Determining the potential distribution of highly invasive plants in the Carpathian Mountains of Ukraine: a species distribution modeling approach under different climate-land-use scenarios and possible implications for regional development

Research Proposal – Fall 2011

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Introduction

The Carpathian Mountains cover an area of more than 200,000 km² in Central and Eastern Europe and are divided between seven countries: Czech Republic, Slovakia, Poland, Ukraine, Romania and Serbia (see Appendix I). The importance of the Carpathians lies in the high level of biodiversity found in the ecoregion compared to other European mountain ranges. This is the reason why the World Wildlife Fund (WWF) classified the Carpathians "as one of 200 ecoregions globally outstanding for their biodiversity" (WWF Carpathian Programme 2007). Preservation of biodiversity can partly be explained by centuries of traditional land management accompanied by relatively low deforestation and development rates (WWF Carpathian Programme 2007).

The Eastern Carpathians located in Ukraine mirror the ecological and economic importance of the whole Carpathian ecoregion. The Ukrainian Carpathians are home to virgin beech forests that are among the oldest in Europe, and, according to the WWF Carpathian Programme (2007), "with 2,012 species of vascular plants, the Eastern Carpathians are also, after Crimea, Ukraine's richest area in terms of flora." The mountains are also one of the last European bastions for the brown bear (*Orsos arctos*) and wolf (*Canis lupus*) (Keeton and Crow 2010). Furthermore, the wealth of natural resources has for centuries provided the basis for economic development in form of traditional forestry and agriculture, animal husbandry, and, as of recently, tourism.

However, in the last decades, increasing pressure has been exercised on the Ukrainian Carpathian ecoregion as traditional as well as regulated development in the socialist era is giving way to integration in a globalized market economy. One major issue threatening biodiversity in the Ukrainian Carpathians that will potentially be amplified in the wake of current development is the establishment and spread of invasive vascular plants. Disturbance has been significant in the past, and future land-use and climatic changes promise more of the same. An investigation of the distribution patterns of the invaders will help to determine habitat suitability and risk of invasion for the mountain range. Maps depicting habitat suitability and invasion risk can then be used to evaluate the potential spread of species under different land-use and climatic scenarios and thus contribute greatly to creating effective strategies for sustainable development.

Statement of Purpose

The project on distribution modeling of invasive species serves as my final graduate project for the Master of Science degree in Environmental Sciences and Policy at the Johns Hopkins

University. Focusing on ecological management, the work incorporates several of the theoretical concepts acquired during my studies. These include environmental policy, advanced GIS modeling, and in particular ecological principles of species distributions.

Aside from academic objectives, the proposed project contributes to an informational database that can be used by ecologists and local authorities when formulating sustainable development and forest management strategies in the Eastern Carpathians (see Keeton and Crow 2010; Maryskevych 2006). Considering the fact that reactive management of invasive species is much costlier than proactive management (see Sakai *et al.* 2001), and that the region suffers from chronic scarcity of financial resources, identifying regions favorable to the survival and spread of invasive plants under different land-use and climatic conditions is an essential step in preventing the establishment of invasive plant populations and maintaining biological diversity and ecosystem health in the Eastern Carpathians.

Statement of Problem

Threats to the Carpathian Ecoregion by Invasive Alien Vascular Plants:
In the last decades, ecologists have increasingly investigated the dynamics of plant invasions and the threats alien plants pose to ecosystems around the world. The recent focus on alien species can be explained by the explosion of worldwide trade that has largely augmented the number of intentional (e.g. ornaments or timber sources) or unintentional (e.g. transport of reproductive plant parts via global trade routes) introductions of invasive plants. Coupled with increasing disturbances of natural ecosystems by human development, alien species are able to profit from higher rates of dispersion and weakened host environments. It has been estimated that invasive species make up 14% of the total flora in Ukraine, and their total numbers have risen from approximately 500 in 1950 to over 800 in 2000 (Protopopova *et al.* 2006). The Ukrainian Carpathians are ecologically still relatively intact but harbor nevertheless highly aggressive invasive plants, especially on south-western macro slopes (Prots, personal communication).

