GIS-BASED ASSESSMENT OF THE LANDFORM DISTRIBUTION OF 2100 PREDICTED CLIMATE CHANGE AND ITS INFLUENCE ON BIODIVERSITY AND NATURAL PROTECTED AREAS IN ROMANIA

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Abstract. Potential effects of climate change include loss of biodiversity and ecodiversity due to direct influences and habitat changes and impacts on agricultural systems resulting into the decrease of productivity. While direct assessment is rarely possible, the evaluation methodology focused on statistical modelling. This study used the Geographical Information Systems to look at the spatial distribution of 2100 predicted temperatures in Romania by landform and biogeographical regions, assess their potential influences on natural protected areas, and model the shift of biogeographical regions under the hypothesis according to which increased temperature result into the expansion of warmer regions over the colder ones. Results suggest that, according to the predictions, the most important threats occur in natural protected areas from the mountain regions and in agriculture, and that the Steppic region could expand over the Continental and Black Sea ones, with caveats due to the hypothesis and methodology.

Keywords: biodiversity, ecodiversity, climate change, biogeographical region.

Rezumat. Evaluarea în Sistem Informaţional Geografic a distribuţiei schimbărilor climatice prezise pentru 2100 în funcţie de relief şi a influenţei acesteia asupra biodiversităţii şi ariilor naturale protejate din România. Efectele potenţiale ale schimbărilor climatice includ erodarea biodiversităţii şi ecodiversităţii datorită influenţei directe şi modificării habitatelor şi impacturi asupra agrosistemelor, care conduc la scăderea productivităţii. Deşi evaluarea directă este arareori posibilă, metodologia de evaluare s-a concentrat asupra modelării statistice. Acest studiu a folosit Sistemele Informaţionale Geografice pentru a analiza distribuţia spaţială a predicţiilor pe 2100 a temperaturii din România în funcţie de relief şi regiunea biogeografică, pentru a evalua influenţa potenţială asupra ariilor naturale protejate şi a modela translaţia regiunilor biogeografice sub ipoteza potrivit căreia creşterea temperaturii determină extinderea regiunilor calde peste cele reci. Rezultatele arată că, pe baza predicţiilor, cele mai importante ameninţări apar în ariile naturale protejate din regiunile montane şi în agricultură şi că regiunea de stepă s-ar putea extinde peste cea continentală şi peste cea a Mării Negre, sub rezerva ipotezei şi a metodologiei.

Cuvinte cheie: biodiversitate, ecodiversitate, schimbări climatice, regiune biogeografică.

INTRODUCTION

Biological diversity means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (UNITED NATIONS, 1993); the latter is called ecodiversity. Based on the spatial scale, several levels of diversity are defined: α - diversity of ecosystems, communities, biocoenoses, taxonomic or functional groups; β - diversity of ecosystems within a complex of ecosystems, diversity of habitats or gradients; γ - diversity of regional complexes of ecosystems, *e.g.* the European biogeographical regions; δ - diversity of macro-regional complexes of ecosystems, *e.g.* the global biogeographical regions; ε - diversity of life environments; and ω - phylogenetic diversity (MAGURRAN, 1988; PUSCEDDU, 2008).

Previous studies have indicated that climate change influences all biological and ecological systems, regardless of being natural or man-dominated, protected or not. Species have been affected directly or due to habitat changes (CONDÉ & RICHARD, 2008) with respect to their interactions (MARSHALL et al., 2008), distribution, extinction rates, reproduction timings, length of growing seasons (SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, 2007). Moreover, most of the important elements of global change have been shown likely to increase the prevalence of biological invaders (DUKES & MOONEY, 1999; DUKES, 2003). Ecosystems have been affected in ways currently difficult to predict due to the influence of climate change on the transport vectors (MARSHALL et al., 2008), due to the exacerbation of the effects of habitat fragmentation (THOMAS, 2003), or due to the influence of the large-scale and regional circulation on local processes (BLENCKNER & CHEN, 2003). Significant changes have been expected in the Alpine ecosystems (CONDÉ & RICHARD, 2008) due to the retreat or disappearance of Alpine species caused by climate change (SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, 2007). The overall trends regarding glaciers, plants, insects, and temperatures have shown remarkable internal consistency at high elevations (EPSTEIN et al., 2008). Impacts on agricultural ecosystems have included increased exposure to heat stress, changes in rainfall patterns, greater leaching of nutrients, more wildfires, greater erosion due to stronger winds, and spread of pests and diseases (SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, 2007).

The methodology used to assess the correlation between climate change and loss of biodiversity has included statistical analyses of correlations between climatic and biological data (BLENCKNER & CHEN, 2003), small-scale experiments that study species dynamics under altered precipitation regimes or simulated warming, identification of functional traits that are related to tolerance of different climates, long-term observations of species composition changes correlated with climate variation (DUKES & MOONEY, 1999), and climate modeling using different software (DUKES & MOONEY, 1999; MALCOLM, 2003; SCHRÖTER et al., 2003; EPSTEIN et al., 2008; MARSHALL et al., 2008).

However, while statistical analyses have been suitable for large scale systems and climate models have been designed for analyses at continental scale, intermediate scale analyses have been performed using the Geographical Information Systems (GIS), representing decision support systems involving the integration of spatially referenced data in a problem solving environment (COWEN, 1988). The use of GIS in relationship with biodiversity has been especially productive when looking at β or γ diversity (PETRIŞOR, 2008).

