusion of native and alien species in temperate nature reserves: An historical study from Central Europe. Conservation Biology 17(5): 1414–1424. https://doi.org/10.1046/j.1523-1739.2003.02248.x

Radovanović N, Kuzmanović N, Vukojičić S, Lakušić D, Jovanović S (2017) Floristic diversity, composition and invasibility of riparian habitats with *Amorpha fruticosa*: A case study from Belgrade (Southeast Europe). Urban Forestry & Urban Greening 24: 101–108. https://doi.org/10.1016/j.ufug.2017.04.006

Rejmánek M (1989) Invasibility of plant communities. Biological invasions: a global perspective. John Wiley & Sons, Chichester, 369–388.

Rempel RS, Kaukinen D, Carr AP (2012) Patch Analyst and Patch Grid. Ontario Ministry of Natural Resources. Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario.

Rew LJ, Maxwell BD, Aspinall R (2005) Predicting the occurrence of nonindigenous species using environmental and remotely sensed data. Weed Science 53(2): 236–241. https://doi.org/10.1614/WS-04-097R

Richardson DM, Pysek P, Rejmánek M, Barbour MG, Panetta FD, West CJ (2000) Naturalization and invasion of alien plants: Concepts and definitions. Diversity & Distributions 6(2): 93–107. https://doi.org/10.1046/j.1472-4642.2000.00083.x

Ricklefs RE, Schluter D (1993) Species diversity in ecological communities: historical and geographical perspectives. University of Chicago Press, Chicago, 414 pp.

Rood SB, Braatne JH, Goater LA (2010) Favorable fragmentation: River reservoirs can impede downstream expansion of riparian weeds. Ecological Applications 20(6): 1664–1677. https://doi.org/10.1890/09-0063.1

Rouget M, Richardson DM, Milton SJ, Polakow D (2001) Predicting invasion dynamics of four alien *Pinus* species in a highly fragmented semi-arid shrubland in South Africa. Plant Ecology 152(1): 79–92. https://doi.org/10.1023/A:1011412427075

Rouse JW, Haas RH, Deering DW, Sehell JA (1974) Monitoring the vernal advancement and retrogradation (Green wave effect) of natural vegetation. Final Rep. RSC, 1978-4, Remote Sensing Center, Texas A&M Univ, College Station.

Sărăţeanu V (2010) Assessing the influence of *Amorpha fruticosa* L. invasive shrub on some grassland vegetation types from western Romania. Research Journal of Agricultural Science 42(1): 536–540.

Seo KW, Son Y, Rhoades CC, Noh NJ, Koo JW, Kim JG (2008) Seedling Growth and Heavy Metal Accumulation of Candidate Woody Species for Revegetating Korean Mine Spoils. Restoration Ecology 16(4): 702–712. https://doi.org/10.1111/j.1526-100X.2008.00485.x

Shea K, Chesson P (2002) Community ecology theory as a framework for biological invasion. Trends in Ecology & Evolution 17(4): 170–176. https://doi.org/10.1016/S0169-5347(02)02495-3

Silveri A, Dunwiddie PW, Michaels HJ (2001) Logging and edaphic factors in the invasion of an Asian woody vine in a mesic North American forest. Biological Invasions 3(4): 379–389. https://doi.org/10.1023/A:1015898818452

Sîrbu C, Oprea A (2011) Plante adventive în flora Românei. Editura "Ion Ionescu de la Brad", Iaşi, 733 pp.

Sîrbu C, Oprea A, Eliáš P, Ferus P (2012) New data addition to the Romanian alien flora. Journal of Plant Development 19: 141–156.

Sîrbu C, Oprea A, Doroftei M (2016a) Invasive Terrestrial Plant Species in Romania. In: Invasive Terrestrial Plant Species in the Romanian Protected Areas. A geographical approach. Romanian Academy Publishing House, 17–29.

Sîrbu C, Oprea A, Doroftei M (2016b) Management and Control of Invasive Terrestrial Plant Species in Romania. Invasive Terrestrial Plant Species in the Romanian Protected Areas. A geographical approach. Romanian Academy Publishing House, 103–112.