A non-native plant is characterized as invasive when its establishment in an ecosystem alters the habitat and displaces native species (see Sakai *et al.* 2001). In the Carpathians, aggressive invasive weeds such as *Heracleum sosnowsky* or *Reynoutria japonica* can form monocultures and outcompete native species for light and nutrients in riparian habitats (see Protopopova *et al.* 2006; Beerling 1991; Nielsen *et al.* 2005). Populations along these types of "ribbon-like" habitats are particularly vulnerable to population fragmentations, and Protopopova *et al.* (2006) note that "expansions of alien plants are powerful factors of destruction of the integrity of linear populations along the rivers of the Carpathian Mountains." In addition, many of the species, for example *Robinia pseudoacacia*, have been used as ornamentals since the 19th century but have only recently been recognized as invasive (Basnou 2006). Having underestimated the threat posed by these aggressive weeds, local authorities lack effective management strategies. Lastly, native species, in particular rare endangered ones, can potentially lose genetic variability and thus viability due to hybridization with exotic relatives. Although species losses due to hybridization have not been reported in the Carpathians, at least one genus of highly invasive plants present here, *Helianthus*, is known to contaminate the gene pool of native relatives elsewhere in Ukraine (Protopopova *et al.* 2006). In conclusion, established populations of invasive alien plants are already a threat for ecosystems in the Eastern Carpathians as they

displace or weaken the genetic pool of native species; and as the relative stability of the ecosystems in this mountain range is being compromised by human development that weakens and destroys habitats and fragments intact communities, the spread of invasive species becomes an increasingly important issue.

Unsustainable Development and Spread of Invasive Plants:
Western Ukraine struggles with the environmental and economic implications of a paradox: despite being one of the richest regions in Europe in terms of natural resources, the area is one of the poorest in Ukraine in terms of socio-economic revenues, with high unemployment and emigration rates (WWF Carpathian Programme 2007). Forestry has traditionally been the main source of income for a majority of the local population. In the Soviet era, forestry and rural development have largely been regulated by state agencies which generally favored sustainable[1] forestry management (Keeton and Crow 2010). However, the Soviet-era management, while favoring policies that maintained overall forest cover quantity, diminished the quality of forests by replacing heterogeneous, complex communities with homogenous plantations of beech or spruce (Kuemmerle *et al.* 2009). Thereafter, in the post-Soviet era, "the prodigious natural resources…[have come] under increasing pressures including illegal logging and poaching as well as habitat fragmentation, habitat destruction from changing land use and destruction from infrastructure development" (WWF Carpathian Programme 2007; see also Kuemmerle *et al.* 2009). Thus, natural resource management in the Eastern Carpathians has taken an increasingly unsustainable road as inefficient regulation and technological know-how struggle to adjust to the demands for natural resources from a global economy, while formerly intact ecosystems are increasingly being disturbed and destabilized.

Meanwhile, invasive alien plants generally profit from such human-caused disturbances to natural ecosystems. Invasive plant species may be introduced to new environments when environmental barriers restricting possible introduction are broken down. As ecologists point out, seemingly harmless exotic plant species can become invasive as transformations of local plant communities create favorable habitats (Protopopova *et al.* 2006). Recently, several scientists have pointed to the ecological damages, e.g. habitat fragmentation, road construction and timber harvest in riparian habitats can bring about (Keeton and Crow 2010). Uncontrolled development of the forestry sector is highly problematic in the light of invasive species distribution because creating disturbance-based corridors within ecologically resilient forest stands creates (increased disturbance and light availability) or connects (cutting through otherwise unsuitable sites of dense forests) habitats for invasive species (von der Lippe and Kowarik 2006). Such corridors are an even bigger issue in single-species forest plantations that can be found in the study area. These plantations lack the structural complexity and hence resilience of natural communities and in riparian habitats where water acts as a major dispersal agent.

Climate Change and Spread of Invasive Plants:
Sustainable forest management and land development in the Ukrainian Carpathians ultimately means proper allocation of protected and actively managed areas. At the same time, determining the extent of these areas depends on predictions of ecosystem responses to climate change – this is true for possible migrations or extinctions of native as well as alien plants under new climate

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[1] Sustainable here means sustaining long-term regeneration capacity and vitality of forests. Concretely, it means that forest resources could only be extracted at a rate at or below their natural regeneration rate.

regimes. Invasive plants in the region have shown great adaptability to a range of climatic and land-use conditions, and it is highly likely that under a warming climate, invasive plants will migrate provided the availability of proper migration routes (Broennemann *et al.* 2007). In contrast, particularly specialist endemic species in the Ukrainian Carpathians that evolved very specific environmental niche requirements might not only be unable to migrate but might also be weakened in their potential response to invaders. While designing protected areas and land management strategies, it is thus of uttermost importance to consider the threats of and minimize the possible future introduction of invasive species to areas of high conservation priorities. Here, analyses of habitat suitability for invasive plants under climate change can be of great value as they can, for example, be compared to areas vulnerable to extinctions due to climate change in order to create appropriate measures of protection.