A special inference was needed to analyze the possible expansion of biogeographical regions due to climate change. The underlying hypothesis is that when regions with colder climates and regions with warmer climates are neighboring, the temperature increase in the colder areas results into a gradual colonization of these areas by species migrating from the warmer climate and finally into a replacement of colder biogeographical regions by the warmer ones, given the modification of abiotic conditions as a result of climate change, and of the species composition as a result of migration. The start point in drawing the new boundaries was represented by current temperature ranges characteristic to each biogeographical region, as indicated by different sources: the EBONE / European Biodiversity Observation Network describes average temperatures for the Pannonian region (WAGENINGEN-UR, 2100a), Alpine region (WAGENINGEN-UR, 2100b), and Continental region (WAGENINGEN-UR, 2100c); other sources published data on the Steppic region (SUNDSETH, 2009) and Black Sea region (ZAITSEV et al., 2002). The intervals are displayed in Table 1; as it can easily be noticed, most intervals overlap. The actual overlap is depicted in Fig. 1.

Table 1. Displaying the range of current temperatures characteristic to all Romanian biogeographical regions.
Tabel 1. Intervale de temperatură caracteristice tuturor regiunilor biogeografice din România.

Biogeographical region	**Minimum temperature (^{0}C)**	**Maximum temperature (^{0}C)**
Pannonian	-3	27
Alpine	-7	20
Continental	-5	23
Steppic	-15	30
Black Sea	6	25

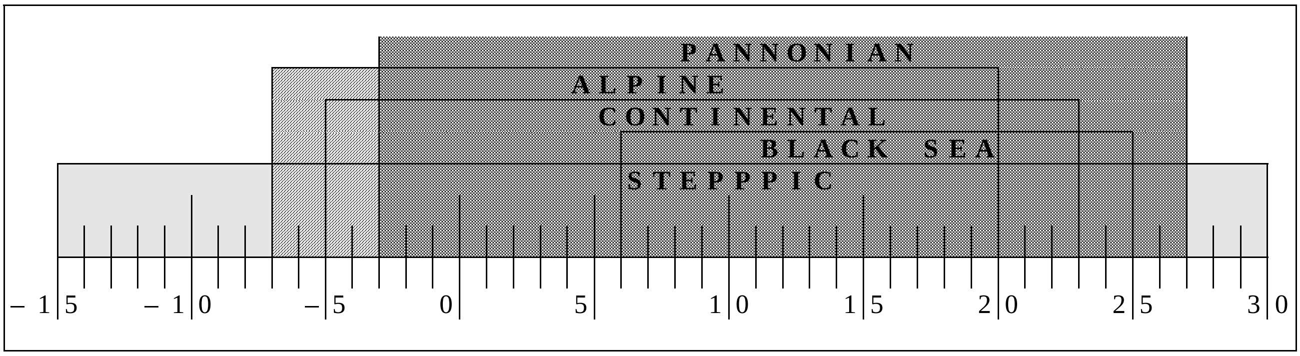

Figure 1. Displaying the overlapping ranges of current temperatures characteristic to each biogeographical region.
Figura 1. Intervale suprapuse ale temperaturilor caracteristice fiecărei regiuni biogeografice.

The problem due to overlapping does not allow the application of discriminatory analysis that could yield a logical separation of biogeographical regions based solely on temperature ranges. However, there is only one supported inference given the hypothesis and current ranges: minimum predicted temperatures below -7^{0}C and/or maximum predicted temperatures over 27^{0}C characterize the Steppic region.

This study aimed to look at the spatial distribution of predicted climate changes by landform, to evaluate their potential influence on the biodiversity and natural protected areas in Romania, and to predict the spatial shifts of biogeographical regions based on current temperature ranges and the assumption that temperature increases will result into the expansion of warmer regions over the colder ones.

MATERIALS AND METHODS

This study integrated five datasets, summarized in Table 2:

(1 and 2) Climate data consist of global current (1) and predicted (2) temperatures. In addition, we computed the difference between actual and predicted average temperatures for each raster cell. The analysis of differences indicated that within the Romanian territories all values were positive, ranging between 2.329 and 2.7125^{0}C. Consequently, we defined three classes to describe the range of temperature differences: low (2.329-2.457^{0}C), average (2.457-2.585^{0}C), and high (2.585-2.713^{0}C).

(3) Landforms: the main methodological issue was related to the definition of landforms by altitude. Different authors propose a wide range of altitude limits to discriminate between landforms: plains - up to 300 m., hills and plateaus - up to 800 m. (MÂRA, 2007); plains - up to 200 m., hills and plateaus - up to 1000 m. (CAZAN et al., 2004). However, even the two works cited above do no provide a clear limit of separation between hills or plateaus and mountains. Moreover, the two classes overlap for an interval of approximately 200 m altitude. This study utilizes the

following limits of the landforms: floodplain - 0 to less than 20 m, plain - 0 to less than 200 m, hill or plateau - 200 to less than 900 m, and mountain - over 900 m (PETRIŞOR, 2009b).

(4) Data on land cover and use: we used the first level of this classification, defining five land cover classes: artificial surfaces, agricultural areas, forests or semi-natural areas, wetlands, and water bodies (Commission of the European Communities, 1995).

(5) Biogeographical regions: five of the twelve regions identified in Europe are present in Romania: Continental, Steppic, Alpine, Pannonian, and Black Sea.

