FINAL Report for SR 2

In-Depth Study on the impacts of climate change threats on ecosystems

Data Project

Project start date: 27 December 2011
Project end date: 27 August 2013
Total Project duration (in months) 20 months

Data Lead Partner FC

Name REC - THE REGIONAL ENVIRONMENTAL CENTER FOR CENTRAL AND EASTERN EUROPE
Contact person Eszter Mogyorosy
Postal address Ady Endre ut 9-11. 2000 Szentendre, Hungary
Visit address Ady Endre ut 9-11. 2000 Szentendre, Hungary
Telephone + 36 26 504 000
Fax: +36 26 311 294
E-mail emogyorosy@rec.org
Project Website carpathcc.eu
<table>
<thead>
<tr>
<th>LEAD PARTNER SR3</th>
<th>REC - THE REGIONAL ENVIRONMENTAL CENTER FOR CENTRAL AND EASTERN EUROPE</th>
</tr>
</thead>
</table>
| COLLABORATING PARTNERS | AQUAPROFIT  
|                     | INCDPMD  
|                     | CAR HAS  
|                     | ARTELIA |
| Authors (in alphabetic order) | Zoltán BARCZA  
|                               | Ján MERGANIĆ  
|                               | Larisa BODEA  
|                               | Katarína MERGANIČOVÁ  
|                               | Győrgi CSÓKA  
|                               | Cecile MONNIER  
|                               | Laura DOBOR  
|                               | Cristina MUSAT  
|                               | Dobromil GALVÁNEK  
|                               | Aniko NEMETH  
|                               | Deák GYÓRGY  
|                               | Ana NICOLESCU  
|                               | Dóra HIDY  
|                               | Marius OLTEANU  
|                               | Tomáš HLÁSNÝ  
|                               | Anatoliy PAVELKO  
|                               | Jaroslav HOLUŠA  
|                               | Ionel POPA  
|                               | Adrian IONASCU  
|                               | Monica RADU  
|                               | Andrei IOSIF  
|                               | Ervin RASZTOVITS  
|                               | Monika JANÍŠOVÁ  
|                               | Jozef ŠÍBÍK  
|                               | Karolina LUKÁŠOVÁ  
|                               | Jaroslav SOCHA  
|                               | František MÁLIŠ  
|                               | Alina TRENTEA  
|                               | Csaba MÁTYÁS  
|                               | Jiří TROMBIK |

Partners:

![Aquaprint](image1.png)  
![Rec](image2.png)  
![Artealia](image3.png)  

This document has been prepared for the European Commission however it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

**Developed by the CarpathCC Framework Project**
# TABLE OF CONTENT

1. **LIST OF FIGURES** ........................................................................................................... 4
2. **LIST OF TABLES** ............................................................................................................ 7
3. **LIST OF ANNEXES** ........................................................................................................ 8
4. **EXECUTIVE SUMMARY** ................................................................................................ 9
5. **ADMINISTRATIVE PART** .............................................................................................. 14  
   5.1. **Background of the SR** ............................................................................................ 14  
   5.2. **Description of the management system** ................................................................. 17  
   5.3. **Task by task – description** ..................................................................................... 18  
      5.3.1. Task 1: Study area definition and project database development .......................... 18  
      5.3.2. Task 2: Climate change impact on forest pests and pathogens ............................. 22  
      5.3.3. Task 3: Adaptive potential of forest management ............................................... 433  
      5.3.4. Task 4: Observed and projected shift of forest tree species in the Carpathians .................................................. 86  
      5.3.5. Task 5: Climate change impact on forest protective functions in montane and alpine areas ........................................... 122  
      5.3.6. Task 6: Integrated assessment of forest vulnerability to climate change .......... 143  
      5.3.7. Task 7: Grasslands and wetlands vulnerability .................................................... 169  
5.4. **Outputs and Results** ................................................................................................ 198  
   5.4.1. Climate change impact on pests and pathogens in the Carpathians and anticipated threats to forests .............................................. 198  
   5.4.2. Forest management in the Carpathians and its capacity to adapt the forest to climate change ................................................. 201  
   5.4.3. Climate change induced forest tree species shift in the Carpathians – observational evidences and modelling ........................................... 203  
   5.4.4. Integrated forest vulnerability assessment ................................................................ 205  
   5.4.5. Effect of changes in forest cover on protective function of montane and subalpine forest .................................................. 210  
   5.4.6. Observed species shift in grasslands communities, wetlands vulnerability and climate change impact on grasslands productivity .................................................. 211  
6. **EVALUATION** ............................................................................................................. 215  
7. **CONCLUSIONS** ........................................................................................................ 226  
8. **IMPLICATIONS** ......................................................................................................... 227  
9. **REFERENCES** ............................................................................................................ 228  
10. **ANNEXES** ............................................................................................................... 245
1. **List of Figures**

Figure 1 Organisation of work and data flows in SR2 .......................................................14
Figure 2 State boundaries and geomorphologic units of the Carpathians used as spatial frame for the assessment of forest vulnerability to climate change. .................................19
Figure 3 Distribution of selected forest tree species taken from the Euforgen database. 19
Figure 4 Time series of airborne infrared imagery showing the progress of spruce trees infestation by spruce bark beetle following the wind calamity in High Tatras Mts. in 2004. .........................................................................................................................26
Figure 5 Damage to forest by spruce bark beetle in the High Tatras Mts. after windstorm in 2004. Hills of the Tíchá and Kôprová valleys. .........................................................28
Figure 6 Position of cross-boundary Slovak-Czech-Polish region affected by spruce forests decline. ..........................................................................................................................288
Figure 7 Long term development of sanitary felling data in the Kyskuče Beskids. ..........29
Figure 8 Spatial progress of forest infestation by bark beetles in the transboundary regions of the Western Beskids (SK-CZ-PL). .................................................................29
Figure 9 Sample areas in the Western Beskids where the remote sensing based assessment of changes in forest cover due to bark beetle infestation was conducted ...............................................................................................................................30
Figure 10 Bark beetle infestation of spruce forests within Romanian forestry departments .........................................................................................................................36
Figure 11 L. dispar gradations in the years 1877-2009 in the Czech Republic ...............366
Figure 12 Outbreaks of L. dispar in the period 1972–2006 in Slovakia. ..............................36
Figure 13 Outbreak areas of gypsy moth (Lymantria dispar) in Czech and Slovak part of the Carpathians in the period 2003-2005. .................................................................36
Figure 14 Outbreaks of L. dispar in the period 1958–2007 in Poland ..............................37
Figure 15 Outbreaks of L. dispar in the period 1961–2007 in Hungary. ...........................38
Figure 16 Infested area (ha) by L. dispar since 2000 in Hungarian part of Carpathians. 38
Figure 17 Distribution of L. dispar indicated by infested area in Hungarian part of the Carpathians. ..................................................................................................................399
Figure 18 Outbreaks of L. dispar in the years from 1953 to 2005 in Romania ...............40
Figure 19 Outbreaks of L. dispar in the period 1990–2017 in Romanian part of the Carpathians. .....................................................................................................................40
Figure 20 Recorded outbreaks of L. dispar in the period 1862-2007 in Serbia. ............41
Figure 21 Subregions of the Carpathians for which functions describing response of tree species abundance to climatic gradients have been calculated. .................................88
Figure 22 Distribution of differences between past and present elevation optimum of surveyed species. .........................................................................................................................90
Figure 23 Example of the comparison between aerial photographs: changes between 1965, 1986, and 2002. .........................................................................................................92
Figure 24 Climate change induced shift of forest vegetation zones in the Czech Republic. ...............................................................................................................................95
Figure 25 Actual distribution of beech-dominated zonal forest stands in Hungary, consensus projection maps for the probability of presence and their uncertainty. ..........99
Figure 26 Actual distribution of sessile oak-dominated zonal forest stands in Hungary, and consensus projection maps for the probability of presence and their uncertainty. 100
Figure 27 Percentage of compartments in West Hungarian forest companies damaged by drought events 2000-2004 in relation to their climatic position. .................................................101
Figure 28 Average Ellenberg quotient value of the drought years 2000-2004 and the health condition of selected mature beech plots at the xeric limit, at the end of the period. .................................................................102
Figure 29 Spatial distribution of tree line advance coefficient imposed over geobotanic map of Ukraine. .........................................................................................................................104
Figure 30 Changes in treeline position on Svidovets mountain ridge. .........................1044
Figure 31 Projected spatial distribution of suitable habitats for establishment of at least one or nine invasive plant species/genera by 2050 and 2100 within the study area and within protected areas and ecological network assuming climate change (CL) and climate change and high economic development (CLandHED). ........................105
Figure 32 Dwarf pine colonizing talus slopes in patches and steep slopes in Pisan Cirque. ..................................................................................................................................................107
Figure 33 Bioclimatic space of oak in the Carpathians in periods 1961-1990, 2021-2050 and 2071-2100. .................................................................................................................................111
Figure 34 Bioclimatic space of beech in the Carpathians in periods 1961-1990, 2021-2050 and 2071-2100. .................................................................................................................................112
Figure 35 Bioclimatic space of hornbeam in the Carpathians in periods 1961-1990, 2021-2050 and 2071-2100. .................................................................................................................................114
Figure 36 Bioclimatic space of spruce in the Carpathians in periods 1961-1990, 2021-2050 and 2071-2100. .................................................................................................................................117
Figure 37 Elevation zones across the Carpathian Mts. showing the distribution of montane and subalpine regions. ................................................................................................................123
Figure 38 Categorisation of Carpathian montane and subalpine forests in Slovakia. ....126
Figure 39 Time series of maps used for the evaluation of human influence on montane Carpathian forests in Central Slovakia (Inner Western Carpathians). .................132
Figure 40 Coniferous deforestation and reforestation in the Moldova region, Eastern Romania and in the watershed covering also the areas outside the region. ..........133
Figure 41 The region of the border triangle of Slovakia, Czech Republic and Poland affected by spruce forest decline. ........................................................................................................1355
Figure 42 Regions used for the documentation of deforestation due to forest decline in the Outer Western Carpathians (Beskid Mts.) using remote sensing images. ...........136
Figure 43 Forest cover changes in the selected part of the Outer Western Carpathians (Beskid Mts.) between 1994 and 2010. ..........................................................................................136
Figure 44 The High Tatras (Western Carpathians) after the windthrow in 2004 with larch trees that survived this extreme event.................................................................137
Figure 45 Areas of the Carpathian Mountains affected by Ips typographus. ...............138
Figure 46 Soil erosion on an unpaved forest road in the Western Carpathians of Slovakia. ..........................................................................................................................139
Figure 47 Location of Iezer and Godeanu Mountains within the Carpathians. ..........140
Figure 48 Avalanche in the valley Ďurková, Low Tatras, Slovakia, Western Carpathians on 14th March 1970 .................................................................114
Figure 49 Scheme of forest vulnerability assessment in the Carpathians. .................144
Figure 50 Intersection of geomorphological subprovinces and state boundaries in the Carpathians. ......................................................................................146
Figure 51 First two components (PCA1 and PCA2) extracted from differences in mean annual air temperature, precipitation totals during vegetation season and Ellenberg climatic quotient. ..........................................................151
Figure 52 Climatic exposure of the Carpathians. .................................................................154
Figure 53 Forest sensitivity to climate change. Assessment is based on current status of
forests, current disturbance regimes, and forests capacity to respond to anticipated
changes in climate and dynamics of pests and pathogens. ...........................................164
Figure 54 Integrated forest vulnerability map of the Carpathians. .................................168
Figure 55 Oographic units with the occurrence of the habitat types 7110* Active raised
bogs and 7120 Degraded raised bogs (still capable of natural regeneration). ...........1777
Figure 56 Oographic units with the occurrence of the habitat type 7230 Alkaline fens. 178
Figure 57 Oographic units with the occurrence of the habitat type 91D0* Bog woodland.
.........................................................................................................................................178
Figure 58 Mean NPP for the different end-members in gC m⁻² year⁻¹ units for the 1961-
1990 time period. ............................................................................................................181
Figure 59 NPP time series for the 1951-2100 time period for all pixels from the Outer
Eastern Carpathians North driven by the REMO-ECHAM5-r3 climate model. Results
from EM1. .........................................................................................................................183
Figure 60 Region-mean smoothed NPP time series based on the ten climate models for
the 1951-2100 time period for Western Romanian Carpathians. SResults from EM1.
.........................................................................................................................................183
Figure 61 Simulated ensemble mean NPP time series for the different Carpathian regions.
EM1. .....................................................................................................................................185
Figure 62 Same as Figure 61 but for EM2. ..........................................................................185
Figure 63 Same as Figure 61 but for EM3. ..........................................................................186
Figure 64 Same as Figure 61 but for EM4. ..........................................................................186
Figure 65 Same as Figure 61 but for EM5. ..........................................................................187
Figure 66 Same as Figure 61 but for EM6. ..........................................................................187
Figure 67 Ensemble mean NPP differences between 2021-2050 and 2071-2100 relative to
1961-1990 mean. Results from EM1. ..............................................................................189
Figure 68 Ensemble mean NPP differences between 2021-2050 and 2071-2100 relative to
1961-1990 mean. Results from EM2. ..............................................................................189
Figure 69 Ensemble mean NPP differences between 2021-2050 and 2071-2100 relative to
1961-1990 mean. Results from EM3. ..............................................................................189
Figure 70 Ensemble mean NPP differences between 2021-2050 and 2071-2100 relative to
1961-1990 mean. Results from EM4. ..............................................................................190
Figure 71 Ensemble mean NPP differences between 2021-2050 and 2071-2100 relative to
1961-1990 mean. Results from EM6. ..............................................................................190
Figure 72 Mean GPP time series for the entire Carpathians as estimated by the different
end-members. .....................................................................................................................191
Figure 73 Same as Figure 69 but for R_{eco}. .......................................................................192
Figure 74 Same as Figure 69 but for NEE. .........................................................................193
Figure 75 The same as Figure 69 but for NBP. Positive NBP means carbon accumulation
within the ecosystem...........................................................................................................194
Figure 76 Overall trend of different carbon balance components in the entire Carpathians
during the 1951-2100 time period based on the combination of end-members and
habitat type distribution. .................................................................................................196
2. **List of Tables**

