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University of Fribourg (CH)
Faculty of Science
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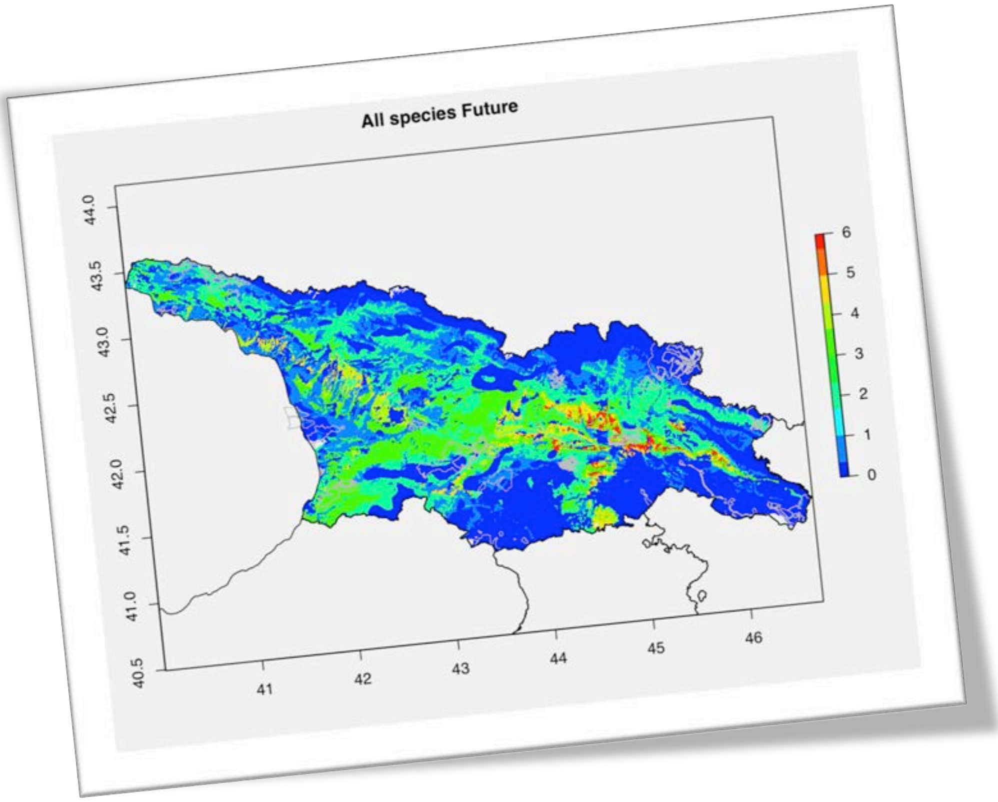
Ecology and Evolution

Areas of high conservation value in Georgia: present and future threats by invasive plants



Daniela Thalmann
2012

Supervised by:
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"Is it too late to prevent us from self-destructing? No, for we have the capacity to design our own future, to take a lesson from living things around us and bring our values and actions in line with ecological necessity. But we must first realize that ecological and social and economic issues are all deeply intertwined. There can be no solution to one without a solution to the others."

Jean-Michel Cousteau

*

“It always seems impossible until it’s done.”

Nelson Mandela

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❖ ABSTRACT

Georgia is known for its extraordinary rich biodiversity of plants. In its 76,400 square kilometres about 4400 species of vascular plants occur of which about 9% are endemic to Georgia. Increasing evidence indicates that this unparalleled wealth is now under threat due to the spread of invasive alien plants (IAP), which has especially increased due to changes in land use, cross-country pipeline construction and habitat destruction. The aim of this study was to identify (i) areas most at risk due to IAP and (ii) the most prominent IAP at present and in the future. For this we established a three-step procedure: First we determined and mapped the areas of high conservation value in Georgia (basically the 43 Protected Areas established by the government), secondly we mapped the present occurrences (based on field and herbarium records) of the 9 potentially most harmful IAP species out of 16 invasive species identified in a previous survey and predicted the distribution under current and future climate conditions at a resolution of 1km^2 using firstly species distribution models based on 6 climate variables. The obtained distributions was than filtered based on maps of soil and vegetation types, and the recorded occurrences, to result into the ecological distribution of the nine IAP's. Finally we overlaid the new combined distribution maps of all 9 IAPs on the one with the areas of high conservation value to identify the Protected Areas most at risk by IAP. To our knowledge, such a procedure to identify areas of high conservation value most at risk by IAP has been applied for the first time.
Our results show two areas in Georgia that are under specifically high threat. These are the area around Tbilisi in the eastern part of Georgia and an area in the western part of Georgia (Adjara). Both are at lower altitudes and close to larger cities what also correlates with our finding that the lower the altitude, the more invasive plant species are predicted. Thus, the 7 areas of high conservation value in these two regions are the ones that are most prone to be negatively impacted by IAP. Furthermore we show that *Ambrosia artemisiifolia*, (24% and 40%) *Robinia pseudoacaia* (14% and 19%) and *Ailanthus altissima* (9% and 11%) are the most abundant (% area covered) invasive plant species in Georgia and in the Protected Areas, respectively, with *Ailanthus altissima* the most increasing one over the next fifty years (from 9% to 13% and from 11% to 25% for Georgia and the Protected Areas, respectively).
In summary, our study provides detailed maps of IAP distributions in Georgia and especially for the 43 areas of high conservation value today and in fifty years and identifies the most prominent IAP for Georgia. This will help national authorities in prioritizing their measures to protect Georgia's outstanding biodiversity from the negative impact of IAP.

Keywords: Biological invasion · Biodiversity · Protected Areas · Georgia · Species distribution models SDM · BIOMOD · Climate change · Conservation

❖ INTRODUCTION

A significant component of human caused global change are invasive species and they can act as active drivers of ecosystem change (Vitousek et al. 1996). To protect global biodiversity from the effect of invasive plant species, it is important to anticipate these invasions and to find the regions and species that are considered to be most at risk for local species extinctions. As rare species are already especially threatened by human activities and environmental change, there is a special need to protect them from additional danger coming from alien invaders (Vicente et al. 2011). In this project we focus specifically on Georgia because it is known for its extraordinary rich biodiversity of plants and its unparalleled diversity of landscapes. Georgia is found within the Caucasus Region, which is ranked by Conservation International (Conservation International 2012) among the planet's 34 most diverse and endangered hotspots. It is also one of WWF's global 200 vulnerable eco-regions, identified as globally outstanding for biodiversity (WWF 2012). Georgia has a unique flora and is a refuge for many plant species that are remnants of ancient Mediterranean flora. Of the approximately 4400 species of vascular plants occurring in Georgia's 76,400 square kilometres, about 380 species, or 9%, are endemic. Increasing evidence indicates that this extraordinary wealth is now under threat due to the spread of alien plants, which has especially increased due to changes in land use, cross-country pipeline construction and habitat destruction. Some of the exotic plants have a high potential to become so called "transformer species", i.e. invasive species with a high impact on the ecosystem. The impact of these invasive plants is increasing. A recent survey identified 380 alien plant species (excluding cultivated species), of which 134 species have become naturalized and 16 species have become invasive (Müller-Schärer 2011). Invasive alien species are non-indigenous species (in general originating from another continent), introduced intentionally or not, which got established in nature and spread to the detriment of native species. They are the second most important factor for biodiversity loss on a global scale. Thus it is very important to identify early the species that have the potential to become invasive. This has recently been done in Georgia (Kikodze et al. 2010).

The question of how plant species are distributed on Earth has a long history and most modelling approaches have their roots in quantifying species-environmental relationships (Guisan and Thuiller 2005). Species distribution modelling is an ideal method to determine how invasive plant species are distributed. One way to assess the pressure of invasive species to the native flora is to define the geographical overlap of biological invasion and native rare and endangered species. Therefore, the distributions of such native and the exotic plant invaders need to be determined both under current and future climatic conditions.