(6) Data on natural protected areas from Romania contain information on the following types: (a) scientific reserves, natural reserves and natural monuments, (b) national parks and natural parks (biological), (c) Sites of Community Importance, (d) Special Areas of Conservation, (e) Special Protection Areas, and (f) area where the Convention on the Protection and Sustainable Development of the Carpathians is applied, even though the latter cannot be considered a natural protected area in the true meaning of this concept, as protective actions are only recommended, but not compulsory within its perimeter. Categories (c), (d), and (e) were established through the Natura 2000 Programme of the European Union.

Table 2. Specifications on the data used in the study: dataset, provider, location, format, remarks and transformations.
Tabel 2. Specificaţii asupra datelor utilizate în acest studiu: set de date, sursă, adresă, format, observaţii şi transformări.

No.	Dataset	Provider	URL	Format	Remarks	Transformations
1	Climate - actual	University of Berkeley	http://biogeo.berkeley.edu/worldclim/diva/diva_worldclim_2-5m.zip	DIVA-GIS software (Hijmans *et al*., 2001)	Produced by the project WorldClim (HIJMANS et al., 2005); 2.5 min × 2.5 min	Imported in ArcView GIS 3.X, projected into Stereo 1970, subsample for Romania
2	Climate - predicted	University of Berkeley	http://biogeo.berkeley.edu/worldclim/diva/diva_wc_ccm3_2-5m.zip	DIVA-GIS software (Hijmans *et al*., 2001)	Predictions for 2100 based on 2×CO_2 concentration and CCM3 model (GOVINDASAMY et al., 2003); 2.5 min × 2.5 min	Imported in ArcView GIS 3.X, projected into Stereo 1970, subsample for Romania
3	Land-form	Consultative Group on International Agricultural Research - Consortium for Spatial Information	http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp	Digital Elevation Model (DEM)	Nearly 90 m × 90 m	Import into Arc GIS, then export to ArcView GIS 3.X, projected into Stereo 1970, subsample for Romania
4	Land cover and use data	CORINE (Coordinated Information on the European Environment) Land Cover 2000 (CLC2000) seamless vector database	http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=950	ArcView GIS 3.X	2000 data	Projected into Stereo 1970, subsample for Romania
5	Biogeo-graphical regions	European Environment Agency data services	http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=308	ArcView GIS 3.X	2001 data	Projected into Stereo 1970, subsample for Romania
6	Natural protected areas	Romanian Ministry of the Environment and Sustainable Development	http://www.mmediu.ro/departament_ape/biodiversitate/	ArcView GIS 3.X	Not all types of protected areas legally defined are available	No transformation needed

The datasets were overlaid for a visual and quantitative analysis of information. Quantitative analyses consisted of using GIS spatial analysis and geo-processing functions to compute areas of specific classes describing the overlapping of the three temperature intervals and either landforms, biodiversity, or natural protected areas. In addition, we computed:

(a) the percentage represented by each combination between the temperature interval and class of specific feature from all temperature intervals, to pinpoint which temperature intervals have more influence on specific feature classes, and

(b) the percentage represented by each combination between the temperature interval and class of specific feature from all feature classes, to analyze which feature classes are more impacted by a certain temperature interval.

To analyze the expansion of regions given the increases of temperatures and provided the methodological limitation described in Figure 1 and Table 1, GIS was used to determine the areas where the minimum predicted temperatures are below -7^{0}C and/or the maximum predicted temperatures are over 27^{0}C. However, the results indicated that such areas are situated in the Continental, Pannonian, and Black Sea regions, where maximum predicted temperatures exceed current minimum values, and in the Alpine region, where minimum temperatures fall below current minimum values. While colonization of the Black Sea and Continental regions could be possible due to spatial proximity, the results were modified to eliminate areas situated in the Alpine and Pannonian regions due to the lack of spatial continuity and impossibility of colonization.

RESULTS AND DISCUSSION

First of all, it is important to reiterate that the differences between the predicted and actual temperatures are positive at all locations composing the territory of Romania, ranging between 2.329 and 2.7125.

The results are presented in Figures 2 - 7. Figure 2 displays the distribution of low, average, and respectively high differences between actual and predicted average temperature by landforms, land cover classes, biogeographical regions, and types of natural protected area. Figure 3 displays information from a reverted perspective, looking at the influence of the classes of differences between actual and predicted average temperature on each type of landform, land cover class, biogeographical region, and type of natural protected area. Figure 4 displays the results of the analyses of the spatial distribution of low, average, and high differences between the predicted and actual temperature based on the landform, Figure 5 displays the spatial relationship between climate predictions and biodiversity, assessed by using the first level of CORINE land cover, and Figure 6 displays the potential impact of increased average temperatures on existing natural protected areas. Figure 7 redraws the boundary of biogeographical regions based on the comparison between predictions and current ranges of temperatures.

This study aimed to analyze the spatial distribution of predicted climate changes by landform and evaluate their potential impact on the biodiversity and natural protected areas in Romania.

Our findings suggest that predicted climate changes, reflected by positive differences between the predicted and actual average temperature, are not distributed uniformly over the Romanian landforms (Figs. 2-4). The highest temperature differences occurred mostly in the plain areas (64.5%), average differences in the floodplains (72.86%), and low differences characterized floodplains (52.26%) and hills or plateaus (44.13%). With respect to the landform, floodplains were dominated by average differences (61.99%), plains by high differences (87.22%), hills or plateaus by low differences (56.5%), and mountains by high differences (98.1%).