Proposed Project
In order to provide a better understanding of the distribution of invasive plants, I will be modeling the habitat suitability for ten highly invasive plant species in the Ukrainian Carpathians using statistical machine-learning software. That is, I will employ a species distribution model, the output of which is a habitat suitability map. My specific research questions are:

1. What variables best describe the environmental niches of the highly invasive plant species?
2. What does the distribution of the significant variables in the Ukrainian Carpathians mean for the potential distribution of the invaders?
3. How will climate change and different land-use patterns affect the future distribution of the invaders?
4. What are some general implications for regional development under different climate-land-use scenarios?

Initially, I will be testing the following hypothesis (see sections below for details):

H_o = Species X is distributed randomly in an environmental space with higher density of presence pixels found where higher densities of covariate pixels are found

H_a = Species X is non-randomly distributed over the environmental space, i.e. distribution is governed by constraints, which are defined by specific responses of a species to a set of environmental variables

Meanwhile, habitat suitability maps do not portray the relative risk of invasion because they do not account for propagule pressure, i.e. the quantity and frequency of invading organisms in one location (Herborg *et al.* 2007). In order to predict relative risk, a measure of abundance will be incorporated into the habitat suitability map that is the result of the first hypothesis test.

If I can reject H_o, I will attempt to extrapolate/project my model to different climatic and land-use conditions. By doing this, I will be testing:

H_o = the distribution remains the same, as opposed to

H_a = there is a significant change in distribution of the species when climatic/land-use variables change

Similar to incorporating a measure of abundance, the risk of invasion under climate change will be approached by incorporating an estimate of migration rate of the species per unit of time (Guisan and Thuiller 2005).

Background Information

Ecology of Invasive Species:
In order to define the parameters for any type of spatial analysis, one has to refer to a theoretical ecological concept that explains the distribution of a given (invasive) plant species within specific biological, environmental, or physical gradients. The widely accepted *species niche concep*t provides such a theoretical framework for species distribution. This concept characterizes the niche of a species as "the hypervolume defined by the environmental dimensions within which that species can survive and reproduce" (Hutchinson 1987, cited in Franklin 2009). The idea of an environmental volume is what differentiates niche from *habitat*, as the latter is formally only defined as the area where an organism lives (Begon *et al*. 2006). Following Hutchinson's definition, a niche can be further distinguished as *fundamental*, a species' potential survival and reproductive success amidst favorable environmental conditions, and *realized*, the actual occurrence of a species in space that depends not only on favorable environmental conditions but also on biotic interactions (competition, predation, facilitation of dispersal) and anthropogenic influences (see Franklin 2010; Begon *et al*. 2006; Phillips *et al*. 2006).

The invasive plants studied in this project are typical representations of invasive species overall. Most invasive weeds are generalists and thus have wide fundamental and realized niches in their non-native range. They are characterized by fast growth, high reproductive rates coupled with vegetative reproduction, the ability to adapt to a wide range of environmental gradients, and tolerance to frequent disturbances – giving invaders a competitive advantage over native species particularly under anthropogenic disturbance regimes (Sakai *et al*. 2001). All ten invaders are shade-intolerant and become predominantly established in riparian habitats or along roads and railway tracks. Dense forest stands represent environmental barriers to spread. Furthermore, the plants must exhibit tolerances (and tolerance limits) to seasonality of the temperate climate and must be adapted to the limits of the growing season. The spatial analysis of the distribution of the species will clearly consider the environmental conditions dictating a species' fundamental and realized niches.

Species Distribution Modeling:
Species distribution models (SDMs) are empirical models that relate field observations of the occurrence of a species to environmental predictor variables by formulating statistically or theoretically derived response surfaces. They essentially do the following: Spatially explicit species occurrence can be linked to layers of environmental data/predictors at the georeferenced location; the values of environmental predictors and species distribution within these values are extracted; and their relationship is described as statistical response functions – the model that describes how the dependent variable (species distribution) behaves under the presence of

independent variables (environmental data). This model is then used to predict the potential occurrence of a species temporally or spatially (see Franklin 2009; Guisan and Thuiller 2005). It becomes evident that SDMs are closely linked to the ecological niche concept.