The assumptions of species distribution models for extrapolation are (Austin 2002; Dormann 2006):

1. The factors that limit a species occurrence/ abundance under observed conditions will also be the limiting factors under the extrapolated conditions.
2. Biotic interaction (competition, predation, symbiosis) will be the same under extrapolated conditions.
3. Genetic variability, phenotypic plasticity and evolutionary changes are negligible.

A recent large-scale test of niche conservatism in plant invasions based on occurrence data for 50 terrestrial plant invaders from Europe to North America and viceversa found that niche shifts are indeed rare, as less than 15% of species show a distribution in the invaded range of >10% outside their native niche (Petitpiere et al. 2012)
Instead of directly assessing the distribution of rare endangered plant species, already established, 'Protected Areas' can be assumed to cover areas of high conservation value composed of a larger number of such endangered plant species that need specific protection. Protected Areas are the foundation of national and international conservation strategies (CBD 2012). They act as refuges for species and ecological processes that cannot survive in intensively managed landscapes and seascapes. They provide space for natural evolution and future ecological restoration. Protecting iconic landscapes and seascapes is seen as being important from a wider cultural perspective as well. Flagship Protected Areas are as important to a country's heritage as, for example, national football teams, works of art, or famous buildings such as the Notre Dame Cathedral or the Taj Mahal (Dudley 2006). The Protected Areas in Georgia also play a special role because eco-tourism is an important source of income for their economy (Agency of Protected Areas Georgia 2009).

For this study, we assume Protected Areas can be seen as biodiversity hotspots and areas of high conservation value because they already have particular reasons for conservation, and therefore, are protected by law and managed by the government. In order to determine which areas have the highest conflict rate, we therefore propose to overlap the areas with potential invasions with the Protected Areas. For efficient cost and time effective conservation, it is important to prioritize and identify those areas, which are under the biggest risks. The aim of this study is now to do so for Georgia in three steps:

1. Determine and map the areas of high conservation value in Georgia
2. Map the present occurrences (based on field and herbarium records) of the selected nine invasive plant species in Georgia and predict their distribution under current and future climate conditions
3. Overlay these maps with the Protected Areas of Georgia to find areas most at risk for invasive species with these predictions.

❖ METHODS

Study area

The study area is Georgia, located at the crossroads of Western Asia and Eastern Europe, between latitudes 41° and 44° N, and longitudes 40° and 47° E, with an area of 67,900 km^2. It is bounded by the Black Sea to the west, Russia to the north, Turkey and Armenia to the south, and Azerbaijan to the southeast. The climate of Georgia is extremely diverse, considering the nation's small size. There are two main climatic zones, roughly separating the eastern and western parts of the country. The Greater Caucasus Mountain Range plays an important role in moderating Georgia's climate and protects the nation from the penetration of colder air masses from the north. The Lesser Caucasus Mountains partially protect the region from the influence of dry and hot air masses from the south. Climatic zones are determined by distance from the Black Sea (west to east) and by altitude (greater to lesser Caucasus) and ranges from subtropical to continental zones.

Invasive study species

In Georgia, 16 invasive species have been identified (Kikodze 2010). Out of these 16 species, the nine most abundant and potentially most harmful ones were selected for the study (Table 1). Among these species, four originate from North America: one tree (*Robinia pseudoacacia*, a forest pant), two shrubs (*Opuntia humifusa* and *Opuntia phaeacantha* both dry grassland plants) and one herb (*Ambrosia artemisiifolia* classified as ruderal plant). The other five originate from East Asia: three shrubs (*Vitex rotundifolia* a pioneer plant, *Clerodendrum bungei* and *Spiraea japonica,* both ruderal plants), one herb (*Miscanthus sinensinsis*, a ruderal plant), and one tree (*Ailanthus altissim*, a dry grassland plant*).* These invasive plants have been naturalized and they produce reproductive offspring, often in very large numbers, at large distances from parental plants and thus have a high potential to spread over a considerable area (Kikodze 2010).

Collection of species occurrence data

To run the ecological niche models, geographic coordinates representing the species occurrence are needed. In a classical approach data from the native range of a species are used to train the models and then to project them into potential invasive ranges. Broennimann and Guisan (2008) proposed to use pooled data from all ranges of a species to fit the models for an improved prediction of the distribution in the invasive range also because of eventual niche shift during invasions (Broennimann et al. 2007). Petitpierre et al (2012) found that niche shifts are in general rare among terrestrial plant invaders but still, the more precise data was obtained the more accurate the models can be produced. Therefore occurrence data were selected for the native and invasive species range on a global scale. Different strategies were used to make the data as complete as possible, because the model accuracy increases with larger sample sizes (Hernandez et al. 2006). For all nine selected invasive species for Georgia, occurrence data were acquired from several online herbarium and state agencies. A list with all considered databases can be seen in Annex 1. Only data with a precision higher than 1km were used. For additional occurrence data on Georgia, herbarium records were also taken from the Tbilisi State University Herbarium and the Batumi Botanical Garden Herbarium. These occurrence data were completed by several field surveys in 2011 and 2012 that we conducted across Georgia and recorded by a Garmin eTrex ® 12

Table 1: **Invasive plant species in Georgia:** Biology, habitat and origin (NA: North America; EA: East Asia) of the selected nine most abundant alien invasive species (all flowering plants) in Georgia.

Family	Genus	Species	Abbrevation	Life form	Sub-form	Ecology	Origin
Cactaceae	Opuntia	humifusa	OPUHUM	Perennial	Shrub	Dry grassland plant	NA
Cactaceae	Opuntia	phaeacantha	OPUPHA	Perennial	Shrub	Dry grassland plant	NA
Compositae	Ambrosia	artemisiifolia	AMBART	Annual	Herb	Ruderal plant	NA
Graminae	Miscanthus	sinensis	MISSIN	Perennial	Herb	Ruderal plant	EA
Leguminosae	Robinia	pseudoacacia	ROBPSE	Perennial	Tree	Forest plant	NA
Rosaceae	Spiraea	japonica	SPIJAP	Perennial	Shrub	Ruderal plant	EA
Simaroubaceae	Ailanthus	altissima	AILALT	Perennial	Tree	Dry grassland plant	EA
Verbenaceae	Clerodendron	bungai	CLEBUN	Perennial	Shrub	Ruderal plant	EA
Verbenaceae	Vitex	rotundifolia	VITROT	Perennial	Shrub	Pioneer plant	EA

parallel channel GPS receiver. A table with the amount of records by species and sampling method can be seen in Annex 2.

Identifying areas of high conservation value

By definition of the IUCN, Protected Areas are ”a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (Dudely 2008). Therefore, these Protected Areas are a good way to find areas of high conservation value that are also reasonable to manage. The IUCN is the most important organisation for setting and defining the different categories of Protected Areas. This organisation is widely accepted on an international level and many countries use these categories. The current categories were built in 1994. There are six categories with one subcategory (IUCN 2012):

- **Ia Strict Nature Reserve**
  Category Ia are strictly Protected Areas set aside to protect biodiversity and also possibly geological/ geomorphological features, where human visitation, use and impact are strictly controlled and limited to ensure protection of the conservation values. Such Protected Areas can serve as indispensable reference areas for scientific research and monitoring.
- **Ib Wilderness Area**
  Category Ib Protected Areas are usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.
- **II National Park**
  Category II Protected Areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
- **III Natural Monument or Feature**
  Category III Protected Areas are set aside to protect a specific Natural Monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small areas and often have high visitor value.
- **IV Habitat/Species Management Area**
  Category IV Protected Areas aim to protect particular species or habitats, and management reflects this priority. Many category IV Protected Areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.
- **V Protected Landscape/Seascape**
  A Protected Area where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
- **VI Protected Area with sustainable use of natural resources**
  Category VI Protected Areas conserve ecosystems and habitats, together with associated cultural values and traditional natural resource

> management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.