Table 1 Characteristics of geomorphologic units in the Carpathians used as spatial frame for the evaluation of species shift induced by climate change. ...........................................18
Table 2 Bias corrected models included in the FORESEE database. ...........................................21
Table 3 Distribution and composition of the Carpathian montane and subalpine forests in the countries and geomorphological subprovinces. ...........................................124
Table 4 Categorisation of forests in the Carpathian countries. ...........................................125
Table 5 Country-wise classification of montane and subalpine forests of the Carpathians into forest categories defined by national legislation. ...........................................1257
Table 6 Overview of protective forest functions defined by legal documents in individual Carpathian countries. ......................................................................................1288
Table 7 Proportion of montane and subalpine forests of the Carpathians in Poland fulfilling a particular protective function.................................................................129
Table 8 Importance of agents causing forest cover change in montane and subalpine areas of the Carpathians.................................................................
Table 9 Characteristics of geomorphologic units in the Carpathians used as spatial frame for the evaluation of species shift induced by climate change. ...........................................125
Table 10 Forests distribution in the Carpathians within spatial units defined as intersection of state boundaries and geomorphologic subprovinces...........................................1477
Table 11 Climatic exposure of countries intersected with geomorphologic subprovinces of the Carpathians. .................................................................
Table 12 Exposure of CoGP units in the Carpathians evaluated on the basis of first principal component scores extracted from differences in mean annual air temperature, precipitation totals during vegetation season and Ellenberg climatic quotient.............153
Table 13 Results of the assessment of forest sensitivity to climate change in the Carpathians. ......................................................................................165
Table 14 Country-wise indicators of climate change adaptive capacities in forestry. ..............125
Table 15 Summary evaluation of climatic exposure, sensitivity and adaptive capacity of Carpathian forests. .................................................................167
Table 16 The actions implemented in the frame of the project with the objectives in the revised proposal. ......................................................................................215
3. **LIST OF ANNEXES**

Annex 1 *Ips typographus* in the Western Carpathians: Pest distribution indicated by damage to forest in the period 2008-2010. ........................................................................................................... 246

Annex 2 *Ips typographus* in the Eastern Carpathians: Pest distribution indicated by damage to forest in the period 1990-2010. ........................................................................................................... 246

Annex 3 *Ips typographus* in the Carpathians: Estimated number of generations completed per year under reference climate 1961-1990. ........................................................................................................... 247

Annex 4 *Ips typographus* in the Carpathians: Estimated number of generations completed per year under the future climate 2021-2050. ........................................................................................................... 248

Annex 5 Change in number of generations per year of *Ips typographus* in the Carpathians between periods 1961-1990 and 2021-2050. ........................................................................................................... 249

Annex 6 *Ips typographus* in the Carpathians: Estimated number of generations completed per year under the future climate 2071-2100. ........................................................................................................... 250

Annex 7 Change in number of generations per year of *Ips typographus* in the Carpathians between periods 1961-1990 and 2071-2100. ........................................................................................................... 251

Annex 8 Remote sensing-based assessment of changes in forest cover due bark beetles infestation in the Western Beskids (part 1). ........................................................................................................... 252

Annex 9 Remote sensing-based assessment of changes in forest cover due bark beetles infestation in the Western Beskids (part 2). ........................................................................................................... 253

Annex 10 Remote sensing-based assessment of changes in forest cover due bark beetles infestation in the Western Beskids (part 3). ........................................................................................................... 254

Annex 11 Outbreak areas of *Lymatria dispar* in the Western Carpathians in the period 2003-2005. ........................................................................................................... 255

Annex 12 *Lymatria dispar* in the Eastern Carpathians: Extent of defoliated forests in the period 1990-2010. ........................................................................................................... 256

Annex 13 Projected outbreak areas of *Lymatria dispar* in oak forests in the Carpathians: Period 1961-1990. ........................................................................................................... 257

Annex 14 Projected outbreak areas of *Lymatria dispar* in oak forests in the Carpathians: Period 2021-2050. ........................................................................................................... 258

Annex 15 Projected outbreak areas of *Lymatria dispar* in oak forests in the Carpathians: Period 2071-2100. ........................................................................................................... 259

Annex 16 Projected outbreak areas of *Lymatria dispar* in beech forests in the Carpathians: Period 1961-1990. ........................................................................................................... 260

Annex 17 Projected outbreak areas of *Lymatria dispar* in beech forests in the Carpathians: Period 2021-2050. ........................................................................................................... 261

Annex 18 Projected outbreak areas of *Lymatria dispar* in beech forests in the Carpathians: Period 2071-2100. ........................................................................................................... 262

Annex 19 Differences in selected climate elements between future and reference climate. ........................................................................................................... 263

Annex 20 Hydrological and ecological analysis of NATURA 2000 wetland habitat types. ........................................................................................................... 266

Annex 21 Region mean NPP climatologies for EM1. ........................................................................................................... 278

Annex 22 Region mean NPP climatologies for EM2. ........................................................................................................... 278

Annex 23 Region mean NPP climatologies for EM3. ........................................................................................................... 279

Annex 24 Region mean NPP climatologies for EM4. ........................................................................................................... 279

Annex 25 Region mean NPP climatologies for EM5. ........................................................................................................... 280

Annex 26 Region mean NPP climatologies for EM6. ........................................................................................................... 280
4. **Executive Summary**

The Special Request 2 *In-Depth Study on the impacts of climate change threats on ecosystems* (SR2 hereinafter) addresses climate change impacts on forests, grasslands and wetlands in the Carpathians, including options for adaptation. Main objective is to deliver the consistent knowledge about expected effects of climate change on Carpathian ecosystems, and to provide the assessment of ecosystems’ vulnerability. The main attention is paid to forests, while grasslands and wetlands are addressed marginally. Carpathians represent the largest European mountain range passing through Austria, Czech Republic, Slovakia, Poland, Hungary, Ukraine, Romania and Serbia. Adjacent populated areas are functionally linked to the mountains, the forests of which provide a range of ecosystem services and functions to local and national economies. Carpathian border used in this study was designated as the union of borders specified by the Carpathian Ecoregion Initiative (www.carpates.org) and Carpathians Environment Outlook (KEO 2007). Size of the region is 229,966 km². Forests cover 48% of the region, with 19% of coniferous, 59% percent of broadleaved and 22% of mixed forests (Corine LandCover 2000). Variety of heterogeneous data has been used to meet the project objectives. Forest tree species distribution data were taken from statistical mapping of tree species over Europe based on the data of national forest inventories, predictive mapping and national forest statistics (Brus et al. 2011). Corine LandCover data and Euforgen maps of tree species distribution in Europe were used as well. Data on pests’ distribution were taken from annual report of national Forest Protection Services, and other materials. Data on grassland distribution were taken from national phytocenological database of Slovakia. The projections of anticipated forest development were based on four Regional Climate Models (RCMs) – RegCM, HIRHAM5, RACMO and REMO taken from the FORESEE database (Dobor et al. 2012).

The SR2 addresses several tasks – (i) climate change impact on pests and pathogens, (ii) assessment of adaptive capacity of forest management, (iii) assessment of climate change impact on shift of forest tree species, and (iv) evaluation of anticipated grasslands species shift, climate change effect on grasslands productivity and wetlands vulnerability. In addition, there are two synthetic tasks focused on the evaluation of protective functions of montane and alpine forests (IV), and on the assessment of integrated forest vulnerability (V); these tasks are mostly based on the synthesis of information collected in tasks i-iv.

Prior to addressing the SR2 tasks, an ensemble of climate change scenarios was used to evaluate the climatic exposure of the Carpathians, i.e. the anticipated change in climate and its spatial variability in the Carpathians. This information is component of forest vulnerability assessment, and it is also used as driving variable in modelling of future forest dynamics. Although a number of bioclimatological variables was available, we focused mainly on three of them – mean annual air temperature, precipitation totals during the vegetation season and Ellenberg climatic quotient, which is reported in

...
Romania. There is a remarkable trend in differences in Ellenberg quotient between the distant and reference climate, increasing from the Western Carpathians towards the Eastern and Serbian Carpathians.