The environmental data that are linked to or predict species distribution represent the requirements represent the species' realized niche. That is so because the statistical response function of the model relies on spatial species occurrences, i.e. locations where a species is actually found, or its realized niche (see Phillips *et al.* 2006). However, it is possible to approximate the fundamental niche. More specifically, climatic variables and their derivatives represent the abiotic, environmental gradients that define a suitable habitat overall, i.e. the fundamental niche, while land-use and habitat variables are indirect indicators for biotic interactions, i.e. the realized niche (see Guisan and Thuiller 2005).

When choosing the environmental variables to analyze the potential spread of highly invasive plants in the Ukrainian Carpathians, two approaches are possible: (1) fitting the model in the natural ranges of the species and then projecting to the invaded range; or (2) fitting the model in the invaded range and projecting to potential source sites in the regions of invasion that have not yet been invaded. In general, it is assumed that because invasive species are unlikely to be in equilibrium with their invaded environment, the former approach produces more accurate results (Guisan and Thuiller 2005). However, several studies have demonstrated that using environmental variables from the invaded range is more appropriate (1) for species that were introduced as food sources or ornamentals and thus experienced artificial selection, making their genetically distinct populations difficult to compare with populations in the native range; and (2) due to the fact that the realized niche in an invaded environment can differ greatly compared to the natural range as species are subject to different types of biotic interactions, e.g. lack of competitors or herbivores (see Dullinger *et al.* 2009; Broennimann *et al.* 2007; Broennimann and Guisan 2008). For these reasons, the species studied in this project will be modeled based on their distribution in the invaded range.

Study Area and Scope:
The project area is the entire range of the East Carpathian Mountains in western Ukraine (see Appendix I). The Ukrainian Carpathians extend over an area of 30,890 km², and 2 million people are estimated to live in the region (UNEP 2007). The region is characterized by a northwest-southeast oriented mountain range of mostly flysch rock and a moderate temperate continental climate, respectively (Kuemmerle *et al.* 2009). The invasion of aggressive plants cannot be confined by human-made boarders, but it is nevertheless desirable to focus the study area to this regional scale for two reasons: (1) species-presence and environmental data are incomplete or have incompatible formats for the entire range of the Carpathians; and (2) the resolution of the habitat suitability and invasion risk maps when choosing a regional focus is sufficiently detailed to derive local-to-regional management strategies for the control of the invasive plants.

Data on Species Distribution

Species Studied:
The focus of the study is ten highly invasive plant species: *Acer negundo, Reynoutria japonica, Reynoutria bohemica, Echinocystis lobata, Impatiens glandulifera, Heracleum sosnowskyi,*

Robinia pseudoacacia, Helianthus tuberosus, Solidago canadensis, and Solidago gigantea. All of the species are invaders from either North America or Asia and have been intentionally introduced as ornamentals or food sources. All are resilient generalists, require abundant sunlight to grow and reproduce, use water or anthropogenic transport routes as major dispersal agents, and have thus become established along disturbance corridors. Despite their adaptability to a wide range of environmental conditions, the species are quite sensitive to frost and the length of the growing season, and some do not tolerate drought. Based on their habitat requirements in the invaded range, the current distribution of the plants can be divided into two groups with *Acer negundo, Echinocystis lobata, Impatiens glandulifera*, *Heracleum sosnowskyi,* and *Helianthus tuberosus* found clearly along rivers and the remaining five species preferring medium-wet to dry habitats (see Prots 2009).

Data on Species Presence and Abundance:
The data on species distributions are in the presence-only data format. Typically, ecological modeling relies on large presence-absence data sets, but such detailed records are not available for all species studied here and, even if available, could be potentially misleading as the species are not in equilibrium with their environment (i.e. absence does not necessary mean unsuitable habitat). Data are available from multiple sources, including herbarium and field-sampling records (point data). The data have been collected in the laboratory of plant ecology of the State Museum of Natural History in Lviv (National Academy of Sciences) based on long term studies (over last 20 years). All data will be arranged in the CSV (comma-separated values) format, which describes tabular information on species name and longitude/latitude location as a text. Further information may be included as needed. In addition, data on the abundance of a species in a given location will be assembled based on a ranking system (the number of localities in a surveying grid).