(IUCN 2012)

Georgia uses the IUCN categories as guidelines to set up their Protected Areas and the parliament controls the decision to establish new Protected Areas. This is regulated by the law of Georgia on Protected Areas (ELAW 2012). At present the total size of Protected Areas is 511,123 hectares, which is about 7 % of the country's territory. Forests cover about 75 % of the Protected Areas. They are classified as 14 Strict Nature Reserves, 8 National Parks, 4 Natural Monuments, 15 Managed Nature Reserves and 2 Protected Landscapes. The primary function of these Protected Areas is the protection of the natural heritage of the country and of unique natural and cultural monuments (Agency of Protected Areas, Georgia 2009). Geo-referenced maps of the Protected Areas of Georgia can be found on the database "protect planet" (protectedplanet 2010) and on the site from the agency of Protected Areas that is part of the Ministry of Environmental Protection and Natural Resources of Georgia (Agency of Protected Areas 2009) (Fig. 1). A more detailed list of the park and their protection objective can be found in Annex 2.

Bioclimatic data sets

Six climatically derived variables considered critical to plant physiological function and survival have been determined (Bartlein et. al 1986). These are tmax (maximal temperature of the warmest month), tmin (minimal temperature of the coldest month), tar (temperature annual range), twetq (mean temperature of the wettest month), pwet (precipitation of wettest month) and pdry (precipitation of driest month). Data were obtained from the WorldClim database (WorldClim 2012) (Hijmans et al. 2005), and the six original WorldClim Bioclimatic variables were used in this study without modifications and with a resolution of 30 arc seconds (1Km).

Future climate projections for the decade of 2060 were extracted from the

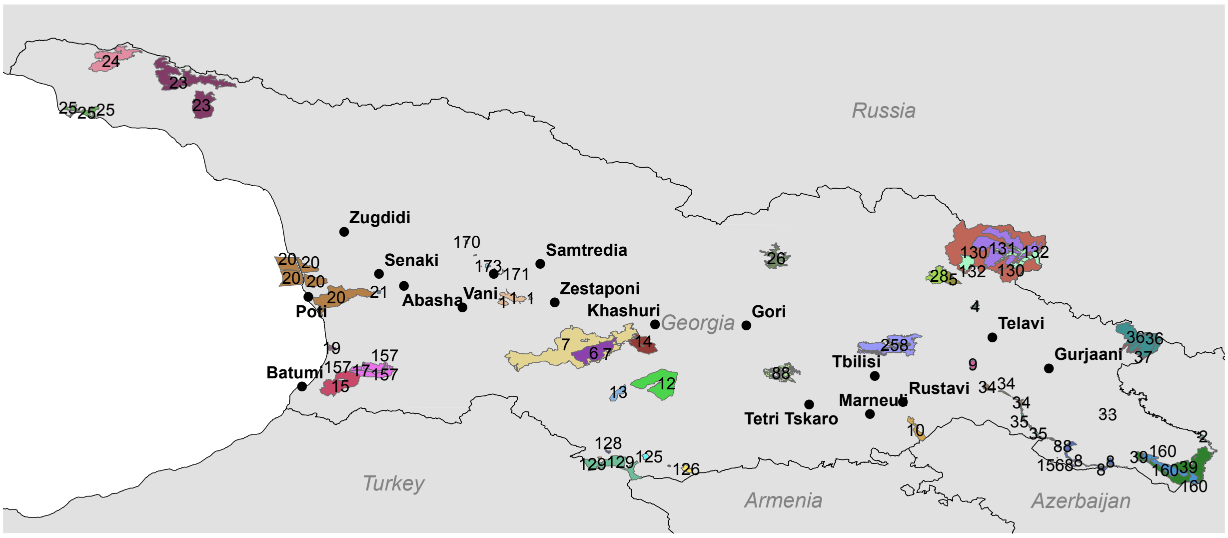

Fig. 1: **Map of Protected Areas of Georgia:** They are shown with their identification Number.

WorldClim dataset (Hijmans et al. 2005) in a 30 arc second grid, based on Scenario A1B from the 4th Assessment Report of the IPCC 2007 (IPCC 2007). The same six Bioclimatic variables as for the actual climate were used (tmax, tmin, tar, twetq, pwet and pdry). The A1 storyline and scenario family describes a future world of very rapid economic growth and global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (IPCC, 2007).

Species distribution modelling

The same three niche-based modelling techniques were used for each species and were all fitted in the R Program (R Development Core Team 2012, version 2.15.0 with the BIOMOD R-Package version 1.1.14, detailed by Thuiller et al. 2009) and repeated 10 times. The whole script can be seen in Annex 3. We used models, which are commonly used for species distribution modelling, and they have been tested by Broennimann et al. (2012). These are:

1. The gradient boosting machine (GBM; Friedman 2001) is an iterative computer learning algorithm. In GBM, model fitting occurs not in parameter space but instead in function space. The GBM iteratively fits shallow regression trees, updating a base function with additional regression tree models. A randomly chosen part of the training data is used for function fitting, leaving the other part for estimating the optimal number of trees to use during prediction with the model.
2. Random forests (RF; Breiman 2001). Random forests grows many classification trees. To classify the species observations (i.e. presences and absences) from the environmental variables, RFs puts the variables down each of the trees in the forest. Each tree gives a classification, and the tree 'votes' for that class. The forest chooses the classification having the most votes (over all the trees in the forest). Random forests is designed to avoid overfitting.
3. MaxEnt (Phillips et al. 2006) is a machine learning algorithm that estimates the probability of occurrence of a species in contrast to the background environmental conditions. MaxEnt estimates species distributions by finding the distribution of maximum entropy (i.e. that is most spread out, or closest to uniform) subject to the constraint that the expected value for each environmental variable under this estimated distribution matches its empirical average. MaxEnt begins with a uniform distribution then uses an iterative approach to increase the probability value over locations with conditions similar to samples.

MAXENT only requires presence data and random background points sampled from a study area to estimate the species distribution that is closest to uniform (maximizes entropy) (Lozier and Mills 2011). In contrast the two other models need information about presence and absence to be able to determine suitable conditions for a given species. Therefore, a set of 10,000 random absences in occupied biomes was selected from the over all area to calibrate the models. The models computed a probability distribution based on climatical variables spread

over the whole world and assigned a probability of suitability to each pixel in the study area (Jiguet et al 2010). For *Clerodenrum bungei*, only the models RF and MAXENT were used because there was not enough precise data to run the GBM model.
First, the fitted models were projected on the whole world and were then projected on Georgia at a resolution of 1x1 Km. Maps were produced which show areas where more than 50 per cent of the models (among 3 modelling techniques) predict the species to be present and thus can be considered as highly suitable for the species.
Models calibrated under current conditions were projected into future climates under the scenario A1B (IPCC 2007) to generate species distribution maps for the decade 2060.
Three different datasets were used to filter the resulting climatic potential distribution to get the real ecological habitat suitability. These are soil type (69 different types), vegetation type (29 different types), and the differentiation between forest, shrub or open vegetation. A Georgian GIS specialist provided these datasets. The filters were used based on the recorded occurrences (our field data and herbarium records) to extrapolate and illustrate, in which environment types the species can realistically occur. Thus, the filtered predicted distribution is a subset of the predicted climate niche,
Finally, a combined map was produced to show the areas with a high risk of colonisation by the most invasive species. To show this, all nine maps, one per species, where more than 50 per cent of the models predicted the species to be present were overlaid under current and future climatic conditions.

Model evaluation

To analyse the predictive success of models, they have to be evaluated. (Guisan and Zimmermann 2000). When model predictions are compared with actual observations, four cases can occur and they can be shown in a contingency table (Fig. 2) (Gibergans-Báguena and Llasat 2007):

		Observed	
		yes	no
Predicted	yes	hits = A	fals alarme = B
	no	misses = C	correct negatives = D

Fig. 2: **Contingency table:** Representation of the contingency table used for the model evaluation.

Three different methods have been used to evaluate the models:

1. Probability of detection (POD):

$$POD = \frac{A}{A + C}$$

This method is sensitive to hits, but ignores false alarms. It ranges from 0 to 1, with 1 being the perfect score.

2. True skill statistic (TSS):

$$TSS = \frac{(A \times D) - (B \times C)}{(A + C)(B + D)}$$

Perfect forecasts receive a score of +1, random forecasts receive a score of 0, and forecasts inferior to random forecasts receive a negative score.