**Pest and pathogens** can be thought of as climate change driven agents the effect of which may induce critical disruption in the provision of forest ecosystem services and functions. The main reason for this is high climatic sensitivity of mainly insect pests, which may respond to even minor changes in climate by substantial changes in their population dynamics and distribution. We collected diverse information on recent pest dynamics in the Carpathians from national forestry statistics and other sources, reviewed literature, and ran our own modelling exercises. In total, 21 forest pests and pathogens have been addressed, though information allowing for the assessment of climate change impacts were available only for some of them. Using this information, we created 36 maps describing both recent pest dynamics and its anticipated changes. For five species – spruce bark beetle (*Ips typographus*) and double-spined bark beetle (*Ips duplicatus*), Gypsy moth (*Lymantria dispar*), pine weevil (*Hyllobius abietis*) and nun moth (*Lymantria monacha*) – projections of anticipated climate change impacts on their distribution and population dynamics were elaborated using modelling tools and GIS for the entire Carpathians. Our findings imply that activity of biotic agents has been elevated in recent decades in many regions of the Carpathians, and that there are indications of the effect of climate change on population growth of some species. Our results imply increasing impact of presently occurring pests on forests, as well as potential emergence of new pests. Bark beetles of the genera *Ips* can be thought of as the most important agents, the outbreak of which can be fuelled by increasing temperature accelerating their development, and elevating drought stress to trees, which is important factor increasing the susceptibility to infestations. While in higher elevations the outbreaks can be fuelled by increasing frequency of windstorms, in lower to medium elevations, where spruce has been extensively planted in many regions, drought can trigger unprecedented outbreaks. One to two generation increase in annual number of generations of spruce bark beetle (*Ips typographus*) was projected for the entire Carpathians, being more pronounced in the Romanian and Ukrainian part. Newly emerging northern bark beetle (*Ips duplicatus*) is expected to respond to changing climate similarly, and damage caused by this pest may further increase, mainly in the Romanian Carpathians. Satellite imagery displaying progress of deforestation due to bark beetle infestation from some regions is used to document some outbreaks. Lower to medium elevations of the Carpathians are expected to face an increased pressure of defoliating insects, among which the Gypsy moth (*Lymantria dispar*) can be thought of as the most important. The pest is expected to benefit from climate change, and its regular outbreaks were projected to expand over larger areas. Upward shift and alternative severe defoliations of beech have been reported from several regions in the Carpathians. We elaborated the maps of pest’s recent dynamics in the Carpathians, and projection of anticipated expansion of outbreak ranges. An important finding is increasing biotic risk to beech, which can be thought of as novel climate change driven phenomenon. Except for already mentioned defoliations by Gypsy moth, which have not been occurring previously, beech damage by bark beetle *Taphryochus bicolour* as a consequence of drought effect, or damage by European hardwood ambrosia beetle *Trypodendron domesticum* can be expected. In addition, beech damage by *Nectria ditissima* disease (fungal pathogen causing beech canker) is frequently reported, having increased incidence mainly in the Romanian Carpathians. These findings generate concern about beech sustainability mainly in drought-exposed sites.

**Species shift** is inherent adaptation mechanism which allows species to track the shifting climatically optimal sites. Inability of species to follow the shifting climate may cause population decline and, in some cases, extinction. We focused on two most distinct features of species shift, i.e. species expansion upward in elevation, including tree line shift, and on the retraction of lower range limit, which may be induced by water scarcity and, in some cases, also by increasing biotic damage. We compiled the information on recent changes in species composition from the Carpathian countries, and evaluated
them critically. In addition, we performed the projections of anticipated shift of species present bioclimatic space under ensemble of climate change scenarios; such information can be used as proxy of species shift. Our survey implied that there is very limited information on observed species shift, evidences are scarce and unpersuasive in some cases. In addition, forest management and natural forest dynamics may largely interfere the climate change signal, what may question some of the reported observations. The main findings of our analysis are the following: (i) in planar to colline zone, continuous change of present oak forests towards oak forests with higher share of drought tolerant species, such as Quercus cerris, may occur. The increased occurrence of species such as Q. frainetto or Q. ilex can be observed in southern regions, or such species can be artificially introduced within the frame of forest adaptation; (ii) although the European beech has been frequently considered as important component of temperate forests adaptation to climate change, recent evidences of its climatic sensitivity implies beech’s retreat from lower elevation, mainly from drought exposed sites. Such retraction can be amplified by newly emerging insect pests damaging beech stand; (iii) Expansion of conditions suitable for oak species suggests increase of their share across almost entire Carpathians, except for the highest elevations. Increased forest dynamics in present contact zone of oaks and beech can be expected; (iv) Expansion of conditions suitable for oaks and worsening conditions suitable for beech implies appearance of communities composed of oaks and coniferous in higher elevations. Such communities rarely occur in some intra-Carpathians valleys, their sensitivity to climate change and future prospects however have not yet been investigated; (v) Spruce needs to be thought of as highly vulnerable species, and climate change will induce additional pressure on decrease of spruce share except for highest elevations where spruce naturally occurs. Conflict with high demand on softwood may however induce increased effort in maintaining spruce also at unsuitable sites under the threat of increased costs; (iv) climate change induced shift of tree line has been reported from several mountain ranges in the Carpathians in terms of expansion of dwarf pine and spruce zone. The fact that such shift can be easily confounded with land abandonment and decline of grazing may generate concern about the validity of some observations.

We assume that future species shift can be largely affected by diverse interactions between natural forest adaptation and forest management which differ among countries and regions in the Carpathians. Contradictory tendencies can be expected even in the adjacent regions, bringing large uncertainty into projections of and expectations on future species shift. The changes described above can be expected to be more pronounced in the Eastern, Southern and Serbian Carpathians as compared with Western Carpathians, because of climatic exposure increasing from the north-west towards the south-east.

Forest management represent powerful tool of forest adaptation to climate change for example through changes in species composition, it may however also act detrimentally in terms of overharvesting or promoting interventions opening the canopy or disrupting stand’s water regime. We elaborated detailed overview of presently applied forest management practices, and collected information on adaptive capacity of forest management in Carpathian countries. National legislation, including National Forest Programmes, has been reviewed, and information on climate change adaptation has been evaluated. Our main findings are the following: (i) none of the Carpathian countries have directly addressed the climate change in their forestry legislation yet. Although this issue is usually included in the national forestry strategy plans, programmes and actions, these document do not specify any adaptive strategies and ways of their implementation; (ii) Research on climate change impacts and adaptation is well developed throughout the Carpathians. However, developed measures are not commonly implemented in forestry practice per se because of insufficient knowledge transfer and rigid policy regulations related to forest management. Hence, introduction of forest adaptation to forest management strongly depends on professional skills and awareness of individuals; (iii) The awareness of the climate change in Carpathian forestry community can be thought of as moderate, though with high regional differences. Practitioners do not usually address
climate change per se, but they operatively respond to actual threats. Such measures can however be often thought of as part of adaptive forest management; (iv) Cross-sectoral cooperation in facing the climate change related threats is generally low, and conflicts among sectors are frequent; (v) remarkable differences in countries economic development imply differences in their capacity to take effective measures. Southern and eastern Carpathian countries reach, on average, 36% of gross domestic product per capita of the Western Carpathian countries, what remarkably affects their adaptive capacity.

On the basis of the facts above we argue that, despite large differences in individual indicators of countries adaptive capacity, none of the Carpathians countries possesses efficient mechanisms to adapt the forests and mitigate the climate change impacts.

As impact of pest and pathogens on forests can be largely amplified by climate change, we addressed separately forest management measures related to forest protection. Extensive literature overview and questionnaire-based survey in the Carpathian countries implied varying level of application of integrated pest management principles, which is generally recognized as important concept of adaptive forest management. Use of models for short- to middle-term prognoses of pests` development was found to be rare, though such models have been developed for several forestry important species. Pest monitoring is not harmonized among countries, and information exchange is insufficient; this fact increases the risk of transboundary spread of invasive species. Forest protection units in all countries are obviously small and overloaded by routine activities; forest management under climate change however calls for consolidating personal and other resources of such units. These facts, though often underestimated in comparison with other ecologically and socially more sound topics, may potentially cause critical inability of forest management to manage the future climate change-driven outbreaks and influx of new pest species.

Assessment of forest vulnerability to climate change was based on the integration of information on forest`s climatic exposure, forest sensitivity and adaptive capacity. Modified borders of geomorphologic subprovinces were used as spatial frames for the evaluation of climatic exposure and forests sensitivity to climate change. Adaptive capacity, which largely depends on national legislation and economy, was evaluated within the frame of countries. The information on forest`s climatic exposure was derived from the available climatic change scenarios. Assessment of countries` adaptive capacity was based on series of socio-economic indicators. Forest sensitivity to climate change was based on comprehensive evaluation of indicators such as present and projected biotic risk to forests, effect of non-climatic stressors such as air pollution and improper management, observations and projections of species shift, etc. While high forest sensitivity in the Western Carpathians (CZ, SK, PL) mainly related to the presence of highly sensitive secondary spruce forests, and to direct or indirect effects of drought (SK, HU), the main factor affecting high forest sensitivity in the Romanian and Serbian Carpathians were coupled effects of drought and related biotic damage acting mostly upon broadleaved forests. High frequency of windstorms and subsequent bark beetle outbreaks were the main impact factors in mountain regions across the Carpathians, and mountain forests were thought of as highly sensitivity to these agents. On the basis of these indicators, most of the Carpathians received “High” and “Very high” score of forest vulnerability. Vulnerability of the Ukrainian Carpathians and Polish part of the Outer Eastern Carpathians was classified as “Moderate” and “Low”. In case of the Polish part, low climatic exposure along with good forest structure and low biotic risk backed-up such ranking. High vulnerability scores received by most of the Western and Eastern Carpathians mostly reflect the results of sensitivity evaluation.

The Slovak Phytosociological Database (Institute of Botany, Slovak Academy of Science) was used to evaluate the species shift in grassland communities in the Western Carpathians. The database contains more than 50,000 phytosociological relevés of all vegetation types in Slovakia. The trends detected in the Western Carpathians should be, with certain limitations, relevant also for the eastern and southern part of the Carpathians. We addressed the following groups of grasslands: mesic semi-natural
grasslands, natural grasslands on siliceous bedrock, natural grasslands on calcaceous bedrock, semi-dry grasslands, dry grasslands, and wet grasslands. Comprehensive statistical evaluation was applied to evaluate the changes in species composition of each group between periods 1925-1970, 1971-1990 and 1991-2010. Although the responses were variable, the main conclusion is that just small differences have occurred in distribution, ecology and species diversity of evaluated plant communities. Most of changes can be attributed to land-use changes and succession of abandoned grasslands rather than to recent climatic trends. Generally, impacts of recent climate changes could not have been identified using the analyzed dataset, and most of changes were either insignificant or they can be detectable after considerable time lag.

Investigations of wetland habitats vulnerability to climate change focused on wetland types protected by the network of NATURA 2000. The main conclusions are the following: (i) the most vulnerable wetland habitats are peatlands, because of their limited plasticity towards climate fluctuations, and their sensitivity to human activities and changes in land use; (ii) less vulnerable are halophytic habitats and some types of water and river banks habitats. These habitats posses some plasticity towards climate fluctuations, but they are highly sensitive to human activities and changes in land use; (iii) The lowest vulnerability was detected in habitats depending on floods, habitats on stands with fluctuating soil moisture, for subterranean wetlands and for some river bank and water habitats. They can be thought of as highly plastic and able to adapt even to extreme fluctuations in climate. Human intervention may represent important threat also in this case.

The final task aimed at the estimation of future changes in grassland productivity and carbon balance in the entire Carpathians. Standard impact analysis protocol was used, i.e. the calibrated and validated biogeochemical model (Biome-BGC MuSo v1.2) was coupled with a number of climate projections to estimate the present day and future developments. The 10 climate projections retrieved from the aforementioned FORESEE database we used to drive the simulations. Our results imply that: (i) simulations under the present-day climate of net primary production (NPP) showed obvious dependence on soil texture. Mean NPP for the entire Carpathians was 665 gC m\(^{-2}\) year\(^{-1}\); (ii) future changes strongly depended on grassland types according to NATURA 2000 categories. NPP of natural grasslands is expected to increase in the future, but poor soil conditions and regional differences in climate and elevation affect the future developments. Grazing was shown to have small effect on the NPP as compared with unmanaged grasslands, while mowing (on hay meadows) negated the overall positive effects of increasing atmospheric CO\(_2\) concentration and climate change; (iii) the overall change in NPP in the Carpathians was found to be close to zero, what can be attributed to the dominant role of mowing in the Carpathians; (iv) Changes in the overall carbon balance, expressed by means of Net Biome Production, indicated zero change, i.e. in spite of the fertilization effect caused by the increasing atmospheric CO\(_2\) concentration, the overall carbon balance remains stable in the future.
5. **Administrative Part**

5.1. **Background of the SR**

The SR2 addresses Carpathian ecosystems vulnerability to climate change; namely forests, grassland and wetland communities. Main objective is to deliver the consistent knowledge about expected effect of climate change on Carpathian ecosystems specifically for individual Carpathian regions, tree species, and pests and pathogens. Project team consisted of 5 institutions – Aquaprotein, INCDPM, REC, CAR HAS and ARTELIA. More than 30 experts were included in the project. Totally, 720 man-days were scheduled to be spent on the SR2 tasks.