Data on Predictor Variables:
A set of different environmental predictor variables is selected based on the review of similar environmental studies that chose the optimal variables to reflect "the three main types of influences on the species" (Giusan and Zimmermann 2000): limiting factors controlling the eco-physiology of a species (e.g. extreme temperature events), natural or human-induced disturbances, and resources that can be assimilated by organisms (e.g. energy). In addition, it is the aim of this project to map the realized niche of organisms, which calls for the inclusion of variables that indirectly express biotic interactions. The initial environmental variables are thus:

- Mean annual precipitation: proxy for soil moisture and the water balance
- Mean precipitation warmest quarter: proxy for dryness
- Mean precipitation wettest/driest quarter: proxy for flooding/drying out in riparian habitats, tolerance limits to soil moisture/xeric conditions
- Mean annual temperature
- Mean minimum temperature of coldest month: proxy for sensitivity to low temperatures
- Mean maximum temperature of warmest month: proxy for sensitivity to high temperatures
- Photosynthetically active radiation (PAR): percent of maximum possible solar radiation is very important for plants under short days
- Length of growing season (in day-degrees): proxy for sensitivity for seasonality

- Ratio of actual to potential evapotranspiration (AET/PET): proxy for aridity (aridity index)
- Land use/land cover: proxy for disturbance

Proximity to water/habitat type: proxy for realized niche

The data on the environmental variables will be available as ESRI's grid layers at a regional scale of 5 x 6 km and in the SWD (samples with data) format. The SWD format is very similar to the CSV format and contains values for each independent variable at a species presence location in single rows (see Phillips 2010). The climatic data will be prepared based on data of regional climatic stations. Meanwhile, data on land-cover change and habitat types will be provided by the Ukrainian National Forestry University in Lviv, Ukraine. Researchers from this institution used 19 mid-summer and early fall Landsat TM and ETM+ images for 1988, 1994, 2000, and 2007 in order to classify forest cover in the Ukrainian Carpathians during the four time periods and then deriving land-cover change and disturbances (see Kuemmerle *et al.* 2009). The output maps of their study will be used as predictor variables for habitat types and land-use. It will be furthermore determined whether the datasets can be used to project habitat suitability to different scenarios of forest-cover change.

The Modeling Approach

Predictor Variable Choice:
In any statistical analysis, it is important to ensure that the predictor variables do not confound each other, or, in other words, do not exhibit collinearity. When testing the contribution of an independent variable to model performance, two variables that potentially influence one another can give false weights regarding their individual contributions. When examining the predictor variables initially selected for this project, one can detect that some variables are indeed correlated, for example mean annual precipitation and mean precipitation of the warmest quarter. Thus, a statistical test called "jackknife" will be applied to all the environmental variables to find the most important ones. This test fits presence data to each environmental variable independently; then excludes one variable, creating a model with the remaining variables; and finally a model containing all variables is created (Phillips 2010). This way, the contribution of each variable to the model can be evaluated and models can be rerun excluding potentially collinear and badly performing environmental variables.

Maxent Modeling:
Maximum entropy (Maxent) modeling is a general-purpose method for making inferences from incomplete information. Maxent estimates a target probability distribution for each pixel on a grid map by finding the probability distribution of maximum entropy (most spread out) that is constrained by the statistical response curves between environmental variables and sample points of species presence (see Appendix II; Phillips et al. 2006; Elith *et al.* 2011). The software is freely available at: http://www.cs.princeton.edu/~schapire/maxent/. For this study, Maxent is preferred over other methods for four reasons: First, only presence data are required. Second, both continuous (e.g. climatic variables) and categorical (e.g. habitat types) data can be used. Third, Maxent frequently outperforms other presence-only modeling methods. And fourth, should solid absence data for some of the species exist, a conditional model can be applied to

enable presence/absence modeling with Maxent (for further information on the advantages of Maxent see Phillips *et al*. 2006; Franklin 2009; Elith *et al*. 2011).

Each of the eight species is individually modeled with Maxent. For each species, the model will be run several times based on different random partitions of the occurrence data into training and test localities. In each case, the pixels of the study area (the Ukrainian Carpathians) make up the background space on which the Maxent probability is defined, the pixels on which species presence is recorded characterize the sample points, and the environmental predictor variables are used to define the constraints of the probability distribution. Furthermore, for each species, the algorithms will be run in two different settings: (1) using only climatic variables, and (2) including land-use/habitat variables. The reason for this is to test how much influence the categorical land-use/habitat variables have on model performance and how they influence climatic projections.