3. Boyce:

This method consists in partitioning the habitat suitability range into different classes. For each class i, it calculates two frequencies: (1) P_i, the predicted frequency of evaluation points, where p is the number of evaluation points predicted by the model to fall in the habitat suitability class i, and (2) E_i, the frequency expected from a random distribution across the study area. Finally, for each class i, the predicted-to-expected (P/E) ratio F_i is calculated by

$$F_i = \frac{P_i}{E_i}$$

F_i increases as suitability increases. Boyce et al. (2002) measure this increase by the Spearman rank correlation coefficient between F_i and i. This "Boyce Index" varies from −1 to 1. Positive values indicate models whose predictions are consistent with the presence distribution in the evaluation dataset. Values close to zero mean that the model is not different from a chance model. Negative values indicate an incorrect model (Hirzel et al 2006).

❖ RESULTS

Predicted combined distribution of all nine invasive alien plants

All predicted distributions were estimated based on three different model techniques. All of the filtered maps where more than fifty per cent of the models predict the species to be present were overlaid with a map of the Protected Areas of Georgia, both under current and future climatic conditions. This showed which areas, especially the Protected Areas, are under the most risk to be colonised by a high number of invasive alien species (Fig.3). Here it can be seen that the area around Tbilisi and some parts in western Georgia have an

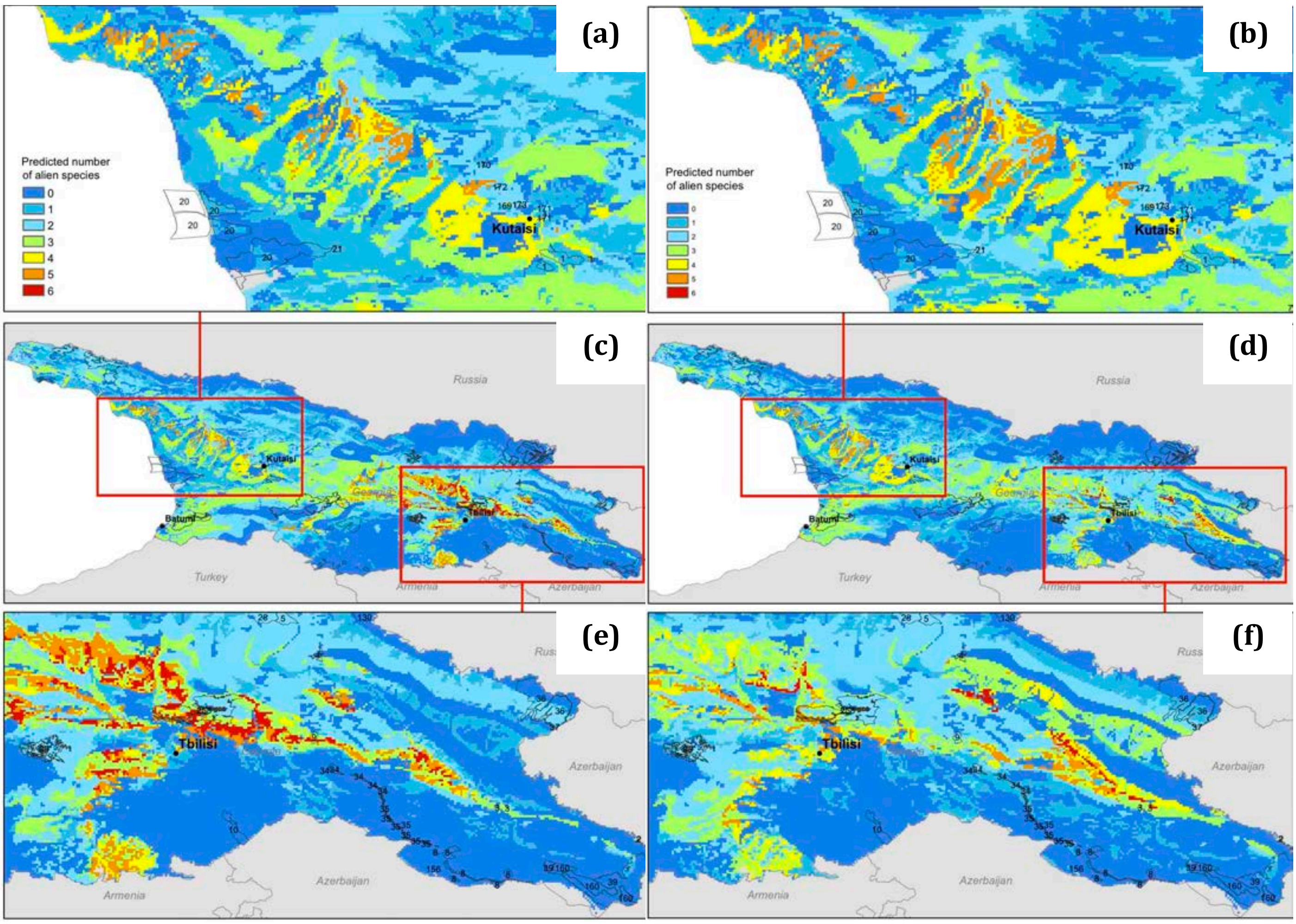

Fig. 3: **Threat potential of the nine invasive alien plants in Georgia:** at present conditions on the left (a, c, e) and in fifty years on the right (b, d, f). Pixel (1km²) in different colours show how many of these nine species are predicted by more than fifty per cent of the models and thus can be considered as highly suitable for these species. Black frames show Protected Areas with their identification number. Figure 3c and 3d show the map for whole Georgia, and a and b give a blow-up for Western Georgia and e and f for the Tbilisi area.

especially high threat potential with areas predicting the presence of at least 6 species having a probability of more than fifty per cent to be present. Another finding is that the region around Tbilisi is specially endangered in the future (fifty years) as there is a high increase in pixels where six invasive plant species are predicted to be present with a probability higher than fifty per cent due to climatic changes. The Adjara region at the Black Sea coast in contrast stays stable over the next fifty years.

Threat potential of invasive plants for Protected Areas

Table 2 gives the threat potential for each Protected Area ordered by IUCN classification. We found 17 Protected

Table 2: Threat potential of the 43 Protected Areas of Georgia: Listed is the percentage of area covered by at least one invasive alien species, the intensity of threat (by the mean number of invasive species predicted per pixel (1km²)), the most abundant invasive species and all invasive species that occur in the park under current and future climatic conditions. For plant species abbreviations see Table 1.