The following objectives were planned to be addressed:

- Assessing the effect of pests and pathogens on the Carpathian forests; climate change induced increase in virulence; change in distributional and outbreak ranges, and change in populations dynamics of both resident and newly-emerging forest pests and pathogens;
- Assessing the effect of climate change on protective function of mountain and subalpine forests in the Carpathians;
- Evaluating the effect of management practices on forest vulnerability to climate change, including expected adaptation potential of forest management;
- Evaluating the anticipated changes in species composition of forests, wetlands and grasslands, including climate change effect on grasslands productivity.

Five tasks of the SR2 (according to the Inception Report) are linked to each other in line with scheme in Figure 1, which describes organisation of work and main data flows.

Three ecosystems are addressed – forests, grasslands and wetlands. Despite those ecosystems are all included in Task 5, they will be addressed separately within the project, as different experts dealing with different databases and analytical tools investigate these ecosystems.

Tasks 2 and 5 (species composition, and pests and pathogens) are analytical, yielding from modelling exercises and based on various observational evidences. Tasks 3 and 4 (integrated impact of climate change and management, and climate change effects on mountain and subalpine ecosystems) are synthetic, based on the outputs from Task 2 and 5.

![Figure 1 Organisation of work and data flows in SR2](image-url)
Main outcomes of individual Tasks, in line with the Inception Report, are the following:

**Task 1: Kick-off meeting**
- Detail structure of the Inception Report, including working plan and specification of responsibilities of the experts involved;
- Overview of national data and national impact studies (to be presented by experts involved), as a support for designating the Inception report;

**Task 2: Assessing the risk of climate change-induced increase in virulence of forest pathogens, and change in outbreak ranges and population dynamics of forest pests**
- Report on presently occurring pests and pathogens in the Carpathians, including recent observations of climate change-induced alteration of pests outbreak ranges, population dynamics, predator-prey and host-parasitoids relations, distribution and virulence of pathogens;
- Matrices containing the list of resident and newly emerging pests and pathogens for representative regions of the Carpathians. Expected climate triggers, expected responses (positive/negative) and magnitude of the response (using qualitative indicators), and present and expected ecological importance of given pest or pathogen will be filled in the matrix;
- Map of exposed main forest classes with indications of their vulnerability to key pests and pathogens; expected climate change-induced alterations of present disturbance regime will be indicated as well;
- Inventory of options to increase forest-stand natural resilience against pests and pathogens, including silvicultural measures to mitigate the mortality of infested trees.

**Task 3: Assessment of the effect of climate change-induced changes in forest cover on protective functions of montane and subalpine forests**
- Report on the effect of changes in forest cover (deforestation due to various disturbances, forest decline, decrease of stand density and canopy closure, etc.) on protective function of montane and subalpine forests;

**Task 4: Assessment of the combined effect of climate change and forest management practices on vulnerability of Carpathian forests; including adaptation potential of forest management**
- Report on forest management practices applied in the Carpathians and their potential to adapt the forests to the forthcoming climate change or on their detrimental effect, respectively;
- Report on the extent in which the concept of continuous-cover forestry, adaptive changes in species composition, and other adaptive silviculture techniques are applied in particular regions of the Carpathians; as well as extent in which detrimental processes such as clear-cuts or logging related soil compaction and rutting occur;
- Report on recent trends in illegal logging, felling of losses and their expected impacts on the environment.

**Task 5: Assessment of climate change impact on changes in species composition of forests, grasslands and wetlands**
- Report on expected climate change-induced shift of main forest tree species, description of recent observational evidences and compilation of the outputs of various modelling exercises of species shifts;
- Report on recent evidences of change in species composition, structure and distribution of grassland communities in the Carpathians;
Report on grassland species and communities, which were found to be most vulnerable to climate change-induced threats; including expected changes in species composition, and climate change effect on grasslands productivity;

Report on present status of wetlands in the Carpathians; identification of main climate change and landscape management-related threats; survey of the most vulnerable wetlands; map of distribution of wetlands in the Carpathians.

Results of the tasks above have been elaborated as independent deliverables, each deliverable representing a report under responsibility of single expert in given field. There are 14 deliverables, the 10 of them refer to research reports. Another two are draft and final report, which provide the condensed overview of results reported in other deliverables. The remaining two deliverables are Kick-off meeting, and the Inception Report.

- **SR2.S2.D1. DELIVERABLE**: Draft report will be prepared based on all completed Deliverables; **Responsible expert**: Tomáš Hlásny (SK)
- **SR2.S2.D2. DELIVERABLE**: Final report will be prepared based on all completed Deliverables; **Responsible expert**: Tomáš Hlásny (SK)
- **SR2.T1.D1. DELIVERABLE**: Kick-off meeting, participation in the meeting, discussing work organisation with project partners and anticipated outputs with Carpivia representatives, giving presentation on SR2 structure; **Responsible expert**: Tomáš Hlásny (SK)
- **SR2.T1.D2. DELIVERABLE**: Agreed structure of the Inception Report, including working plan and specification of responsibilities of the experts involved; **Responsible expert**: Tomáš Hlásny (SK)
- **SR2.T2.D1. DELIVERABLE**: Report on presently occurring pests and pathogens in the Carpathians, including recent observations of climate change-induced alteration of pest outbreak ranges, population dynamics, predator-prey and host-parasitoids relations.; **Responsible expert**: Jaroslav Holuša (CZ)
- **SR2.T2.D2. DELIVERABLE**: Inventory of options to increase forest-stand natural resilience against pests and pathogens, including silvicultural measures to mitigate the mortality of infested trees. **Responsible expert**: Jaroslav Holuša (CZ)
- **SR2.T2.D3. DELIVERABLE**: Map of exposed main forest classes with indications of their vulnerability to key pests and pathogens; expected climate change induced alterations of present disturbance regime will be indicated as well; **Responsible expert**: Tomáš Hlásny (SK)
- **SR2.T3.D1. DELIVERABLE**: Report on the effect of changes in forest cover (deforestation due to various disturbances, forest decline, decrease of stand density and canopy closure, etc.) on protective function of montane and subalpine forests; **Responsible expert**: Katarína Merganičová (SK)
- **SR2.T4.D1. DELIVERABLE**: Early delivery of information on illegal felling and felling of losses in the Carpathians, with described effects on the environment (tentative version of the SR2.T4.D3 provided for the purposes of the assessment of changes in forest cover on forest water cycle in SR1); **Responsible expert**: Aniko Nemeth (HU)
- **SR2.T4.D2. DELIVERABLE**: Report on forest management practices applied in the Carpathians and their potential to adapt the forests to the forthcoming climate change or on their detrimental effect; **Responsible expert**: Katarína Merganičová (SK)
- **SR2.T5.D1. DELIVERABLE**: Report on expected climate change induced shift of main forest tree species, description of recent observational evidences and compilation of the outputs of various modelling exercises on species shifts; **Responsible expert**: Tomáš Hlásny (SK)
- **SR2.T5.D2. DELIVERABLE**: Maps of integrated assessment of forest vulnerability to climate change in the Carpathians, including climate change effect of pests and pathogens, and tree species composition; **Responsible expert**: Tomáš Hlásny (SK)

- **SR2.T5.D3. DELIVERABLE**: Report on grasslands and wetlands vulnerability to climate change-induced threats; including expected changes in species composition, effect on grasslands productivity; **Responsible expert**: Dobromil Galvánek (SK)

### 5.2. Description of the management system

There were four levels of SR2 management – project management (The Scientific Advisory Committee, the Steering Committee and the Project Management Team), SR2 lead, deliverable leads (responsible experts), and national experts.

**SR2 lead** was responsible for proper scheduling of the work of all experts, formulating methodologies and approaches to individual tasks, and securing quality control of final results submitted by the SR. The SR lead secures all communication within the SR, including guidanance of data flows among national experts and deliverable leads. In addition, SR lead transfers the information from project management to deliverable leads to secure the in-time and proper delivery of all outputs expected.

**Deliverable leads** are responsible for the quality and in-time delivery of planned deliverables, and for the soundness and quality of methods and data used in addressing the topics in question.

**National experts** are responsible for delivery the data and country-specific information in such a way that allows deliverable leads compiling the reports in line with the Inception Report. National experts are also responsible for including all available and relevant data into SR outputs, and for the use of all available data sources.
5.3. **Task by task – description**

There are five tasks in SR2 specified in the Inception Report. Task 1 is Kick-off meeting, which will not be considered here. In addition, supportive activity focusing on the development of database containing Carpathians data used in all Tasks and Deliverables had to be introduced. Therefore, we firsts describe the data collected, and then we describe the methods and outputs of four research tasks of the SR2.

5.3.1. **Task 1: Study area definition and project database development**

5.3.1.1. Study region

Carpathian border used in SR2 was designated as the union of borders specified by the Carpathian Ecoregion Initiative and Carpathians Environment Outlook (KEO 2007) (Figure 2) in order to provide the vulnerability assessment within a broader spatial frame suitable for various initiatives in the Carpathians. Size of the area is 229,966 km². We performed the evaluation of species shift in the frame of geomorphologic subprovinces (Kondracki 1989) of the Carpathians. Outer Eastern Carpathians were divided into two parts by Ukraine-Romanian border, as several climate elements were intensively changing between these two sub-regions (see changes in air temperature and precipitation, Table 1); these two units were named Outer Eastern Carpathians North and Outer Eastern Carpathians South. As only a minor part of Austria stretches into the study region (680 km², 0.29% of the study region), Austria has not been considered. Broader definition of the study area that includes part of the Panonnian Lowland and Transylvanian Plateau allows for investigating forest species shift and anticipated alteration of species composition.

<table>
<thead>
<tr>
<th>Geomorphologic unit</th>
<th>Area (km²)</th>
<th>Forest cover (%)</th>
<th>T (°C)</th>
<th>P (mm)</th>
<th>Countries proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern Carpathians</td>
<td>19,019</td>
<td>60.8</td>
<td>6.7</td>
<td>703</td>
<td>RO 100</td>
</tr>
<tr>
<td>Western Romanian Carpathians</td>
<td>22,968</td>
<td>58.0</td>
<td>6.8</td>
<td>639</td>
<td>RO 100</td>
</tr>
<tr>
<td>Serbian Carpathians</td>
<td>9,607</td>
<td>45.3</td>
<td>9.7</td>
<td>642</td>
<td>Serb 100</td>
</tr>
<tr>
<td>Transylvanian Plateau</td>
<td>29,664</td>
<td>24.1</td>
<td>8.4</td>
<td>485</td>
<td>RO 100</td>
</tr>
<tr>
<td>Inner Eastern Carpathians</td>
<td>27,971</td>
<td>49.7</td>
<td>6.9</td>
<td>704</td>
<td>RO 77, UA 21, SK 2</td>
</tr>
<tr>
<td>Outer Eastern Carpathians North</td>
<td>35,974</td>
<td>63.2</td>
<td>6.9</td>
<td>878</td>
<td>UA 60, PL 29, SK 11</td>
</tr>
<tr>
<td>Outer Eastern Carpathians South</td>
<td>23,545</td>
<td>53.8</td>
<td>7.9</td>
<td>558</td>
<td>RO 100</td>
</tr>
<tr>
<td>Inner Western Carpathians</td>
<td>36,561</td>
<td>47.0</td>
<td>7.7</td>
<td>683</td>
<td>SK 68, HU 32</td>
</tr>
<tr>
<td>Outer Western Carpathians</td>
<td>24,659</td>
<td>40.1</td>
<td>7.1</td>
<td>773</td>
<td>PL 38, CZ 30, SK 30, AU 3</td>
</tr>
</tbody>
</table>

T (°C) – average annual air temperature during the period 1961-1990; P (mm) – average annual precipitation totals during the period 1961-1990; * proportion of the forested area. Climatic data were taken from the FORESEE database described in the next chapter.
5.3.1.2 Forest distribution data

Data on forest tree species distribution in the Carpathians have been taken from the results of statistical mapping of tree species over Europe (Brus et al. 2011), and this data represent the main information of tree species distribution used in the project. Distribution maps of the following tree species are available in this dataset: *Abies* spp., *Alnus* spp., *Betula* spp., Broadleaved misc., *Carpinus* spp., Conifers misc., *Fagus* spp., *Fraxinus* spp., *Larix* spp., *Pinus* misc., *Quercus* misc., *Quercus robur* and *Quercus petraea*, *Picea* spp., *Pinus sylvestris*, *Populus* spp. and *Robinia* spp. Tree species available in the dataset but not occurring in the Carpathians at the scale of mapping are *Castanea* spp., *Eucalyptus* spp., *Pinus pinaster* and *Pseudotsuga menziesii*. Species shift modelling was run for Oak species (*Quercus robur* and *Quercus petraea*), European beech (*Fagus sylvatica*), hornbeam (*Carpinus* spp.) and spruce (*Picea* spp.).