Model Evaluation:
The accuracy of the models is evaluated by estimating commission (a pixel is described as presence where it is actually random) and omission (a pixel is described as random where it is actually presence). These type I and II errors are described using receiver operating characteristic (ROC) curves. The ROC is produced by plotting commission errors against the absence of omission errors when testing the classification of the training data, with each point on the graph representing a test instance. The area under the ROC curve (AUC) can then be interpreted as "the probability that a random positive instance and a random negative instance are correctly ordered by the classifier" (Phillips *et al*. 2006). Meanwhile, the statistical significance of the models is predicted using binomial statistical tests.

Climatic and Land-Use Projections:
In general, Maxent estimates the habitat suitability under different conditions by applying a model trained on one set of environmental layers to another set of environmental layers – a process called "projection" (Phillips 2010). For the purposes of this project, two types of projections will be made: climatic and land-use. Climatic projections will assume the A1B scenario developed by IPCC Special Report on Emission Scenarios (SRES): an estimated increase in CO2 concentration levels of 532 ppm and 717 ppm by 2050 and by 2100, respectively (Bartholy *et al*. 2011). For each time reference, new values for the climatic variables regarding temperature and precipitation will be calculated using the data and models provided by the European ENSEMBLES project, which developed a series of regional climate models for the Carpathian Mountains based on three different global models (for details see Bartholy et al. 2011). The new values for the climatic variables, acquired by applying the results of the regional models on our study area, represent the new set of environmental variables used for projection.

Land-use projections will utilize the Landsat TM and ETM+ images for 1988, 1994, 2000, and 2007 and species records with detailed temporal identifications in order to train models for one time period and project them to another. By doing so, patterns of species distributions under different land-use conditions will become visible. It will be difficult to test the accuracy of the climatic models because we obviously lack presence data of future distribution that could be used to statistically validate the model. However, because we have records of species presence in

different time periods, traditional statistical tests can be utilized to validate the predictions based on land-use.

Measure of Invasion Risk:
A habitat suitability map does not necessarily convey relative risk of invasion in one area. That is, if two pixels represent highly suitable habitat, the pixel that is in closer vicinity to locations where the species in question is found in high abundance has a greater risk of become invaded. Thus, in order to identify locations that might be successfully invaded, one requires not only knowledge about habitat suitability but also a measure of propagule pressure, or "the number of individuals introduced into a particular area over time" (Herborg *et al.* 2007; see also Sakai *et al.* 2001). Conceptually, if the risk of invasion is defined as chance of survival (i.e. habitat suitability) X propagule pressure, relative risk at two locations with similar Maxent probability should vary based on the ratio between the measures of propagule pressure at each location.

Two measures of propagule pressure are possible and will both be considered. First, because waterways and traffic along roads are effective long-distance dispersal vectors, the overall length of roads and rivers per raster cell are considered as a proxy for propagule pressure. Second, a neighborhood distance function that depicts the distance of species presence localities to adjacent habitat can be applied to locations depicting highly suitable habitat (see Dullinger *et al.* 2009). Similarly, for the climatic projections, it is important to have an idea of the typical rate of migration of a given species in order to estimate how likely it is to reach future suitable habitat. Rates of migration will thus be determined for all the species studied. Once propagule pressure and rate of migration are determined, both can be incorporated into the models to refine the habitat suitability maps.

Timetable
- Fall 2010: Phone conversation with Dr. McGurty to discuss project

- Winter 2011: Intensive research and correspondence with Dr. Prots
    - February 14: First research proposal draft discussed
    - February 15: Second draft submitted

- Early May 2011: Submission of Research Proposal

- May-September 2011: Practical work in Lviv, Ukraine (including field work in the Carpathians), combined with writing of final thesis