The impact on biodiversity can be assessed by looking at the relationship between predicted temperature differences and diversity assessed using the land cover and biogeographical regions (Figs. 2, 3, and 5). In the first case, high differences affected the agricultural surfaces and forest or semi-natural areas (47.15, respectively 44.92%), while both average and low differences impacted only the agricultural surfaces (74.12, respectively 63.24%). With respect to the land cover classes, artificial areas received predominantly high temperatures (65.88%), agricultural areas were impacted by high (50.67%) and average (40.1%) temperature differences, forest or semi-natural areas were affected by high differences (80.98%), and wetlands and water bodies by low differences (63.25%, respectively 45.95%). In the second case, high and average differences had a significant impact mostly on the Continental region (61.67%, respectively 58.64%), while low differences predominated in the Steppic region (81.94%). With respect to the biogeographical region, high differences were expected in the Continental and Alpine regions (67.63, respectively 99.82%), the Pannonian region was characterized by average differences (96.47%), and the Black Sea region was situated exclusively within the low differences range (100%). The Steppic region was mostly affected by average and low differences (42.45, respectively 41.70%).

Finally, the analysis of the potential impact of predicted temperature differences on the natural protected areas, summarized in Figures 2, 3, and 6, indicated that high and average temperature differences affected the area where the Convention on the Protection and Sustainable Development of the Carpathians is applied (58.66%, respectively 31.84%), while low temperature differences were predominant in the SPAs. High temperature differences were the most common regardless of the type of natural protected area (scientific and natural reserves and natural monuments - 62.82%, national and natural parks - 48.95%, SCIs - 59.51%, the area under the Convention on the Protection of the Carpathians - 88.68%, SPAs - 49.37%, and SACs - 73.37%).

Overall, the evolution of average temperatures in Romania suggests an increasing trend, with positive differences between the current and predicted values all over the national territory, ranging between 2.329 and 2.7125. Our results, consistent with the findings of CONDÉ & RICHARD (2008) and the SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY (2007), also indicate that the highest temperature differences will occur in the mountain areas (Fig. 4), situated in the Alpine biogeographical region (Fig. 5) and covered in majority by forests or semi-natural areas and agricultural surfaces. Since most of the Romanian natural protected areas are situated at high altitudes (the percentage ranged from 55% for SACs to 93% for SPAs, excluding the area where the Convention on the Protection and Sustainable Development of the Carpathians is applied, situated exclusively at high altitudes - PETRIŞOR, 2009b), the additional pressure due to climate changes will significantly threaten the existing natural protected areas.

Moreover, since most of the Romanian territory is covered by agricultural surfaces, the influence of high temperatures on floodplains and plains, and on agricultural surfaces (Figs. 1 and 2) will most likely result into a decrease of the agricultural production (consistent with the results published by the SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, 2007) and would potentially affect the entire economy.

Figure 7 indicates a possible expansion of the Steppic region over the Black Sea region and over some parts of the Continental region. Moreover, the predicted maximum temperatures in the current Steppic region exceed current maximum values, which could result into disappearance of species less tolerant to high temperatures. However, these findings are subject to caveats due to the hypothesis and due to the methodological limitation of discriminating between the intervals. Another limitation is that the hypothesized process will have a time span characteristic to the large regional complexes of ecosystems, exceeding the prediction horizon, excepting perhaps for pioneer and invasive species.