The original maps have spatial resolution 1x1km, and grid cells contain values of given tree species proportion within a cell. The original maps have been transformed to vector file and adjusted by Corine LandCover data to eliminate the presence of given species outside the border of the Corine LandCover categories “broadleaved” and “mixed” in case of broadleaved species, and “coniferous” and “mixed” in case of coniferous species. Corine LandCover data is not available for Ukraine, thus we corrected species distribution maps using borders of European Forest Map (EFI Forest Map, Kempeneers et al. 2011).

Euforgen species distribution data (http://www.euforgen.org) have been used as complementary information on species distribution in the Carpathians. The dataset contains polygonal data with areal of occurrence of 32 tree species across Europe (see Figure 3 for an example). The distribution maps were produced by members of the EUFORGEN Networks and other experts, based on existing bibliography and other information sources. We consider the boundaries of species occurrence more reliable as those produced using the above-described statistical mapping. Therefore, Euforgen data have been considered in cases when national experts of the CarpathCC project indicated
concern about the reliability of the species distribution data taken from the statistical mapping. Visual comparison of produced maps for several tree species with data from national forestry databases for Slovakia and Romania was satisfactory for most species, deficiencies were found in case of *Alnus* spp. and *Pinus sylvestris*. As can be seen, species distribution taken from statistical mapping is underestimated in the Eastern Carpathians.

![Maps of species distribution](image)

*Figure 3 Distribution of selected forest tree species taken from the Euforgen database.*

**5.3.1.3 Climatic data**

Observation based datasets and climate model results were used to create a daily meteorological database for the period 1951-2100 for Central Europe, which contains minimum/maximum temperature and precipitation time series. For the past (1951-2009) the daily E-OBS database (created within the framework of the ENSEMBLES FP6 project; Haylock et al. 2008) and the monthly CRU TS 1.2 (Climatic Research Unit, University of East Anglia, UK; Mitchell et al. 2004) high resolution gridded dataset were used. For future climate description, we selected ten RCM-GCM (Regional Climate Model – Global Climate Model) couplings (data is provided by the ENSEMBLES FP6 project; van der Linden et al. 2009), and we executed a bias correction on the daily meteorology fields for the period 1951-2100.

All RCMs used were driven by the A1B greenhouse gas emission scenario (a balanced emphasis on all energy sources; IPCC 2000). The data were interpolated to a common 1/6×1/6 degree horizontal resolution grid using an inverse distance interpolation technique.
### Table 2 Bias corrected models included in the FORESEE database.

<table>
<thead>
<tr>
<th>Model ID</th>
<th>Model name (RCM-GCM)</th>
<th>Developing institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ALADIN-ARPEGE</td>
<td>National Centre for Meteorological Research (CNRM)</td>
</tr>
<tr>
<td>2</td>
<td>CLM-HadCM3Q0</td>
<td>Swiss Federal Institute of Technology Zürich (ETHZ)</td>
</tr>
<tr>
<td>3</td>
<td>HadRM3Q0</td>
<td>Hadley Centre for Climate Prediction and Research (HC)</td>
</tr>
<tr>
<td>4</td>
<td>HIRHAM5-ARPEGE</td>
<td>Danish Meteorological Institute (DMI)</td>
</tr>
<tr>
<td>5</td>
<td>HIRHAM5-ECHAM5</td>
<td>Danish Meteorological Institute (DMI)</td>
</tr>
<tr>
<td>6</td>
<td>RACMO-ECHAM5</td>
<td>Royal Netherlands Meteorological Institute (KNMI)</td>
</tr>
<tr>
<td>7</td>
<td>RCA-ECHAM5</td>
<td>Sweden's Meteorological and Hydrological Institute (SMHI)</td>
</tr>
<tr>
<td>8</td>
<td>RCA-HadCM3Q0</td>
<td>Sweden's Meteorological and Hydrological Institute (SMHI)</td>
</tr>
<tr>
<td>9</td>
<td>REGCM-ECHAM5</td>
<td>The Abdus Salam International Centre for Theoretical Physics (ICTP)</td>
</tr>
<tr>
<td>10</td>
<td>REMO-ECHAM5</td>
<td>Max-Planck-Institute for Meteorology (MPI)</td>
</tr>
</tbody>
</table>

Four regional climate models out 10 models listed in Table 2 have been selected for the present study. The selection criterion was model’s position within a bounding rectangle specified as all-model-mean ± standard deviation of 30-year mean of annual air temperature, and ± 30-year mean of annual precipitation totals during the period 2071-2100. On the basis of this criterion, the following models have been selected: RegCM, HIRHAM5, RACMO and REMO (close to all-model-average). The models lying outside the above-specified bounding rectangle were not used as these models are supposed to produce quite diverging outputs which would be difficult to interpret within a single study.

We used geostatistical interpolation technique Kriging with External Drift (Matheron 1973) to produce the maps of selected climatic variables. Digital elevation model with spatial resolution of 350 m has been used as supportive variable correlated with all addressed climate variables. The use of this technique for interpolation of gridded climatic data, as is the case of used data, has been described by Vizi et al. (2011). Three time periods were addressed – 1961-1990 (reference climate, based on E-OBS data), 2021-2050 and 2071-2100 (near and distant future, based on the ensemble of selected RCMs). To investigate the climatic exposure we produced the maps of differences between climate elements in the future time periods and reference climate, and charts indicating the absolute and proportional change between future and reference climate for all geomorphologic units of the Carpathians.
5.3.2 Task 2: Climate change impact on forest pests and pathogens

The results of Task 2 “Assessing the risk of climate change-induced increase in virulence of forest pathogens, and change in outbreak ranges and population dynamics of forest pests” are compiled in three deliverables:

- **SR2. T2. D1. DELIVERABLE**: Report on presently occurring pests and pathogens in the Carpathians, including recent observations of climate change-induced alteration of pest outbreak ranges, population dynamics, predator-prey and host-parasitoids relations.
- **SR2. T2. D2. DELIVERABLE**: Inventory of options to increase forest-stand natural resilience against pests and pathogens, including silvicultural measures to mitigate the mortality of infested trees.
- **SR2. T2. D3. DELIVERABLE**: Map of exposed main forest classes with indications of their vulnerability to key pests and pathogens; expected climate change induced alterations of present disturbance regime will be indicated as well.

The final outputs are the definition of potential distributional ranges of the most important forest pests and pathogens; description of present (real) distributional ranges, if such information is available; projection of potential and present distribution ranges of selected pests using an ensemble of climate change scenarios; description of forestry and ecological importance of all listed pests under climate change; and surveying the procedures applied in countries in the Carpathians to reduce forest stands susceptibility to infestation.

Species-based approach has been applied, i.e. the results are presented in species-by-species structure. Pest and pathogen species investigated in this task were selected in two steps. First, collection of species which are generally recognized as causing damage to forest in the Carpathians we prepared, and ecology and bionomy of each species was compiled. Then, this material was distributed among national experts, and several new species were added on the basis of their feedback. Level of detail provided for individual species in the report substantially varies, as knowledge of pest ecology, distribution and climate change effect is variable, and, generally, only species of key forestry importance are systematically monitored and studied. For this reason, structure and content of chapters for individual species are not uniform, and it corresponds with data and information available.

The following pests and pathogens have been considered:

- **Defoliators**: *Cephalcia abietis*, *Cephalcia alpine*, *Cephalcia arvensis* (Web-spinning sawfly); *Lymantria dispar* (Gypsy moth); *Lymantria monacha* (Nun moth); *Operophtera brumata* (Winter moth); *Pristiphora abietina* (Lesser spruce sawfly); *Thaumetopoea processionea* (Oak Processionary); *Tortrix viridana* (Green oak moth).
- **Bark beetles**: *Agrilus biguttatus*, *Agrilus viridis* (Oak Splendor beetle; Beech Splendor beetle); *Hylobius abietis* (Pine weevil); *Ips amitinus* (Small spruce bark beetle); *Ips duplicatus* (Double spined bark beetle); *Ips typographus* (European spruce bark beetle); *Polygraphus poligraphus* (Small spruce bark beetle); *Taphrorychus bicolor* (Beech bark beetle); *Tetropium castaneum* (Black spruce longhorn beetle); *Tetropium gabrieli* (Larch longhorn beetle); *Dreyfusia nordmannianae* (Silver fir woolly adelgid).
- **Fungal pathogens**: *Phytophthora* sp.; *Armillaria* sp.; *Sirococcus conigenus*; *Chalara fraxinea*.

Annual reports of national Forest Protection Services on amount of sanitary feeling or other indicator of forests damage, scientific papers on pests occurrence, and other material where used to produce the maps of present occurrence of outbreak areas of
selected forest pests. Some outbreak areas or outbreak events have been documented in greater detail using photographs, remote sensing imagery, and statistical evaluations. Projections of future population dynamics and distribution were developed for species for which sufficient information has been collected. These are mainly spruce bark beetle (*Ips typographus*) and double-spined bark beetle (*Ips duplicatus*), Gypsy moth (*Lymantria dispar*), pine weevil (*Hylobius abietis*) and nun moth (*Lymantria monacha*). Generally, information allowing for the assessment of climate change effects on pests and pathogens markedly differ between species and mainly species which presently represent the threat to forest are sufficiently described in the literature. Ecology and, specifically, climate-pest/pathogen relationships for species which are of minor importance, are not known enough to allow for projecting their future distribution and dynamics; therefore only expert judgments will be given in these cases with indication of uncertainty of such information.

5.3.2.1 Models used for projecting changes in pests distribution and population dynamics under climate change

**Gypsy moth *Lymantria dispar***

The analysis of Gypsy moth (*Lymantria dispar*) potential outbreak areas was based on model proposed by Hlásny and Turčáni (2009). Canonical Correspondence Analysis was used to identify environmental variables controlling species abundance (Hlásny and Turčáni 2009). An ordination plot suggested the pest’s positive correlation with *Quercus* sp. and air temperature. The weighted combination of these variables, rescaled to unit range was used to identify those stands providing suitable conditions for outbreaks under both current and future climates.

Under favorable conditions, the species feeds on beech (and occasionally other broadleaves) as alternative hosts. Two hypotheses were evaluated for beech stands. The first hypothesis considers identified oak outbreak areas as initial spots for pest spreading to beech stands. Parameters used in the prediction were distance from the oak outbreak spots and mean annual average air temperature. The “pessimistic” hypothesis supposes that the shift of gypsy moth to higher elevations will be limited only by pest’s upper temperature limit of 8°C (mean annual air temperature), regardless of position of oak outbreak areas.