- Fall Semester 2011: Completion and submission of thesis
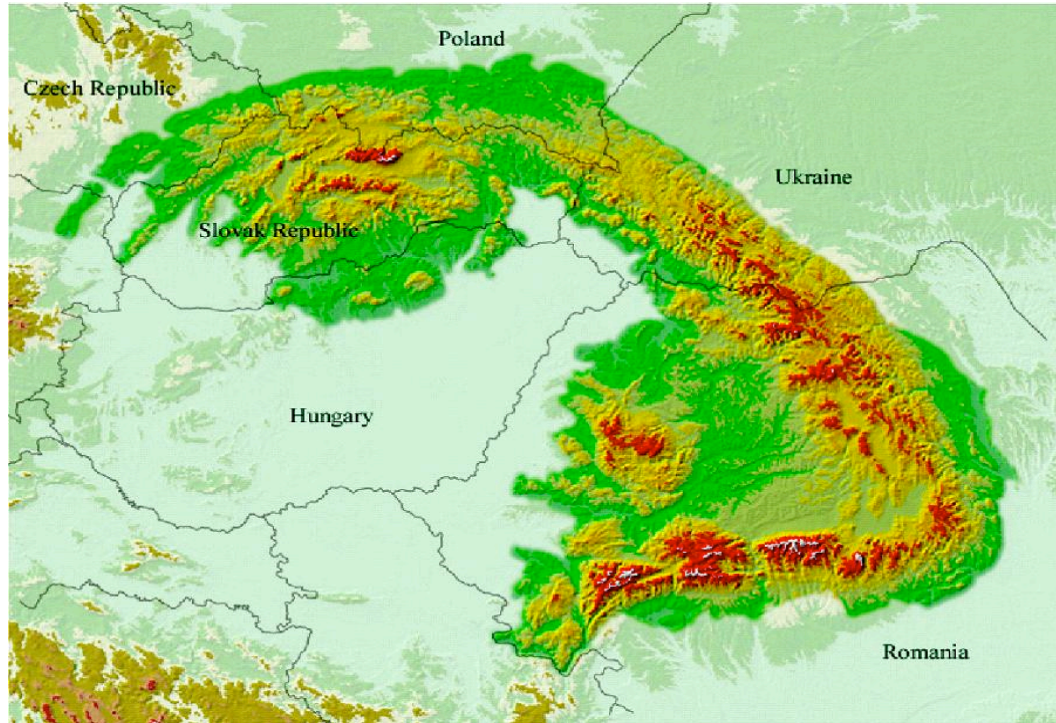
Appendix I: Location of Study Area

Figure 1: Map of Carpathian ecoregion (Source: WWF/Carpathian Ecoregion Initiative)
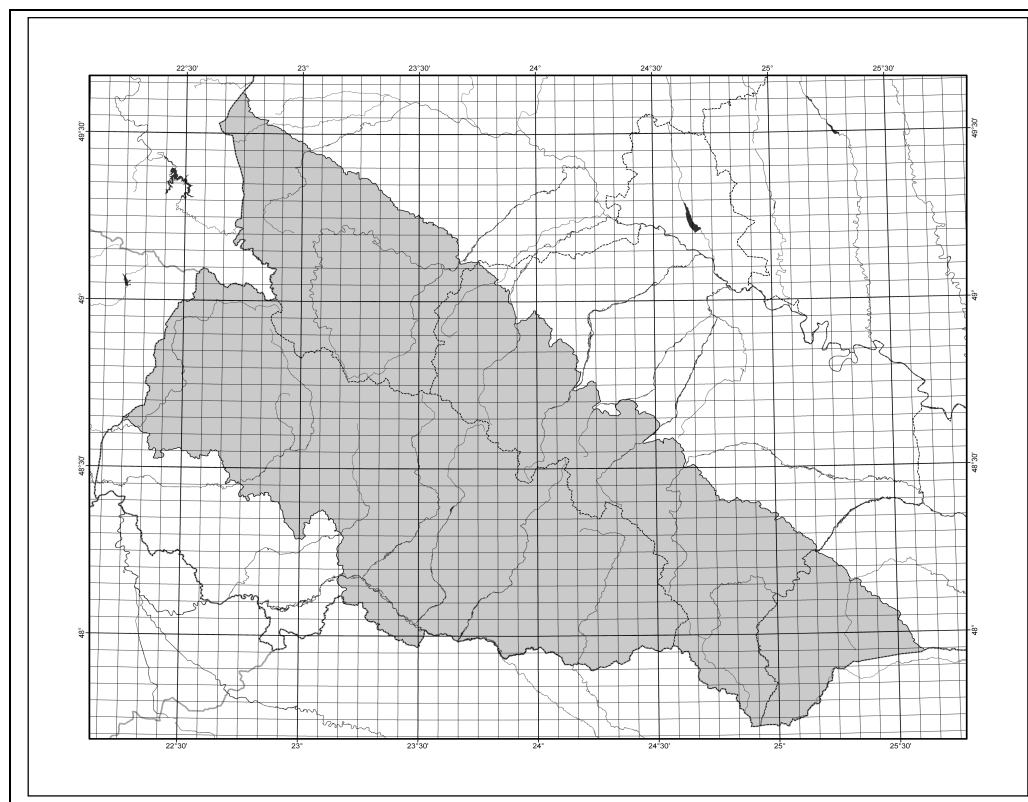