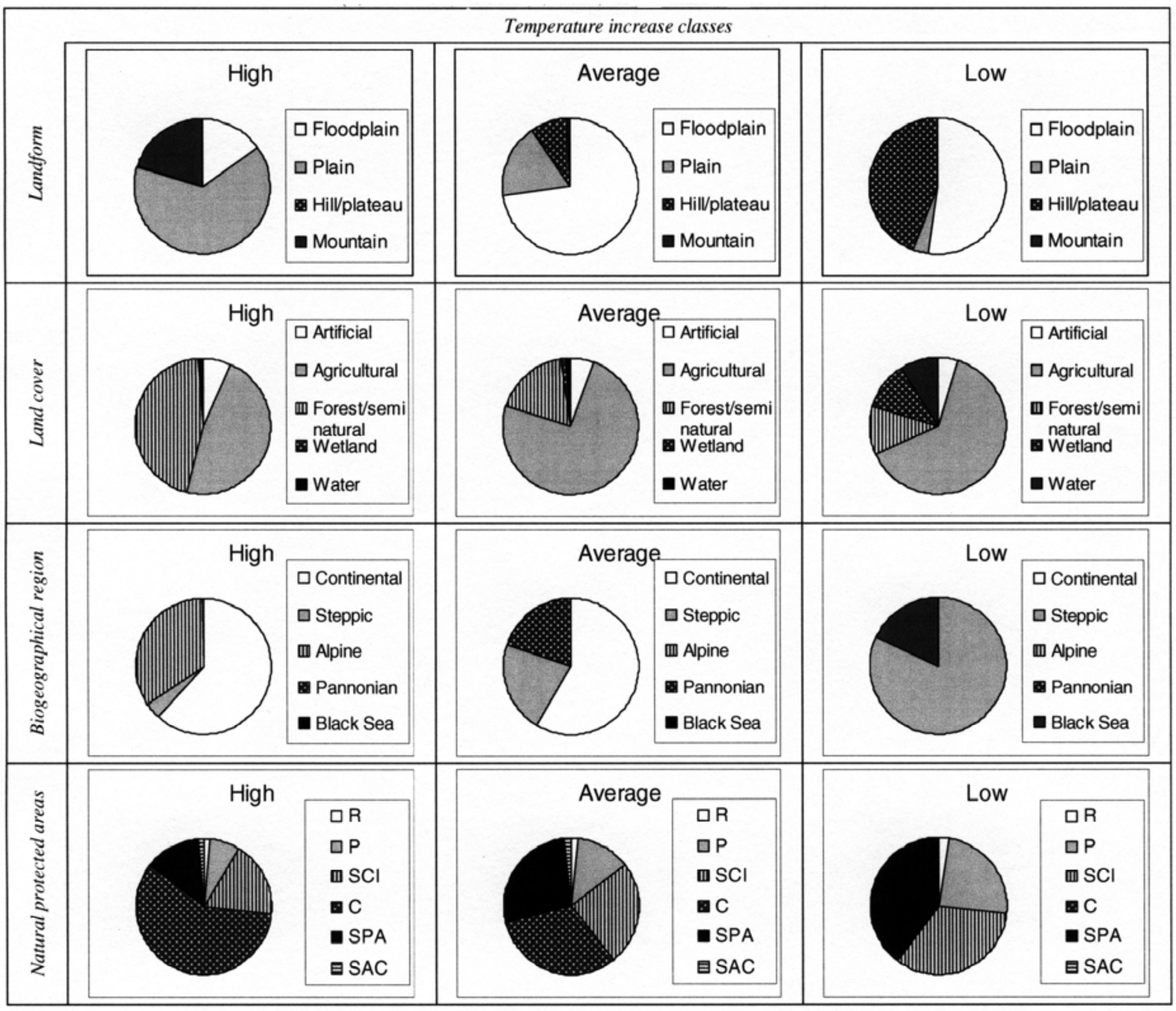

Figure 2. Distribution of low, average, and respectively high differences between actual and predicted average temperature by landforms, land cover classes, biogeographical regions, and types of natural protected area - scientific and natural reserves and natural monuments (R), national and natural parks (P), Sites of Community Importance (SCI), area under the Convention on the Protection of the Carpathians (C), Special Protection Areas (SPA), and Special Areas of Conservation (SAC). Temperature differences are grouped in three classes: low (2.329-2.457), average (2.457-2.585), and high (2.585-2.713).
Figura 2. Distribuţia diferenţelor mici, medii şi mari dintre temperaturile existentă şi prezisă în funcţie de relief, categoriile de acoperire a terenului, regiunile biogeografice şi tipurile de arii naturale protejate - rezervaţii ştiinţifice şi naturale şi monumente naturale (R), parcuri naţionale şi naturale (P), situri de importanţă comunitară (SCI), zona de aplicare a Convenţiei Carpatice (C), arii de protecţie avifaunistică (SPA), şi arii speciale de conservare (SAC). Diferenţele de temperatură sunt grupate în trei categorii: mici (2,329-2,457), medii (2,457-2,585) şi mari (2,585-2,713).

CONCLUSIONS

In summary, findings indicate that predicted climate change for 2100 could possibly affect the biodiversity of Romania. Most important changes will occur in the mountain regions that are already a priority on the European environmental agenda. Other changes will occur in the continental region, which could result into the transformation of some parts of it into a steppe. However, the later statement should be interpreted with the caveats of the hypothesis according to which temperature increase lead to the expansion of warmer regions over the colder ones, and the methodological limitations. Last but not least, the changes are likely to affect natural protected areas, especially those situated at higher altitudes.

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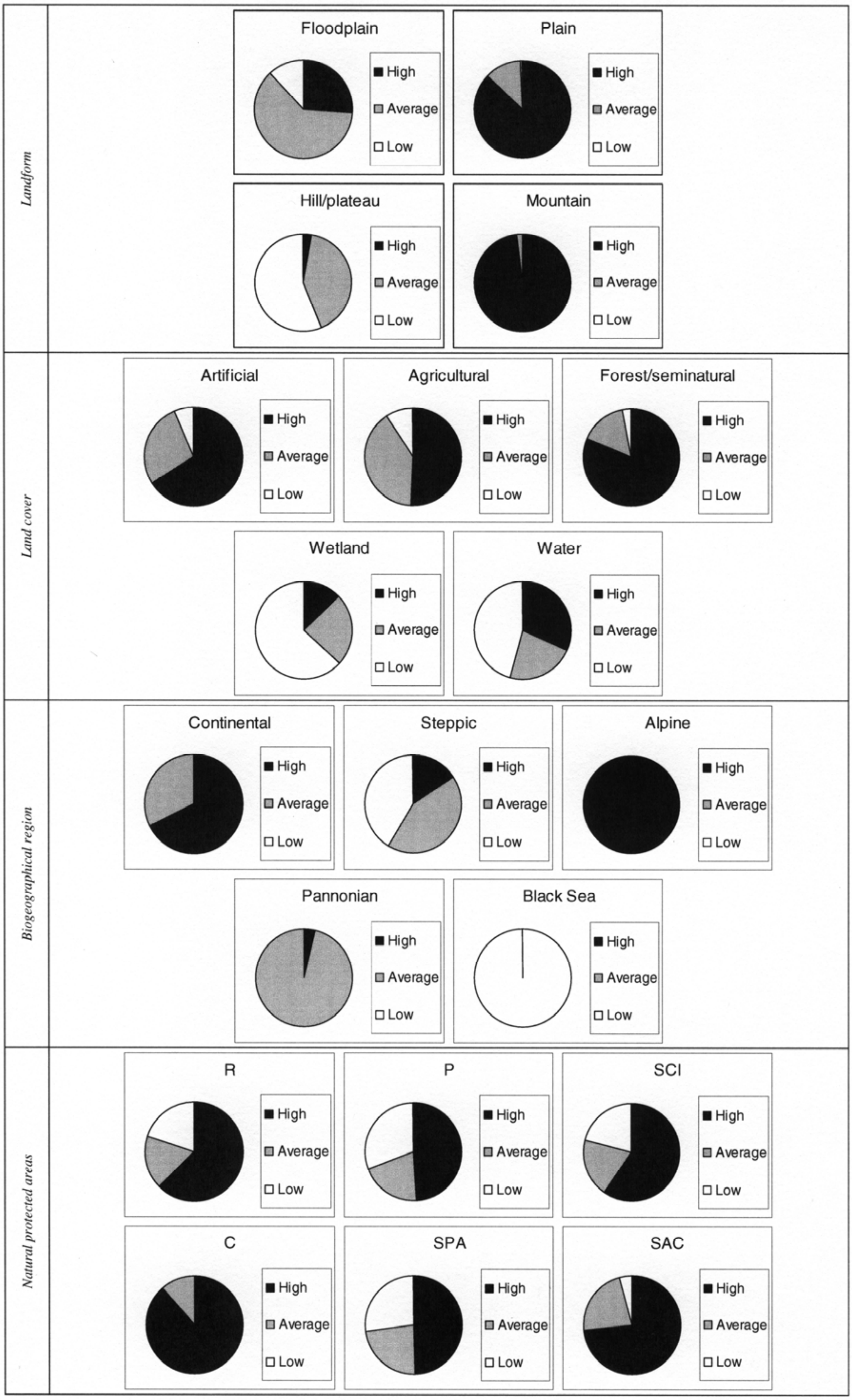
Landform
Floodplain
Plain
Hill/plateau
Mountain
Land cover
Artificial
Agricultural
Forest/seminatural
Wetland
Water
Biogeographical region
Continental
Steppic
Alpine
Pannonian
Black Sea
Natural protected areas
R
P
SCI
C
SPA
SAC
High
Average
Low