**Nun moth *Lymantria monacha***

The model used was designated by Turčáni et al. (2011) Model parameters were derived from the data on historical occurrence of the Nun moth gradations in the Czech Republic. Optimal conditions for Nun moth development were defined as function of altitude, terrain exposure and proportion of Norway spruce, Scots pine and European larch in forest stands. The risk of outbreak incidence is evaluated on the basis of shifting temperature range, which specifies the optimum, suboptimum and pessimum for the development. This information is further modified by outputs of multivariate regression featuring the relationship between intensity of observed outbreaks and selected stand and site conditions (exposure, host plants proportion).

**Spruce bark beetle *Ips typographus***

The analysis of bark beetles development was based on the model PHENIPS – A Complex Phenological Model of I. typographus (Baier et al. 2007). The used stage-specific developmental thresholds were proposed by Wermelinger and Seifert (1998). A general principle of the PHENIPS model is as follows: maximum daily air temperature indicates the year day of infestation onset, while mean bark temperature determines the development of particular developmental stages of parental generations. Mean bark temperature is calculated by regression of daily mean air temperature and solar radiation. The equation proposed by Baier et al. (2007) has been used without any modification.
Northern bark beetle *Ips duplicatus*

The analysis of *I. duplicatus* development was based on the model PHENIPS described above. It seems that in the Central Europe the phenological model for *I. typographus* could copy the behaviour of *I. duplicatus* (Holuša et al. 2012). The main distinct feature is that *I. duplicatus* does not occur in higher altitudes (Holuša et al. 2010). It prefers altitudes lower than 800 m a.s.l (Holuša et al. 2013). To define this altitudinal limit pheromone monitoring data was used. The altitudinal preference was studied in the Western and Eastern Carpathians (Holuša 2004; Duduman et al. 2011). According to results of such research, the elevation limits of *I. duplicatus* occurrence were set as follows: 800 m a.s.l. for the Western and 1000 m a.s.l. for the Eastern Carpathians.

Pine weevil *Hylobius abietis*

The analysis was based on developmental threshold temperatures and estimated degree-days needed for the completion of pine weevil life stages. Used stage-specific developmental thresholds were proposed by Inward et al. (2012). Linearly related to temperature, the development rate was estimated using a combination of physiological time (DD) for all stages except prepupae, and calendar time for the duration of the prepupal stage. Because used stage-specific developmental thresholds were not originally designed for investigating *H. abietis* development under climate change, the climate change scenario data were adopted to this purpose. Developmental rate in each of time periods addressed was calculated as the ratio of projected number of generations and length of the time period (30 years). Areas with time development one, two years and > 2 years (multiple years) were designated. The areas where development may last more than 5 years for one generation were classified as “unsuitable climatic conditions”.

Note: Because of large number of species addressed, and relatively detailed elaboration of their description, the respective deliverable (SR2.T2.D1) is rather extensive. For this reason, present here the results for two species only – spruce bark beetle and gypsy moth.

### 5.3.2.2. Spruce bark beetle *Ips typographus*

*I. typographus* is the most destructive species of the genus *Ips* and the most serious pest on spruce in Europe. There are records of outbreaks dating back to the eighteenth century. Losses of millions of cubic meters of wood that occurred during some of these outbreaks were as follows (Wellenstein 1954; Schwerdtfeger 1955; Worrell 1983; Christiansen and Bakke 1988): Germany 1857-1862, 1868-1875, 1917-1923, 1940-1941, 1944-1948, Sweden 1976-1979, Norway 1970-1981, Central Europe 1994-1997, 2003 till today. Outbreaks have also occurred in Italy (Lozzia 1993), Poland, the Czech Republic (Pfeffer and Skuhravý 1995) and in Japan (Hokkaido) in the early 1950s (Inouye and Yamaguchi 1955). Though *I. typographus* is the most damaging of all European *Ips* spp. and the one which is sometimes reported to behave as a primary pest, it is nevertheless most often a secondary pest attacking and killing trees which are already stressed for other reasons (Schwenke 1996) or damaged by windstorms (Forster 1993). The pest is in distributed in the entire Carpathians, and it covers the whole distribution range of the host plant. Anyway, there are areas suffering from persisting outbreaks, which represent the threat to sustainability of forests, and supply of forest goods and services. In these areas, several concurrent stress factors used to compromise forest ecological stability and trees resistance to bark beetles, hence these areas must be thought of as especially vulnerable to climate change.

Spatial distribution on *I. typographus* in the Carpathians was evaluated on the basis of national statistic on forest damage published by national Forest Protection Services. Using this information pan-Carpathians maps of pests distribution were produced (Annexes 1-2).

In the Western Carpathians, information about sanitary felling (m³) in the period 2008-2010 were obtained from the reports published by national Forest Protection
Services: administrative rural districts in the Czech Republic (Knížek 2009–2011) and Slovakia (Kunca et al. 2009–2011) and for forest districts in Poland (data published in Hlásny et al. 2010). Data for the Hungarian part was not available; *I. typographus* importance in Hungary is however marginal.

In the Eastern Carpathians, the most important outbreak occurred in 1995 in the period 1990-2000. The most affected Forestry Departments were Harghita, Covasna and Mures and adjacent Bistrita-Nasaud, Suceava and Neamt. As infested trees were removed in time, infested surface reached in 2000 up to 300,000 ha (Simionescu et al. 2001). The outbreak was further amplified by drought periods in some years after the event. Maximum extent of infestations was reached in 2000, which was fed also by additional windthrown which occurred in 1998 in the area of Mureș, Neamț and Suceava Forestry Departments.

Information about infested surface (ha) in Romania were taken from Simionescu et al. (2001) for period 1990-2000 and Simionescu et al. (2013) for period 2001-2010. Data for Ukrainian and Serbian parts were not available.

**Selected outbreak areas in the Carpathians**

Spruce bark beetle related problems in the **High Tatras Mts.** have been inseparably related during the recent decade to extensive windstorm damage from 2004, which triggered the nation-wide discussion on after-calamity management of mountain protected areas. Spruce forests were damaged at 12,600 hectares in shape of belt long 50 km and wide up to 5 km, in elevation range 800–1,300 m a.s.l.

Intensive works on revitalisation of damaged areas had started soon after the event, and question on effects of spruce bark beetle on the remaining undamaged forest was raised almost immediately. Presently, after a lapse of 10 years, some assessment can be given. The case of High Tatras Mts. serves in this deliverable as example of spruce bark beetle dynamics after extensive windthrows in the Carpathian Mountains. One of key issues discussed was the treatment of damaged wood, which provides breeding material for bark beetles, and represent subsequent risk for undamaged trees in the surrounding of windstorm area. Highest level of nature conservation, and intention to consider windstorm damaged areas as part of natural forest development, argued to remain all or parts of damaged wood on spot. Finally, 165,000 m$^3$ of volume remained on the spot.

In the next years, intensive forest monitoring has been applied to evaluate the processes related to after-calamity development, including bark beetle infestations, forest fires, forest regeneration, soil erosion, water and air quality, etc. Infrared aerial imagery was taken annually, and detail progress of infestation in undamaged spruce stands surrounding the damaged area was evaluated. Figure 4 shows tree-scale evaluation of the progress of infestation in sample area adjacent to main calamity body, with scattered damaged trees. As can be seen, first two years after the windthrown (2005-2006), no progress of infestation has been observed. The reason for this was that freshly damaged wood provided attractive breeding material for bark beetles. In 2007, however, beetles left drying damaged stems are started colonize surrounding spruce stands. The same process was observed in the following years, and, despite more optimistic expectations, bark beetle reached in some location even the tree line. Process described in this sample area was typical of the most of the damaged area.
Spatial progress of infestation was evaluated using both airborne and satellite imagery, and these observations corroborate the large scale dynamics similar to that observed and stand scale presented above (Figure 4). Figure 5 presents progress of infestation on the surrounding of two valleys in the High Tatras Mts. – Tichá and Kôprová valleys. Image 2000-2003 present forest cover before the windstorm, and dark brown colour describes coniferous forests. Image 2000-2005 portrays in red areas damaged by windstorm. Up to 2006, no progress was observed, and, as noted above, bark beetle was feeding on damaged wood. Later, bark beetle left the damaged drying wood, and started infesting progressively the surrounding slopes.
The second outbreak areas which we focus on here, is in the **Western Carpathians, the Western Beskids Mts.** (Figure 6), and it is one of the most important outbreak areas in the Carpathians (Hlášny and Sitková 2010; Hlášny and Turčáni 2013). Even-aged spruce forests growing outside the range of spruce natural distribution dominate the region; this forest has been constituted during the last 400 years in response to a growing need for fuel wood and construction material and has replaced the original beech–fir forests.

Forests in the Beskids have been affected by air pollution loads from industrial plants in the Ostrava and Katowice coal basin since the late 18th century, when mining activities in this region began. Productive forestry oriented on fast growing Norway spruce timber was established in the region at that time. In the second half of the 20th century, the concentrations of sulphur dioxide (SO₂), in particular, were critical, causing forest decline in the upper part of the Moravian-Silesian Beskids in the Czech Republic and in the Silesian Beskids in Poland.

Air pollution from industrial sources that started in the late 18th Century and which peaked in the second half of the 20th century (Kopáček and Veselý 2005) affected forest health and soil conditions in the region. Although heavy industry declined and signs of forest recovery became evident after 1990, in 2002 a new period of spruce forest decline began (Hlášny and Sitková 2010).

A large-scale outbreak began in 1993 and persists to the present (2012). The entire study area has been intensively managed, and control measures have been regularly applied. The infestation was mainly caused by *I. typographus*, *Pityogenes chalcographus*, *Ips amitinus* and *Ips duplicatus* (Turčáni and Hlášny 2007). Field surveys confirmed that
*I. typographus* accounted for up to 95% of the dead trees in the study region (Slovak Forest Protection Service, internal data).

The relatively uniform age structure and composition of such forests provide a conducive environment for *I. typographus* dispersal. Uniform structure and poor site matching of investigated forests may allow for rapid development of large-scale *I. typographus*–induced damage (Jönsson et al. 2007; Netherer and Nopp-Mayr 2005) even in the absence of windstorms, which are the main triggers of *I. typographus* outbreaks (Økland and Berryman 2004).

**Figure 6** Position of cross-boundary Slovak-Czech-Polish region affected by spruce forests decline.

Persisting bark beetle outbreak causes substantial damage to forests in the region. Long term development of sanitary felling data in the Kysuce Beskids subregion (SK) can be seen in the Figure 7. As can be seen, amounts of felling were stable during the period 1973-1991. Then, large scale outbreak was triggered, and it persists till present (Hlásny and Turčáni 2013). Similar outbreak development is typical for most of the Western Beskids.

Spruce stands infestation by bark beetles during the period 1999–2008 within rural districts in the Slovak and Czech republics and forest districts in Poland describes well the spatial pattern of infestation in this region (Figure 8). The presented quantity is the ratio of the amount of felling in a district to the extent of coniferous stands (in Slovak and Czech republics) and to the extent of spruce stands in state forests (in Poland) in m\(^3\).ha\(^{-1}\) (Hlásny and Sitková 2010). Bark beetle infestation was most intensive during the entire investigated period in the northern districts of the study region (Opava, Ostrava, Karvina, Ustroń, Wisła and Wegierska Gorka). In 2003, intensity of infestation culminated in the districts Ostrava, Karvina and Ustroń and minor increase was observed also in several other districts. The years 2007–2008 can be regarded as critical, as spruce stands in most districts were heavily infested. The amounts of felling in the most heavily infested districts ranged from 5 to 75 m\(^3\) per hectare of coniferous stands (mostly spruce in the study region). Districts in the Moravian-Silesian Beskids (Vsetín, Frydek-Místek) exhibited the lowest amount of sanitary felling. Increase of infestation in the Kysuce and Orava Beskids can be seen mainly since 2004, especially in Kysucké Nové Mesto, Námestovo, Čadca and Púchov districts (at up 22 m\(^3\).ha\(^{-1}\)).
Figure 7 Long term development of sanitary felling data in the Kyskuce Beskids. Source: National Forest Centre, Slovakia.