Figure 2: Detailed view of the study region (Source: Prots, B.)
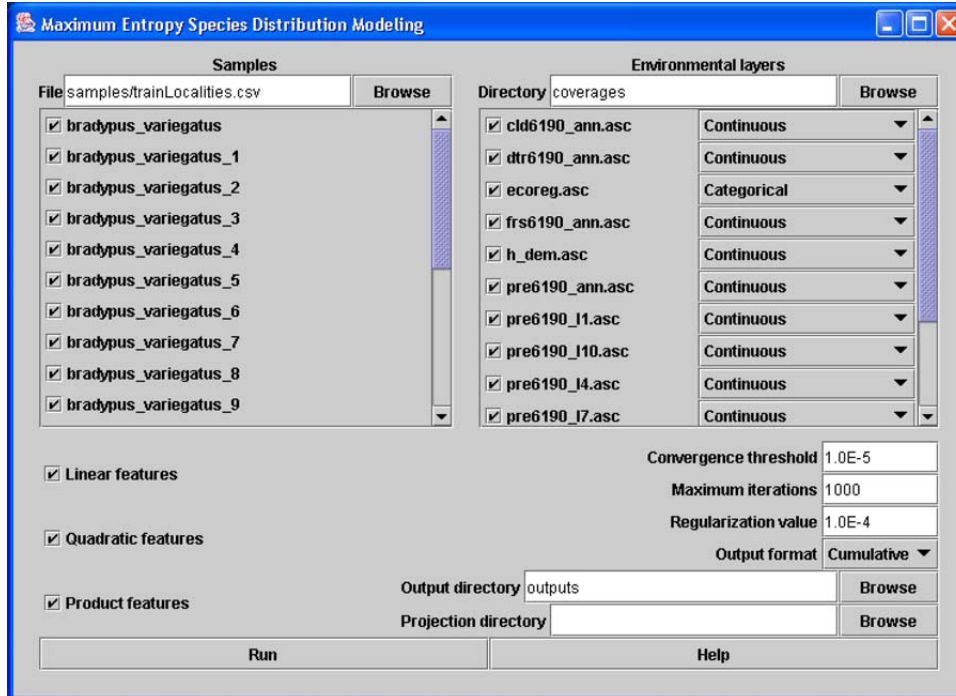
Appendix II: Maxent Interface

Figure 3: User interface for the Maxent application for modeling species geographic distributions using georeferenced occurrence
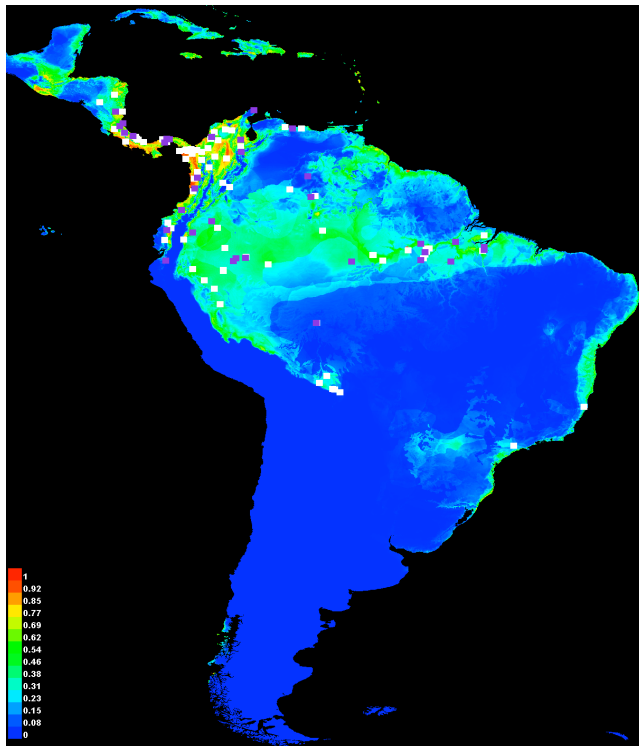

Figure 4: A representation of the Maxent model for Bradypus variegates; Warmer colors show areas with better predicted conditions; White dots show the presence locations used for training, while violet dots show test locations.

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