PA No (1)	Name	Area (ha)	Occ PA by min 1sp % Today	% Future	Intensity of threats (2) Today	Future	Sp occuring the most Today	Future	All species occuring in Park Today	# Sp Today	All species occuring in Park Future	# Sp Future
IUCN classification: Ia Strict Nature Reserve												
9	Mariamjvari	1040	86.67	86.67	2.3116	2.8597	ROBPSE	AMBART	AILALT, AMBART, CLEBUN, ROBPSE	4	AILALT, AMBART, CLEBUN, OPUHUM, OPUPHA, ROBPSE	2
157	Kintrishi	10703	86.75	96.39	2.2820	2.5482	AMBART	AMBART	AILALT, AMBART, ROBPSE	3	AILALT, AMBART, ROBPSE	3
173	Sataplia	354	100.00	100.00	1.8507	1.5680	ROBPSE	AMBART	AMBART, ROBPSE	2	AMBART, ROBPSE	3
5	Batsara	862	86.00	96.00	1.5698	1.4890	AMBART	AMBART	AMBART, ROBPSE	2	AMBART, ROBPSE	1
23	Pskhu-Gumista- Skurcha	40819	36.70	68.91	1.2794	1.4531	AMBART	AMBART	AILALT, AMBART, ROBPSE	3	AILALT, AMBART, ROBPSE	3
24	Ritsa	16289	16.85	45.69	0.9926	1.1645	AMBART	AMBART	AILALT, AMBART, ROBPSE	3	AILALT, AMBART, ROBPSE	2
4	Babaneuri	2986	40.00	40.00	0.9100	0.7758	AMBART	AMBART	AILALT, AMBART, ROBPSE	3	AILALT, AMBART, ROBPSE	2
6	Borjomi	14820	12.17	44.35	0.5884	0.8354	AMBART	AMBART	AILALT, AMBART, ROBPSE	3	AILALT, AMBART, ROBPSE	6
26	Liakhvi	6388	3.96	8.91	0.5715	0.6941	AMBART	AMBART	AMBART, ROBPSE	2	AMBART, ROBPSE	3
36	Lagodekhi	22295	6.32	35.63	0.5014	0.6534	AMBART	AMBART	AILALT, AMBART, ROBPSE	3	AILALT, AMBART, ROBPSE	1
80	Kobuleti	331	0.03	0.02	0.3323	0.2320	AMBART	AMBART	AMBART	1	AMBART	0
25	Pitsunda-Miussera	4014	4.69	4.69	0.1237	0.1101	AMBART	AMBART	AMBART, ROBPSE	2	AMBART, ROBPSE	3
132	Tusheti	10858	0.12	0.18	0.0251	0.1115	AMBART	AMBART	AMBART	1	AMBART	3
160	Vashlovani	14820	0.00	0.00	0.0000	0.0000				0		2
IUCN classification: II National Park												
15	Mtirala	15806	99.17	98.35	2.5647	2.5102	AMBART	ROBPSE	AILALT, AMBART, CLEBUN, MISSIN, ROBPSE	5	AILALT, CLEBUN, MISSIN, ROBPSE	4
258	Tbilisi	22425	95.85	95.85	2.3106	2.5311	ROBPSE	AMBART	AILALT, AMBART, CLEBUN, OPUHUM, OPUPHA, ROBPSE	6	AILALT, AMBART, CLEBUN, OPUHUM, OPUPHA, ROBPSE	6
88	Algeti	6822	55.86	68.47	1.1305	1.3395	AMBART	AMBART	AMBART, ROBPSE	2	AMBART, ROBPSE	2
7	Borjomi-Kharagauli	61234	27.43	54.64	0.8928	1.2766	AMBART	AMBART	AILALT, AMBART, ROBPSE	3	AILALT, AMBART, ROBPSE	3
20	Kolkheti	39001	2.52	0.01	0.2265	0.1933	AMBART	AMBART	AILALT, AMBART, ROBPSE, SPIJAP	4	AILALT, AMBART	2
39	Vashlovani	24820	1.05	1.05	0.1045	0.0640	ROBPSE	ROBPSE	AMBART, ROBPSE	2	ROBPSE	1
130	Tusheti	10858	0.09	0.27	0.0350	0.0971	AMBART	AMBART	AMBART	1	AMBART	1
129	Javakheti	13642	0.00	0.00	0.0000	0.0000				0		0
IUCN classification: III Natural Monument												
3	Artsivis Kheoba	10	100.00	100.00	3.0457	2.5870	AMBART	AMBART	AILALT, AMBART, CLEBUN, OPUPHA, ROBPSE	5	AILALT, AMBART, CLEBUN, OPUHUM, OPUPHA, ROBPSE	6
171	Imeretis Mgvimeebi	355	100.00	100.00	1.7975	1.5905	AMBART	AMBART	AMBART, ROBPSE	2	AMBART, ROBPSE	2
170	Imeretis Mgvimeebi	354	95.34	94.32	0.9270	0.8605	AMBART	AMBART	AMBART	1	AMBART	1
2	Alazani Floodplain	204	75.00	54.00	0.5030	0.0490	AMBART	AMBART	AMBART	1	AMBART	1
IUCN classification: IV Managed Nature Reserve												
21	Katsoburi	295	100.00	100.00	1.8901	1.1159	SPIJAP	AILALT	AILALT, ROBPSE, SPIJAP	3	AILALT	1
37	Lagodekhi	2156	96.97	72.73	1.6193	1.2024	AMBART	AMBART	AILALT, AMBART, ROBPSE	3	AILALT, AMBART, ROBPSE	3
14	Nedzvi	8992	51.75	88.81	1.5868	2.7972	AMBART	AMBART	AILALT, AMBART, ROBPSE	3	AILALT, AMBART, OPUHUM, OPUPHA, ROBPSE	5
28	Ilto	6971	57.41	77.78	1.2318	1.2958	AMBART	AMBART	AMBART, ROBPSE	2	AILALT, AMBART, ROBPSE	3
1	Ajameti	5117	21.79	21.79	1.1693	1.0855	AMBART	AMBART	AILALT, AMBART, CLEBUN, ROBPSE	4	AILALT, AMBART, CLEBUN, ROBPSE	4
34	Korughi	2068	21.21	0.00	0.9531	0.4683	AMBART	AMBART	AMBART, ROBPSE	2	AMBART, ROBPSE	2
12	Ktsia	22000	1.30	2.40	0.3680	0.7509	AMBART	AMBART	AMBART, ROBPSE	2	AILALT, AMBART, ROBPSE	3
19	Kobuleti	439	87.90	76.34	0.3302	0.2275	AMBART	AMBART	AMBART	1	AMBART	1
13	Tetrobi	3100	26.50	27.66	0.2715	0.7336	AMBART	AMBART	AMBART, ROBPSE	2	AILALT, AMBART, ROBPSE	3
35	Iori	1336	9.52	0.00	0.2156	0.0421	ROBPSE	ROBPSE	AMBART, ROBPSE	2	AMBART, ROBPSE	2
8	Chachuna	5200	2.50	0.90	0.0315	0.0043	AMBART	AMBART	AMBART	1	AMBART	1
10	Gardabani	3484	0.00	0.00	0.0000	0.0000				0		0
128	Sulda	320	0.00	0.00	0.0000	0.0000				0		0
125	Khanchali	839	0.00	0.00	0.0000	0.0000				0		0
126	Madatafa	1484	0.00	0.00	0.0000	0.0000				0		0
IUCN classification: V Protected Landscape												
17	Kintrishi	3190	77.27	84.09	2.0662	2.1451	AMBART	AMBART	AILALT, AMBART, ROBPSE	3	AILALT, AMBART, ROBPSE	3
131	Tusheti	10858	2.10	2.20	0.0014	0.0176	AMBART	AMBART	AMBART	2	AMBART	1

(1): PA = Protected Area, (2): Intensity of threats = the mean number of invasive species predicted per pixel (1km²)

Areas that have more than fifty per cent of their area covered by at least one invasive species. Eight of them are quite small with less than 1000 hectares and their conservation objectives are rather monumental structures than the local biodiversity. Two of the large Strict Nature Reserves have a high percentage of area covered by invasive species under current conditions and additionally a high intensity of threat. These are the Kintrishi Strict Nature Reserve with 86.75% of area covered and a predicted intensity of threat of 2.28 IAP/1km^2 and the Mariamjvari Strict Nature Reserve with 86.67% of area covered and an intensity of threat of 2.31. Furthermore, the area of Kintrishi is predicted to increase in the future by 9.64%. Focusing on the National Parks, also the Tbilisi and the Mtirala National Park are among the most threatened ones with 95.85% 99.17%, respectively, of area predicted to be occupied by at least one invasive species and a predicted intensity of threat of on average 2.5 IAP/1km^2. Among the Managed Nature Reserves we found three specifically threatened parks. These are the Lagodekhi, Nedzvi and the Ilto Managed Nature Reserve with 96.97%, 51.75% and 57.41% of area predicted to be occupied by at least one invasive species under current conditions. The Nedzvi Nature Reserve has the highest increase with 37.06%. over the next fifty years for the area predicted to be occupied. It can further be seen that *Ambrosia artemisiifolia, Robinia pseudoacacia* and *Ailanthus altissima* are the most abundant invasive plant species in the Protected Areas occurring in 36, 29 and 17 parks, respectively (cf. also next paragraph).