Figure 3. Influence of the classes of differences between actual and predicted average temperature on each type of landform, land cover class, biogeographical region, and type of natural protected area - scientific and natural reserves and natural monuments (R), national and natural parks (P), Sites of Community Importance (SCI), area under the Convention on the Protection of the Carpathians (C), Special Protection Areas (SPA), and Special Areas of Conservation (SAC). Temperature differences are grouped in three classes: low (2.329-2.457), average (2.457-2.585), and high (2.585-2.713).
Figure 3. Influenţa claselor de diferenţe dintre temperaturile existentă şi prezisă asupra fiecărei unităţi de relief, fiecărei categorii de acoperire a terenului, fiecărei regiuni biogeografice şi fiecărui tip de arii naturale protejate - rezervaţii ştiinţifice şi naturale şi monumente naturale (R), parcuri naţionale şi naturale (P), situri de importanţă comunitară (SCI), zona de aplicare a Convenţiei Carpatice (C), arii de protecţie avifaunistică (SPA), şi arii speciale de conservare (SAC). Diferenţele de temperatură sunt grupate în trei categorii: mici (2,329-2,457), medii (2,457-2,585) şi mari (2,585-2,713).

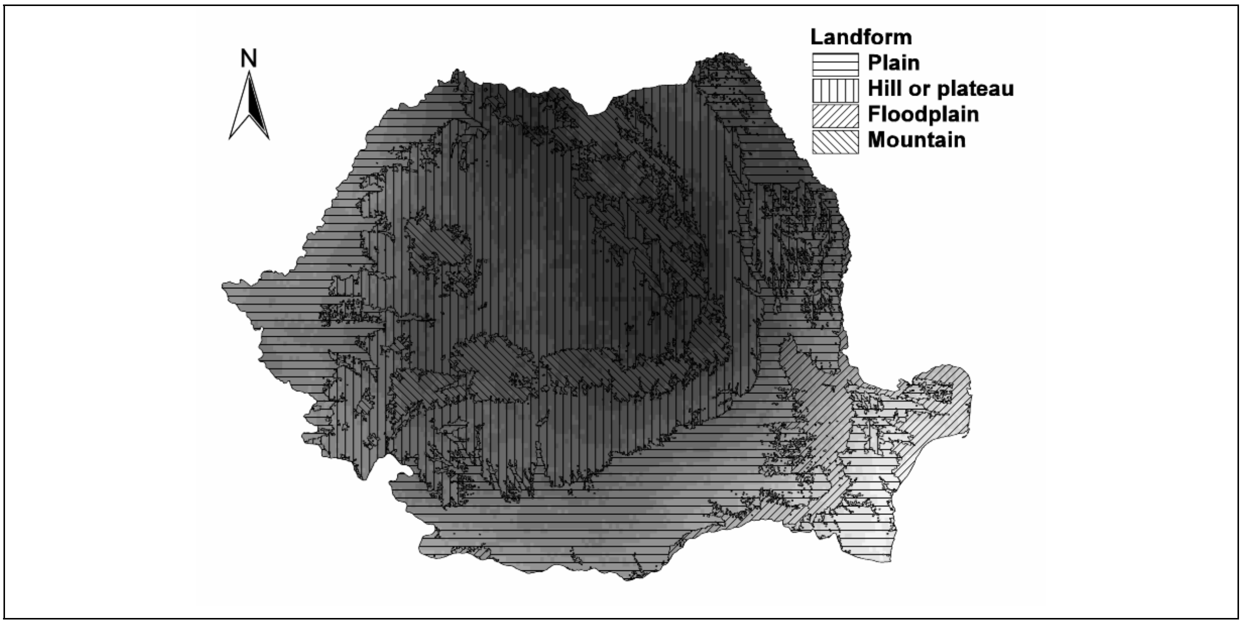

Figure 4. Distribution of 2100 predicted temperature increase by landform in Romania. The magnitude of temperature differences is displayed using gray shades; darker shades indicate higher values, suggesting an important increase of the average temperature.
Figura 4. Distribuţia temperaturilor prezise pentru 2100 în funcţie de relief în România. Mărimea diferenţelor este indicată prin nuanţe de gri; nuanţele închise indică valori mari, sugerând creşteri importante ale temperaturii medii.