Figure 8 Spatial progress of forest infestation by bark beetles in the transboundary regions of the Western Beskids (SK-CZ-PL) (Hlásny and Sitková 2010).
Assessment of changes in forest cover using satellite imagery is important tools for continuous updates of the extent of forest damage as well as for the planning the allocation of control measures. Next, we provide several assessments of forest damage by bark beetles in the Western Beskids. Position of sample areas within the Western Beskids, where the assessment was conducted, is displayed in Figure 9. The maps with classification of deforestation due to bark beetle infestation are presented in the Annexes 9-11. The maps were taken from the deliverable SR2.T2.D3 on the development of pest distribution maps.

**Figure 9 Sample areas in the Western Beskids where the remote sensing based assessment of changes in forest cover due to bark beetle infestation was conducted**

Deforestation due to the decline of spruce forests is described using the satellite imagery LANDSAT TM and LANDSAT ETM+ with spatial resolution (cell size) of 30x30 and 15x15 meters respectively. The so-called false color spectral composites was used to better differentiate between broadleaves and coniferous.

Sample area 1 (Annex 9) represents the Javorské massive (860 m a.s.l.) in Slovakia with size 57 km² (28.8 km² of forests in 1994). Landsat TM imagery acquired in July 1994 describes the forest before the main period of decline, with clearly visible regular-shaped areas of planned felling. The September 2005 image describes the first irregularly shaped areas of accidental felling, the extent of which rose dramatically up to June 2010. The fourth image with the composite of 1994 and 2010 spectral bands describes in red the changes in forest cover between 1994 and 2010.

Sample area 2 (Annex 9) describes a part of the Kysucké Beskids mountain crest from the Veľká Rača Mt. (1,236 m a.s.l.) to the Bugaj Mt. (1,140 m a.s.l.). Size of this area is 90 km² with 75% cover of both state and private forests in 1994. Two thirds of the total forest cover was originally made up of spruce. The LANDSAT imagery from 1994 describes the first appearing spots of declining stands, portrayed in turquoise in the centre of compact spruce forest (dark brown) close northerly from the village of Stará Bystrica. The 2005 image describes widespread belt of declining spruce stands as well as vast deforested area. Regular turquoise stripes in the northern edge of the image portray ski slopes.

The 2010 image describes almost total disappearance of spruce stands in the central part of the sample area; and spread of the decline to the west. The fourth image describes in red the aforementioned changes.
Sample area 3 (Annex 10) describes the highest parts of the Silesian Beskids with Barania Góra Mt. (1,220 m a.s.l.) a Skrzyczne massive (1,257 m as.l.), and with source of the Wisła river. Plot's size is 368 km$^2$. The 1994 image describes the initial status with continuous spruce forest cover in the central and southern part of the mountain crest. The 2005 and 2007 images describe the progress of decline. Compact spruce stands in the south-west of the Barania Góra Mt. were stricken as the last. The fourth image describes in red the aforementioned changes.

Sample area 4 (Annex 10) with size of 87 km$^2$ describes compact spruce forest in the Gluchová Mt. (822 m a.s.l.) on Slovak-Polish border (Slovakia). Landsat TM imagery acquired in September 1994 describes the initial stage of decline of private spruce forests, occurring mainly in the southern part of the forested area. This is the initial spot from where the decline spreads to the central part (May 2001 image) and further to all the remaining parts (June 2010 image). This area represents one of the main initial spots of spruce decline in the Orava region. Armillaria disease was extremely important agent in the initial stages of decline. As can be seen in the fourth image, the decline occurred both in Slovak and Polish parts of the forested area.

Sample area 5 (Fig. 10.7) describes the total area of the Kysuce, Horná Orava and adjacent regions in the Czech Republic and Poland. Size of this area is 4,096 km$^2$. Dark red color portrays the changes induced primarily by accidental felling. The centre of spruce forests decline is located in the Kysucké Beskids, mainly in the southern and eastern parts of the main mountain crest. Similar damage can be seen in the adjacent parts of the Solá basin in the Silesian and Živiec Beskids. Smaller spots of decline occurred in the eastern part of the Javorníky Mts. The northern part of the Kysucká vrchovina Mts. is largely stricken.

The most affected areas in the Orava region can be seen in the surrounding of the Námestovo (eastern edge of the Oravská Magura Mt. and Podbeskydská vrchovina Mts.) and northerly from the village of Oravská Polhora. Forest stands in the Biela Orava basin (surrounding of the Oravská Lesná village and large part of the Oravská Magura Mt.) remain relatively healthy. Important focal area of decline is located close to the right bottom part of the image.

**Eastern Carpathians – Romania**

For the period 1990-2000 the most important outbreak occurred in 1995 (for more details see Deliverable: SR2.T3.D1.). The most affected Forestry Departments were Harghita, Covasna and Mures and adjacently Bistrita-Nasaud, Suceava and Neamţ (Figure 10). As infested trees were removed in time, infested surface reached in 2000 up to 300,000 ha (Simionescu et al., 2001). This process was further amplified by drought periods in some years after the event. Maximum extent of infestations was reached in 2000, which was fed also by additional windthrown which occurred in 1998 in the area of Mureş, Neamţ and Suceava Forestry Departments.

Information about infested surface (ha) in Romania were taken from Simionescu et al. (2001) for period 1990-2000 and Simionescu et al. (2013) for period 2001-2010. Data for Ukrainian and Serbian parts were not available.
Projection of future development

Using the models described above, pre ran the simulations of climate change impact on number of annual bark beetle generations. We evaluated the extent of areas which are expected to face the increase in number of generations, and produced respective maps (Annexes 3-7). Further we broke down this information at level of countries and geomorphologic subprovinces of the Carpathians.

Czech Republic – Outer Western Carpathians

In the reference period, two-generation regime of *I. typographus* dominated in the Czech part of the Carpathians (73.2% area of spruce forest). At higher altitudes of the Moravian-Silesian Beskids (above 800 m a.s.l.), the one-generation development (26.7%) was present.

In the near future (2021-2050), occurrence of two-generation development (78.5%) was projected to dominate, while three-generation regime (21.5 % of the area) may
occur at lower altitudes (up to 400 m a.s.l.). Area allowing for one-generation regime was projected to disappear.

In the distant future (2071-2100) three-generation regime (90.4 %) is projected to dominate across the analysed area, while areas with a two-generation development may occur at 8.3 % of the area only. In the lowest altitudes spruce stands on very small area (10.7 km²) may be under pressure of four-generations at 0.4% of the area.

**Slovakia – Outer Western Carpathians, Inner Western Carpathians**

In the reference period, the one-generation regime was estimated to dominate at higher altitudes of the Tatra and Fatra Mts. (above 700 m a.s.l.) in the Slovak part of the Carpathians (66.0 % in Inner Western Carpathians and 50.2 % in Outer Western Carpathians). Two-generation development was present (33.0 % in Inner Western Carpathians and 49.8 % in Outer Western Carpathians) only at altitudes below 700 m a.s.l. Areas allowing three generation will be very restricted (0.5 km²).

In the near future (2021-2050), occurrence of two-generation development (81.1 % in Inner Western Carpathians and 94.5 % in Outer Western Carpathians) was projected to dominate, while three-generational development (about 5 %) will be present at lower altitudes (up to 400 m a.s.l.). Areas allowing only one generation will be restricted (14.0 % in Inner Western Carpathians and 0.5 % in Outer Western Carpathians).

In the distant future (2071-2100) three-generational development (48.7 % in Inner Western Carpathians and 72.8 % in Outer Western Carpathians) will dominate while areas with a 2-generation development will be still at about 50.9 % and 27.2% respectively of the area. In the lowest altitudes (about 300 m a.s.l.) spruce stands on very small area will be under pressure of four generation population (about 0.2 % of area).

**Poland – Outer Western Carpathians, Outer Eastern Carpathians North**

In the reference period two-generational development dominated over the Polish Carpathians (99.2% of the spruce stands in Outer Eastern Carpathians and 56.9 % in Outer Western Carpathians), at higher altitudes of the Beskids and Tatra Mts. (more than 700 m above sea level) 1-generational development (0.3 % in Eastern Carpathians and 43.1 % in Outer Western Carpathians) was present.

In the near future (2021-2050) occurrence of two-generational development (38.5 % of the spruce stands in Outer Eastern Carpathians and 91.8 % in Outer Western Carpathians) will still dominate, while three-generational development (61.5 % of the spruce stands in Outer Eastern Carpathians and 7.7 % in Outer Western Carpathians) will be frequently present at lower altitudes (up to 400 m a.s.l). Area allows only one generation will be very restricted (0.5 % of spruce stands).

In the distant future (2071-2100) three-generational development (85.8 % of the spruce stands in Outer Eastern Carpathians and 76.9 % in Outer Western Carpathians) will dominate while areas with a 2-generational development will be only at about 23.0 % of spruce stands in Outer Western Carpathians. Area allowing for one-generation regime was projected to disappear. On the other hand in the lowest altitudes (up to 300 m a.s.l.) spruce stands on very small area (0.4 %) will be under pressure of four-generation population.

**Ukraine – Outer Eastern Carpathians North, Inner Eastern Carpathians**

In the reference period one-generational development dominated in the Ukrainian Carpathians (over 90 % of the spruce stands), at lower altitudes of the Schidni Karpaty Mts. (less than 800 m a.s.l) two-generation development (9.2 % in Outer Eastern Carpathians) was present. Area allows three generation was very restricted (0.3 % of spruce stands).

According to climate change scenario in the near future (2021-2050) occurrence of two-generational development (68.2 % of forest stands in Inner Eastern Carpathians and 81.6 % in Outer Eastern Carpathians) will dominate, while three-generational development (about 1 % of the area) will be present at lower altitudes (up to 400 m
above sea level). Area allowing only one generation will be restricted (31.1 % of forest stands in Inner Eastern Carpathians and 16.8 % in Outer Eastern Carpathians).

In the distant future (2071-2100) two-generational development (90.7 % and 78.6 % respectively) will still dominate while areas with a 3-generational development will be about 15 % of the area. Small areas in lowest parts could be suitable for development of four generations per year.

**Romania – Inner Eastern Carpathians, Outer Eastern Carpathians South, Southern Carpathians, Western Romanian Carpathians**

In the reference period one-generational development dominated at higher altitudes (more than 700 m a.s.l) in the Romanian Carpathians (about 80 % of the area). Two-generation development (about 18 %) was present at lower altitude (less than 700 m a.s.l). But there were also small areas in Southern and Western part of Romanian Carpathians with three-generations per year (about 0.5 %).

In the near future (2021-2050) occurrence of two-generational development (about 82 % of spruce stands) will clearly dominate, while three-generational development (about 6.5 % of the area) will be present at lower altitudes (up to 400 m a.s.l) in Southern Romania. Area allowing only one generation will be reduced (about 11 % of spruce stands, mainly in Southern Carpathians).

According to climate change scenario in the distant future (2071-2100) two-generational development (about 55 %) will be still dominate, but areas with a three-generation development will occupy already about 44 % of the spruce stands area. In the lowest altitudes (about 300 m a.s.l) almost 1.5 % of spruce stands will be under pressure of four generation population. Area allowing for one-generation regime was projected to disappear.
5.3.2.3. Gypsy moth *Lymantria dispar*

Gypsy moth (*Lymantria dispar* (L.)) is the most important defoliator of broadleaved stands (oak mainly) (Hlášny and Turčáni 2009). It’s known as a polyphagous herbivore in Eurasia (native) and North America (introduced) (Doane and McManus 1981). It is characterized by cyclical abundance fluctuations resulting in defoliation of large areas across Southern, Eastern and Central Europe, Northern Africa, Asia Minor, Central Asia and the Middle East (Villemant and Fraval 1998) as well as the eastern part of North America (Doane and McManus 1981). The cyclicity of outbreaks seems to be regular in a wide range of natural conditions (Johnson et al. 2006). They fluctuate from 3-4 years in Southern Europe to 8-10 years in Central Europe and 20-25 years in northern regions (Johnson et al. 2006).