Invasion potential of the nine alien plant species in Georgia and of its Protected Areas

The distribution for each of the nine invasive alien species was predicted based on the occurrences in their native and invasive range. All of the models made for the nine invasive plant species in Georgia resulted in a good model evaluation score from the three different techniques POD, TSS and Boyce (c.f. Methods) and thus can be plausible. The unfiltered maps only show the climatic habitat suitability but by using the filters we could model the plant's predicted ecological niches in Georgia. Table 3 shows again that *Ambrosia artimisiifolia, Robinia pseudoacacia* and *Ailanthus altissima* are by fare the most abundant invasive plant species over all Georgia as

Table 3: **Threat potential of the studied nine invasive alien plants to Georgia**: Percentage of area predicted to be covered by each of the selected invasive exotic plants and for the Protected Areas alone, and the number of Protected Areas predicted to be occupied by each species under current and future conditions, with respective increase/ decrease over the next 50 years.

Species name	% Surface predicted in Georgia		Δ %	% Surface predicted in parks		Δ %	# Parks		Δ
	Today	Future		Today	Future		Today	Future	
Ambrosia artemisiifolia	23.99	25.07	+ 1.08	40.40	43.53	+ 3.13	36	34	-2
Robinia pseudoacacia	13.82	13.28	-0.55	18.93	21.36	+ 2.42	29	27	-2
Ailanthus altissima	8.73	13.19	+ 4.46	10.54	25.10	+ 14.55	17	20	+3
Clerodendrum bungei	4.27	4.32	+ 0.05	1.88	1.98	+ 0.10	5	5	0
Opuntia phaeacantha	0.82	1.56	+ 0.75	0.77	1.64	+ 0.87	2	4	+2
Spriraea japonica	0.62	0.29	-0.32	0.29	0.00	-0.29	2	0	-2
Miscanthus sinensis	0.23	0.21	-0.03	0.06	0.06	0	1	1	0
Opuntia humifusa	0.10	0.81	+ 0.71	0.01	1.51	+ 1.50	1	4	+3
Vitex rotundifolia	0.04	3.66	0	0.00	0.00	0	0	0	0

well as in the Protected Areas. *Ambrosia artemisiifolia* has 23.99% surface of area predicted in Georgia and 40.40% in Protected Areas under current conditions. This will slightly increase in the next fifty years to 25.07% and 43.53%,respectively. Under current conditions *Robinia pseudoacacia* is the second most occurring invasive plant species with 13.83% all over Georgia and 18.93% in Protected Areas. In future conditions *Ailanthus altissima* is the second most occurring invasive plant in Protected Areas with 25.10% due to a very high increase of 14.55%. *Clerodendrum bungai* occurs with 4.27% surface predicted all over Georgia and 1.88% in Protected Areas as an intermediate invasive plant and it is predicted to be stable over the next fifty years. *Opuntia phaeacantha, Spiraea japonica, Miscanthus sinensis, Opuntia humifusa* and *Vitex rotundifolia* are predicted to occur at lower levels than the other species, with areas predicted all over Georgia between 0.82% and 0.04%. Noteworthy is that *Vitex rotundifolia* does not occur in one single Protected Area under current and future climatic conditions and will not cause many problems for Georgia. Because it is a coastal plant, it does not have a large spread potential further in Georgia (Cousins et al. 2010).

All these values are based on maps produced for each species. Figures 4-12 show the various maps produced for *Ambrosia artimisiifolia* as an example. All maps of the other species are given in Annex 4. Fig. 4 shows the predicted

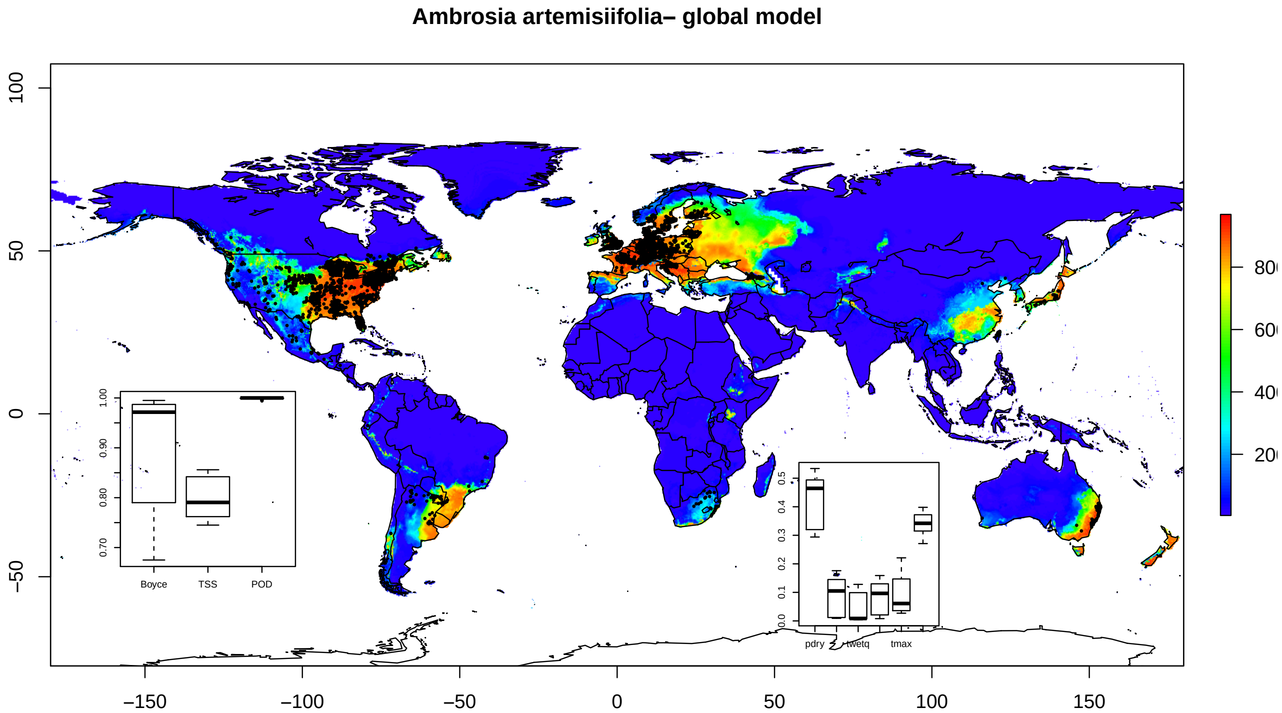

Fig.4: Predicted potential distribution of *Ambrosia artemisiifolia* based on both native and invasive climatic niches: The different colours on the map show the predicted climatic suitability in per cent of models among 10 iterations of three modelling techniques. Black dots indicate known occurrences of the species. The boxplot on the left present the model evaluations. Boyce and TSS ranges from -1 to 1 with a perfect score of 1 and POD ranges from 0 to 1, also with a perfect score of 1. The boxplot on the right indicate the importance of the variables pdry, pwet, twetq, ter, tmax and tmin for the model predictions (cf. text for details).

climatic suitability worldwide for *A. artimisiifolisa,* with two boxplots, one for the model evaluations and one for the variable importance, Fig. 5 shows the climatic suitability for Georgia under current and Fig. 6 under future conditions. Fig. 7 and 8 illustrate the predicted habitat suitability using the filters. The final maps produced for *Ambrosia artimisiifolia* show the predicted potential distribution under current (Fig. 10) and under future conditions (Fig. 11), without using filters (Fig. 12) and with using filters (Fig.13). Each pixel, representing 1x1 Km, is considered 'predicted' when more than fifty per cent of the models predict the species to be present, and 'non-predicted' when less than fifty per cent of the models predict the species to be present. Based on these predicted individual species distribution maps (c.f. Annex 4), it can be seen that *Ambrosia artemisiifoia, Ailanthus altissima* and *Robinia pseudoacacia* are predicted to be widespread all over Georgia. This is also reflected in the calculations shown in Table 3. *Ambrosia artmisiifolia* is extremely widespread, especially within the Protected Areas. *Clerodendrum bungei, Spiraea japonica, Miscanthus sinensis* and *Vitex rotundifolia* are only predicted in the lowlands of the western part of Georgia in the Adjara region. In contrast, the two Cactaceae species, *Opuntia humifusa* and *Opuntia phaeacantha,* are only predicted in the drier climates around Tbilisi and the eastern part of Georgia.