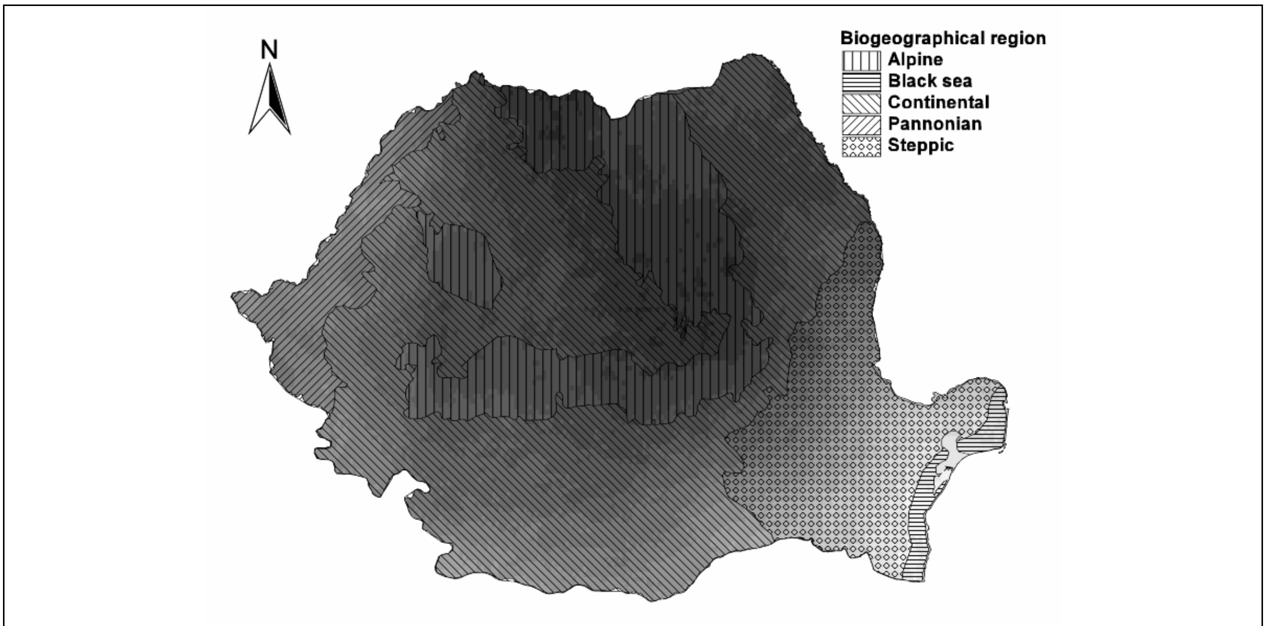

Figure 5. Distribution of 2100 predicted temperature increase in the Romanian biogeographical regions. The magnitude of temperature differences is displayed using gray shades; darker shades indicate higher values, suggesting a significant increase of the average temperature.
Figura 5. Distribuţia temperaturilor prezise pentru 2100 în regiunile biogeografice din România. Mărimea diferenţelor este indicată prin nuanţe de gri; nuanţele închise indică valori mari, sugerând creşteri importante ale temperaturii medii.