Stănescu V, Şofletea N, Popescu O (1997) Flora forerstieră lemnoasă a României. Edit. Ceres, Bucureşti.

Szigetvári C (2002) Initial steps in the regeneration of a floodplain meadow after a decade of dominance of an invasive transformer shrub, *Amorpha fruticosa* L. TISCIA 33: 67–77.

Turner MG (1989) Landscape ecology: The effect of patterns on process. Annual Review of Ecology and Systematics 20(1): 171–197. https://doi.org/10.1146/annurev.es.20.110189.001131

Underwood EC, Klinger R, Moore PE (2004) Predicting patterns of non-native plant invasions in Yosemite National Park, California, USA. Diversity & Distributions 10(5–6): 447–459. https://doi.org/10.1111/j.1366-9516.2004.00093.x

Václavík T, Meentemeyer RK (2009) Invasive species distribution modeling (iSDM): Are absence data and dispersal constraints needed to predict actual distributions? Ecological Modelling 220(23): 3248–3258. https://doi.org/10.1016/j.ecolmodel.2009.08.013

Wang ET, van Berkum P, Sui XH, Beyene D, Chen WX, Martínez-Romero E (1999) Diversity of microbial associated with *Amorpha fruticosa* isolated from Chinese soils and description of *Mesorhizobium amorphae* sp. nov. International Journal of Systematic Bacteriology 49(1): 51–65. https://doi.org/10.1099/00207713-49-1-51

Weber E, Gut D (2004) Assessing the risk of potentially invasive plant species in central Europe. Journal for Nature Conservation 12(3): 171–179. https://doi.org/10.1016/j.jnc.2004.04.002

Williamson M (1996) Biological invasions. Chapman and Hall, London, 1–244.

Xiang S, Xiaolei Z, Guangcai C, Yitai C, Ling W, Xiaoquan S (2011) Seedling growth and metal accumulation of selected woody species in copper and lead/zinc mine tailings. Journal of Environmental Sciences (China) 23(2): 266–274. https://doi.org/10.1016/S1001-0742(10)60402-0

Yemshanov D, Koch FH, Ducey MJ (2015) Making invasion models useful for decision makers: incorporating uncertainty, knowledge gaps, and decision-making preferences. Pest Risk Modeling and Mapping for Invasive Alien Species. Wallingford, UK, CABI Publishing, 206–222. https://doi.org/10.1079/9781780643946.0206

Dumitrascu M, Grigorescu I. (Ed.) (2016) Invasive Terrestrial Plant Species in the Romanian Protected Areas. A geographical approach, Romanian Academy Publishing House, 155 pp.

McCullagh P, Nelder JA (1989) Generalized Linear Models. Chapman and Hall, New York. https://doi.org/10.1007/978-1-4899-3242-6

Kleinbaum D. (1994) Logistic regression: a self-learning text. SpringerVerlag, New York. https://doi.org/10.1007/978-1-4757-4108-7

Liebetrau AM (1983) Measures of association. Sage, Newbury Park, CA. https://doi.org/10.4135/9781412984942

Nagelkerke NJD (1991) A note on a general definition of the coefficient of determination. Biometrika, 78(3), 691–692. https://doi.org/10.1093/biomet/78.3.691

Pontius Jr RG, Schneider LC (2001) Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. Agriculture, ecosystems and environment, 85(1–3), 239–248. https://doi.org/10.1016/S0167-8809(01)00187-6

Mas JF, Soares Filho B, Pontius RG, Farfán Gutiérrez M, Rodrigues H (2013) A suite of tools for ROC analysis of spatial models. ISPRS International Journal of Geo-Information, 2(3), 869–887. https://doi.org/10.3390/ijgi2030869

Marian M, Nicula C, Mihaly-Cozmuta L, Peter A, Mihaly-Cozmuta A (2010) Participation of the indigenous vs. alien herbaceous species to the constitution of vegetal layer on the Bozânta Mare tailing ponds, Analele Universităţii din Oradea – Fascicula Biologie, XVII, 1, pp. 134–141.