❖ DICUSSION

Species distribution modelling

Ecological science is challenged to predict potential consequences of global change for biodiversity (Guisan and Rahbek 2011). Predictive species distribution modelling can provide a useful and cost effective tool for conservation planning and biodiversity management (Rodriguez et al 2007 and Araújo and Guisan 2006). Earlier studies and model comparisons identified novel modelling techniques such as RF and GBM as outperforming and therefore as excellent techniques for an accurate distribution prediction (Marmion et al 2009). To our knowledge, such a procedure to identify areas of high conservation value most at risk by IAP has been applied for the first time. Bustamante and Seoane (2004) conducted a pilot study in this sense, but this was restricted to just two species of IAP and two target endangered native plant and using generalized linear model.

Predicted combined distribution of all nine invasive alien plants

Two regions in Georgia have been identified to be under special threats by IAP. This means that the ecological conditions of these regions are suitable for many of the invasive species and are therefore under a high risk to negatively impact their local biodiversity. The intensity of threat is predicted to be especially high around Tbilisi in fifty years and there is now substantial evidence that climatic changes are increasingly affecting ecosystems and the distribution of invasive plant species (Broennimann et al 2006) and most probably also their impact. There is, however, no straight correlation between the distribution of an IAP and its impact on the invaded plant community (Sun et al. in revision), but impact can be assumed to be larger for more widely distributed than for locally restricted IAP. It is important to focus on these particular areas under high risk when the instruments for conservation are limited and especially when we know how the climatic conditions are going to change over the next fifty years.

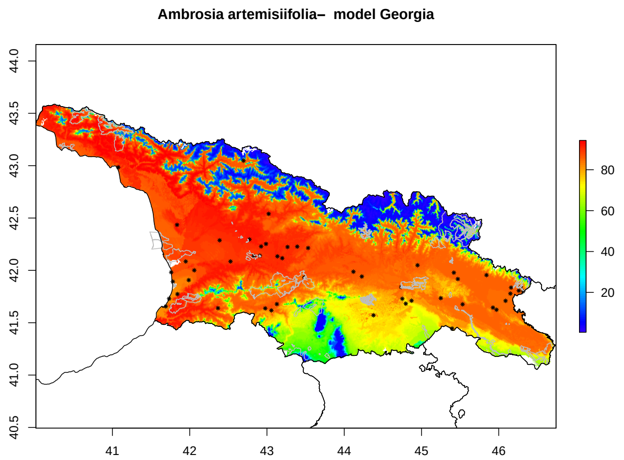

Fig. 5: Predicted potential distribution of *Ambrosia artemisiifolia* in Georgia based on native and invasive climatic niches under todays conditions: Different colours show percentage of predicted climate suitability under current conditions. Asterisks indicate known occurrences of the species and grey frames show Protected Areas (cf. text for details).

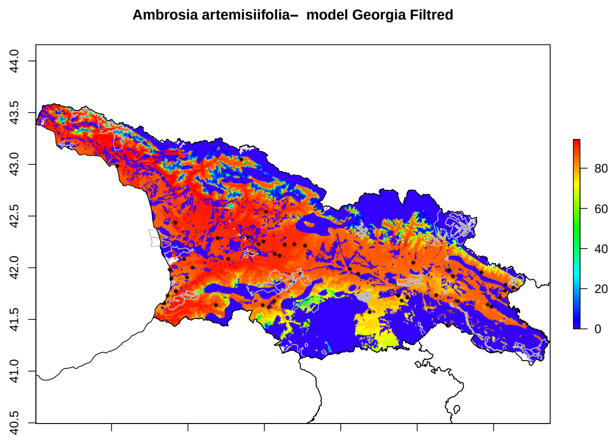

Fig. 7: Predicted potential distribution of *Ambrosia artemisiifolia* in Georgia based on native and invasive climatic niches under todays conditions with considering the environmental filters: Different colours show percentage of predicted habitat suitability under current conditions. Asterisks indicate known occurrences of the species and grey frames show Protected Areas (cf. text for details).

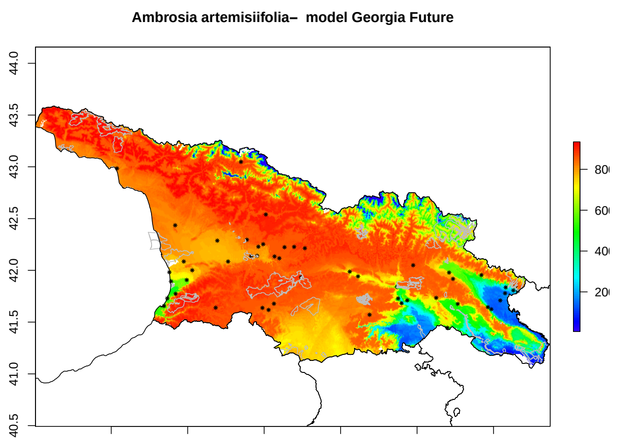

Fig. 6: Predicted potential distribution of *Ambrosia artemisiifolia* in Georgia based on native and invasive climatic niches under conditions in fifty years: Different colours show percentage of predicted climate suitability under current conditions. Asterisks indicate known occurrences of the species and grey frames show Protected Areas (cf. text for details).

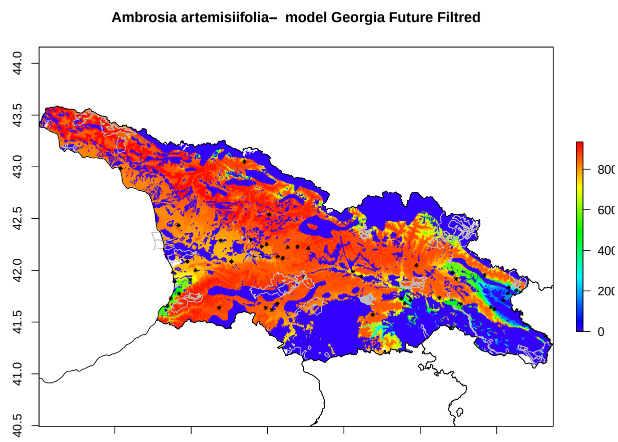

Fig. 8: Predicted potential distribution of *Ambrosia artemisiifolia* in Georgia based on native and invasive climatic niches under conditions in fifty years with using environmental filters: Different colours show percentage of predicted habitat suitability under current conditions. Asterisks indicate known occurrences of the species and grey frames show Protected Areas (cf. text for details).

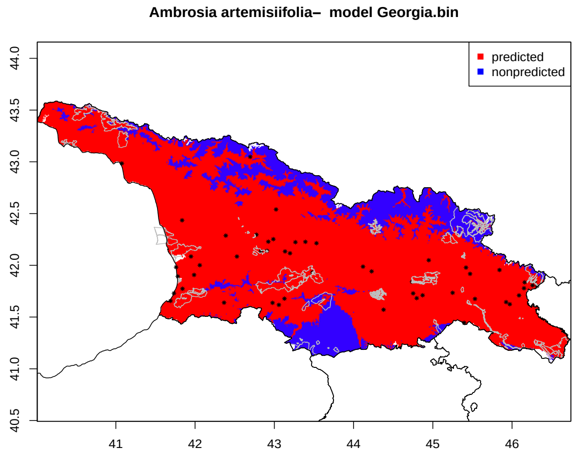

Fig.9: Predicted potential distribution of *Ambrosia artemisiifolia* in Georgia based on both native and invasive climatic niches under current conditions: Pixels in red show areas where more than 50% of the models (among 10 iterations of three modelling techniques) predict the species to be present and thus be considered as highly suitable for the species. Black asterisk indicate known occurrences of the species and grey shapes show Protected Areas (cf. text for details).