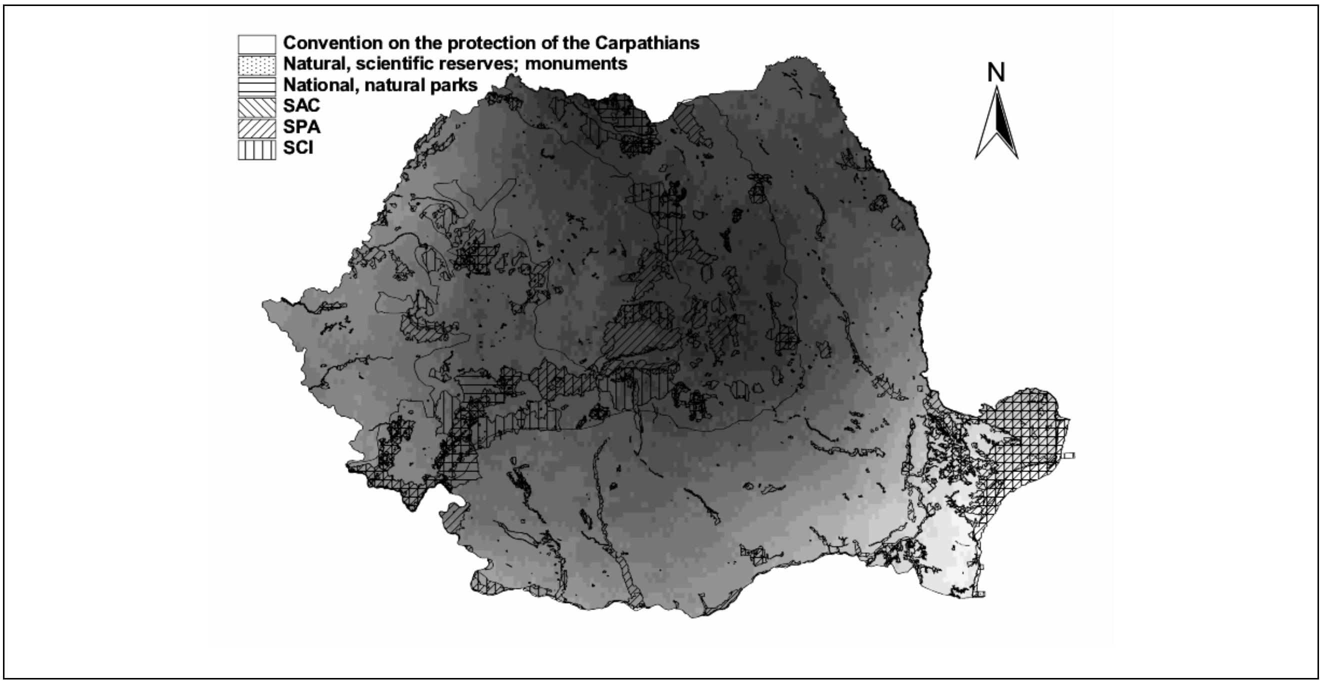

Figure 6. Distribution of 2100 predicted temperature increase in the Romanian natural protected areas. The magnitude of temperature differences is displayed using gray shades; darker shades indicate higher values, suggesting a significant increase of the average temperature.
Figura 6. Distribuția temperaturilor prezise pentru 2100 în ariile naturale protejate din România. Mărimea diferențelor este indicată prin nuanțe de gri; nuanțele închise indică valori mari, sugerând creșteri importante ale temperaturii medii.

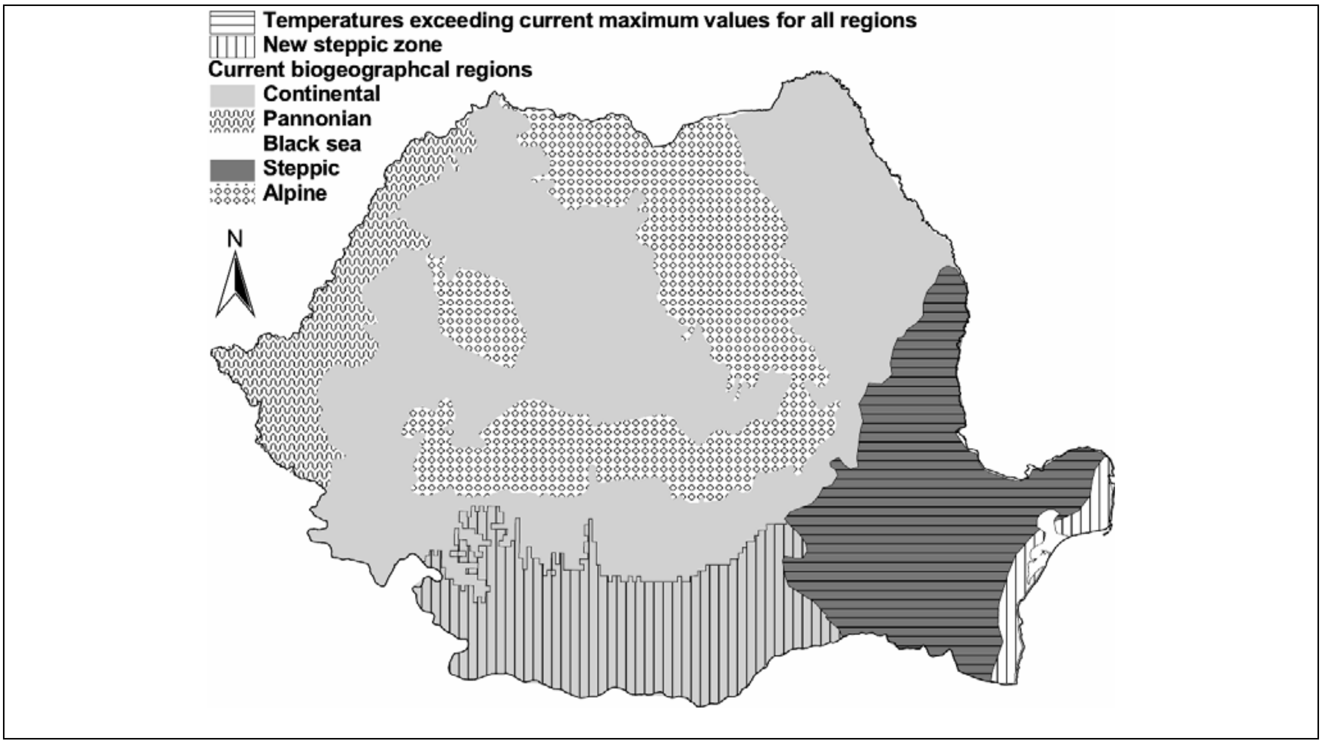

Figure 7. 2100 predicted shift of biogeographical regions. The image displays the limits of the expanded Steppic region; its current boundaries correspond to an area where the predictions indicate that current maximum temperatures will be exceeded, possibly resulting into the disappearance of some species and ecosystems.
Figura 7. Translații ale regiunilor biogeografice prezise pentru 2100. Imaginea arată limita de extindere a regiunii de stepă; limitele actuale corespund unei regiuni unde conform predicțiilor vor fi depășite temperaturile maxime actuale, ceea ce probabil va conduce la dispariția unor specii și ecosisteme.

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