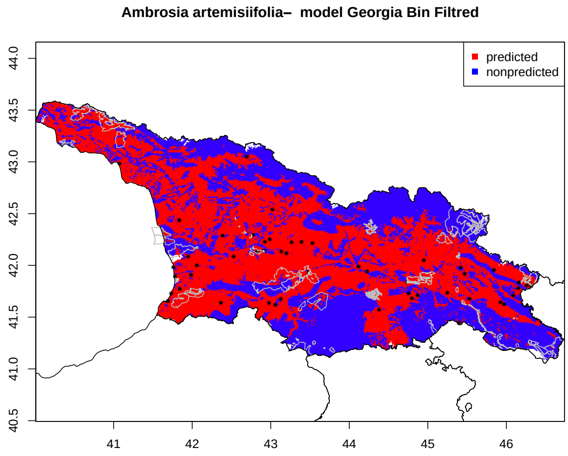

Fig.11: Predicted potential distribution of *Ambrosia artemisiifolia* in Georgia based on both native and invasive climatic niches under current conditions using filters: Pixels in red show areas where more than fifty per cent of the models (among 10 iterations of three modelling techniques) predict the species to be present and thus be considered as highly suitable for the species. Black asterisk indicate known occurrences of the species and grey shapes show Protected Areas (cf. text for details).

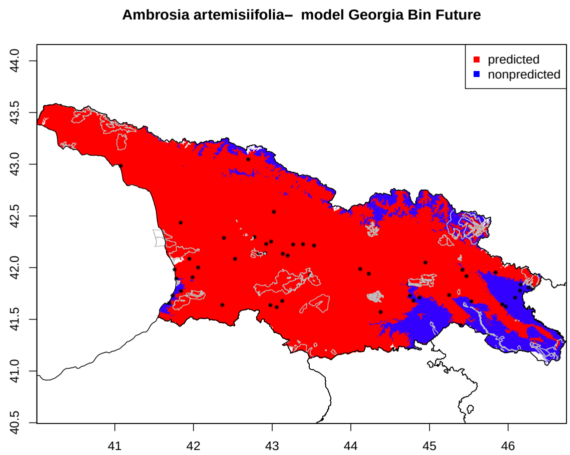

Fig.10: Predicted potential distribution of *Ambrosia artemisiifolia* in Georgia based on both native and invasive climatic niches in fifty years: Pixels in red show areas where more than fifty per cent of the models (among 10 iterations of three modelling techniques) predict the species to be present and thus be considered as highly suitable for the species. Black asterisk indicate known occurrences of the species and grey shapes show Protected Areas (cf. text for details).

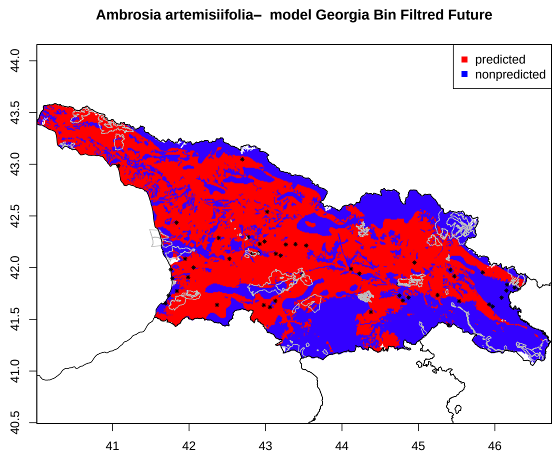

Fig.12: Predicted potential distribution of *Ambrosia artemisiifolia* in Georgia based on both native and invasive climatic niches in fifty years with using filters: Pixels in red show areas where more than fifty per cent of the models (among 10 iterations of three modelling techniques) predict the species to be present and thus be considered as highly suitable for the species. Black asterisk indicate known occurrences of the species and grey shapes show Protected Areas (cf. text for details).

Threat potential for Georgia and for Protected Areas by invasive plants

In our study we found that the most abundant alien plant invaders all over Georgia are also the most abundant invasive plant species in the Protected Areas. This means that the parks are generally affected in the same way as whole Georgia. The most abundant invasive plant, *Ambrosia artemisiifolia* is, however, not the one which increases the most over the next fifty years. It is *Ailanthis altissima* with a very high increase of 14.5% to a total amount of 25.10% of surface predicted in Protected Areas. Two species stay stable over time, *Miscanthus sinensis* and *Vitex rotundifolia*, while *Spiraea japonica* even decreases a little in its surface predicted in Protected Areas. Another finding indicates that the most threatened Protected Areas are located at lower altitudes and close to large cities. In contrast, the areas that are situated in the Greater and Lesser Caucasus Mountains are less threatened. This corresponds with the relationship between altitude and amount of invasive species predicted (Fig. 14). The lower the levels are above sea, the more the invasive species are predicted. This is in line with findings by Alexander (2009).

Invasion potential of the nine alien plant species in Georgia and of its Protected Areas

The invasive plant species we detected to be the most abundant are *Ambrosia artemisiifolia, Ailanthus altissima* and *Robinia pseudoacacia and* they are all on the black list of invasive plant species for Europe (EPPO 2012). Furthermore *Miscanthus sinensis* is on the EPPO alert list (EPPO 2012). This means that these invasive plant species cause a lot of ecological and economical damage all over Europe, and our study now shows that this also holds true for Georgia. It is not only for Georgia important but also for all European countries to manage these invasive plants. Therefore our study has importance for many more countries than Georgia because it can be taken as an example of effective conservation strategies.

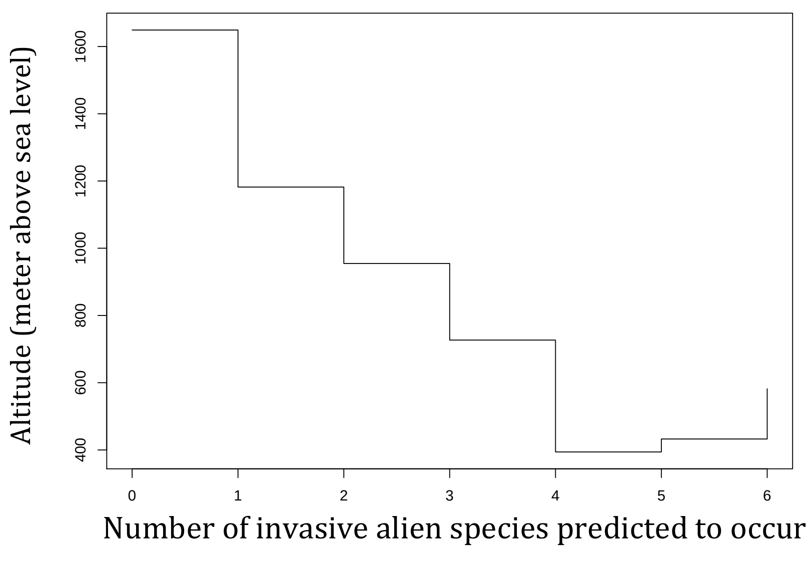

Fig. 13: Relationship between altitude and number of invasive plant species predicted. With number of species predicted on the X-axes and meter above sea level on the Y-axes.

❖ CONCLUSION

In this study, we determined the overlap between the Protected Areas and selected invasive plant species in order to identify the areas with the highest conflict rate. Therefore, our findings allow to give concrete suggestions for the conservation of Georgia's outstanding biodiversity by prioritizing Protected Areas most at risk and ranking the IAP according to their distribution patterns.

At present the total size of Protected Areas is 511,123 hectares, which is about 7 % of the country's territory. Of these we now know on which we should focus and which invasive plant species are the most widely distributed, thus providing a time and cost effective way to protect the endemic species of Georgia from the effect of invasive plants. This study thus also demonstrates how useful species distribution models are to develop conservation strategies, especially in combination with predictions of future climatic conditions, and that they can be applied all over the world with little cost.
We believe that our predictions are especially realistic, as the models not only consider the climate envelope, but also the ecological niche based on the environmental filters available at a very high resolution for Georgia. As the Protected Areas are established by the government and managed through the Georgian law, they are a good place to start for conservation, as the legal tools are already available.

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