Defoliation, caused by larvae, may reduce the vitality of infested trees, increase trees susceptibility to attack by other pests such as oak bark beetles or increase trees susceptibility to attack by fungal diseases. Intense defoliation may reduce tree increments and in extreme cases it may result in tree mortality.

Spatial distribution on *L. dispar* in the Carpathians was evaluated on the basis of national statistic on forest damage published by national Forest Protection Services. Using this information pan-Carpathians maps of pests distribution were produced (Annexes 11-12). In the Western Carpathians, information about infested surface (ha) for the period 2003-2005 presented in the maps were obtained from reports published by national Forest Protection Services. Data are reported for administrative districts in the Czech Republic (Kapitola et al. 2004; Kapitola and Baňař 2005; Knížek 2006) and in Slovakia (Kunca et al. 2005; 2006). Data for the Polish and the Hungarian part of the Carpathians were not available; importance of *L. dispar* in Poland is however marginal.

The data shows the last outbreak which was observed in the period 2003-2005, culminating in 2004. In Slovakia, about 45 thousands ha of broadleaved forests were defoliated. The next outbreak is expected to commence in 2012-2013.

Information about infested surface (ha) in Romania were taken from Simionescu et al. (2001) for period 1990-2000 and Simionescu et al. (2013) for period 2001-2010. Data for Ukrainian and Serbian parts were not available.

The first records on *L. dispar* outbreaks in Romania come from 1928. Large scale gradations were observed in the period 1942–1943 in oak forests in the southern Romania ( Dobrogea, Muntenia and Oltenia). Low intensity defoliations were observed also in year 1948. New gradation started in 1951, and intensive defoliations were observed at large areas in south, west (Banat) and north–west (Crisana and Maramures) of the country. The largest extent of defoliated forests was recorded in the period 1987–1988, when it reached 700,000 ha, more than 250,000 ha of which were strongly defoliated (Tomescu and Netoiu 2006). Frequency of gradations during the last 55 years implies that *L. dispar* gradations in Romania occur with period ca. 7-10 years. Defoliations are most intensive in forests of *Quercus cerris* and *Q. frainetto* in the southern regions, and rarely also in other parts.

**Outbreak areas in the Carpathians**

### Czech and Slovak part

In the Czech Republic the oldest records of Gypsy moth outbreaks go to 1877. Then large outbreaks were recorded in 1907-1908, 1924-1927 and 1931-1932. Other important outbreak in the Czech Republic occurred in years 1950-1955, and then in the mid60th - end70th of the 20th century. Another outbreak occurred in 1994-1996 in the southern and south-western Moravia as well as in warmer areas of central, northern and eastern Bohemia. The latest outbreak was observed during the years 2002-2006 in the southern regions (Turčáni et al. 2011; Figure 11).

*L. dispar* gradations in Slovakia have been recorded periodically, and their intensity increases with each passing outbreak (Zúbrik 2004). Outbreaks occur periodically every 8-11 years (Figure 12). Southern part of Slovakia is most
affected (districts Nové Zámky, Levice, Krupina, Velký Krtíš, Lučenec and Zlaté Moravce) (Figure 13; Annex 12). Last gradation occurred from 2003 to 2006 and peaked in 2004, when approximately 25,000 hectares of forest were infested (Figure 12).

![Figure 11 L. dispar gradations in the years 1877-2009 in the Czech Republic based on defoliation intensity (the maximum intensity is outbreak area in 2004) (Turčáni et al. 2011).](image)

![Figure 92 Outbreaks of L. dispar in the period 1972–2006 in Slovakia (Zúbrik 2006).](image)
Figure 13 Outbreak areas of gypsy moth (Lymantria dispar) in Czech and Slovak part of the Carpathians in the period 2003-2005 (Kapitola et al. 2004; Kapitola and Baňař 2005; Knížek 2006; Kunca 2005, 2006)

**Polish part**

Similar fluctuation cycles, as in Czech Republic and Slovakia, were observed also in Poland (Figure 14), however gypsy moth is not economically important in Polish part of Carpathians and occurs only sporadically.

Figure 10 Outbreaks of *L. dispar* in the period 1958–2007 in Poland (Turčáni et al. 2011).
**Hungarian part**

In Hungary *L. dispar* is consider as the most important pest, mainly due to warmer climate compared to north-lying states and larger proportion of main host trees (*Quercus cerris* L.), and therefore larger area of potentially endangered forests. Gradations occur with much shorter period than in Poland or the Czech Republic in the last 100 years (Turčáni et al. 2011; Figure 15).

![Figure 11 Outbreaks of L. dispar in the period 1961–2007 in Hungary (Turčáni et al. 2011).](image1)

Last major outbreak occurs in the period 2004-2006 and peaked in 2005, when approximately 20,000 hectares of forest were defoliated (Figure 15). During last outbreak serious egg mass densities were reported also in beech stands. The 2006 outbreak spread over thousands of hectares of beech stands of different ages at 500–700 meters (Bakony Mts., Bükk Mts., Mátra Mts.).

In the Hungarian part of the Carpathians, during last outbreak (2004-2006) nearly 80,000 ha of forest were infested (Figure 16). Központi-Bükk (31,945 ha in 2005), Borsodi-dombság (5,707 ha in 2005) and Középső-Cserhát-vidék (7,606 ha in 2006) Forest districts were most affected (Figure 17)

![Figure 12 Infested area (ha) by L. dispar since 2000 in Hungarian part of Carpathians.](image2)
Romanian part

The first records of *L. dispar* outbreak in Romania came from 1928. Large scale gradations were observed in the period 1942–1943 in oak forests in the southern Romania (Dobrogea, Muntenia and Oltenia regions). Low intensity defoliations were observed also in year 1948. New gradation started in 1951, and intensive defoliations were observed at large areas in south, west (Banat) and north–west (Crisana and Maramures) of the country. The largest extent of defoliated forests was recorded in the period 1987–1988, when it reached 700,000 ha, more than 250,000 ha of which were strongly defoliated (Tomescu and Netoiu 2006; Figure 18). Frequency of gradations during the last 55 years implies that *L. dispar* gradations in Romania occur with period ca. 7-10 years. Defoliation is most intensive in forests of *Quercus cerris* and *Quercus frainetto* Ten. in the southern regions, and rarely also on other tree species.
In the Carpathian part of Romania, last major outbreak occurs in the period 2003-2005, when approximately 85,000 hectares of forest were infested (Simionescu et al. 2011; Figure 19).

**Figure 148 Outbreaks of L. dispar in the years from 1953 to 2005 in Romania (Tomescu and Netoiu 2006).**

In Serbia, the climate and natural conditions are very similar to those in Hungary, resulting in shorter period between gradation cycles (Turčáni et al. 2011). From 1862 to the present 17 gradations were recorded (Figure 20). Data on the extent of damage are not however available.

**Serbian part**

In Serbia, the climate and natural conditions are very similar to those in Hungary, resulting in shorter period between gradation cycles (Turčáni et al. 2011). From 1862 to the present 17 gradations were recorded (Figure 20). Data on the extent of damage are not however available.
Projections of future development

Using the models described above, we ran simulations of climate change impact to project potential outbreak areas of Gypsy moth in the Carpathians. We evaluated the extent of areas which are expected to face the increase risk of gradation of this pest, and produced respective maps (Annexes 13-18). Further we broke down this information at level of countries and geomorphologic subprovinces of the Carpathians.

Czech Republic – Outer Western Carpathians

In the Czech part of the Carpathian region we expect enlarge in outbreaks areas of *L. dispar* into more than 20% of oak forests and in 30% of beech forests in the near future (2021-2050) and even more than 30 % of oak forests and of more than 50% in beech forests in the distant future (2071-2100) compared to the reference period (1961-1990).

Slovakia – Outer Western Carpathians, Inner Western Carpathians

*L. dispar* outbreak areas are expected to enlarge significantly in the near future from 2% of oak forests in 1961-1990 to about 20% in the 2021-2050 and nearly 40% in the 2071-2100.

The area of endangered beech stands will be almost thirty times bigger, in the period 2021-2050 the pest can potentially spread to almost 20 % and in the period 2071-2100 to over 60 % of beech stands in the Slovakian part of Carpathians.

Poland – Outer Western Carpathians, Outer Eastern Carpathians North

In the Polish part of the Carpathian region we expect significant increase in range of outbreaks in the distant future. The potential outbreak areas of *L. dispar* will cover up to to 22% of oak forest and more than 69 % of beech forests in the distant future (2071-2100), compared to the reference period (1961-1990) and near future, where risk of outbreak was minimal.

Hungary - Inner Western Carpathians

*L. dispar* outbreak areas are expected to enlarge in the near future in oak forest (from 35% in 1961-1990 to about 50% in the 2021-2050) and beech forest (from 50% in 1961-1990 to about 55% in the 2021-2050), while further it remains stable, because of reaching the upper distributional range of both *Quercus* spp. and beech.
Ukraine – Outer Eastern Carpathians North, Inner Eastern Carpathians

In the Ukrainian part *L. dispers* outbreak areas are expected to enlarge significantly in the distant future in oak forest (from 1% in 1961-1990 to nearly 10% in near future and more than 50% in the 2071-2100) and beech forest (from 0,5% in 1961-1990 to nearly 5% in near future and more than 50% in the 2071-2100).

Romania – Inner Eastern Carpathians, Outer Eastern Carpathians South, Southern Carpathians, Western Romanian Carpathians

In the Romanian part *L. dispers* outbreak areas are expected to enlarge significantly in the distant future in oak forest (from 12% in 1961-1990 to 30% in near future and more than 50% in the 2071-2100) and beech forest (from 3% in 1961-1990 to nearly 30% in near future and nearly 60% in the 2071-2100).

Serbia - Serbian Carpathians

*L. dispers* outbreak areas are expected to enlarge in the near future in oak forest (from 35% in 1961-1990 to about 60% in the 2021-2050) and beech forest (from 25% in 1961-1990 to about 65% in the 2021-2050), while further it remains stable, because of reaching the upper distributional range of *Quercus* spp. and beech.
5.3.3. Task 3: Adaptive potential of forest management

Dominant share of Carpathian forests is managed, and forest management practices differ in various aspects among countries. Forest management represent powerful tool of forest adaptation to climate change for example through changes in species composition, it may however also act detrimentally in terms of overharvesting or promoting interventions opening the canopy or disrupting stand’s water regime. Adaptive capacity of forest management is also important part of forest vulnerability assessment, the assessment of which in the Carpathians is described in the next sections.

We elaborated detailed overview of presently applied forest management practices, and we collected using questionnaires the information on adaptive capacity of forest management in Carpathian countries. National legislation, including National Forest Programmes, has been reviewed, and information on climate change adaptation has been evaluated. Except for "standard” practices such as alterations of tree species composition, applied thinning and harvesting techniques, etc., also broader issues such as awareness of forest managers and policy makers, and level of cross-sectoral cooperation have been addressed. Gross domestic product per capita was used as indicator of countries` economic development indicating counties’ capacity to implement the adaptation measures effectively. The detailed information on adaptive capacity of forest management in the Carpathians is presented in Deliverable SR2.T4.D2.

Adaptive management is “a systematic process for continually improving forest management, in conditions of complexity and uncertainty, by learning from the outcomes of operational practice” (Lawrence and Gillet 2011). Its aim is to respond to uncertainty and increase resilience in complex social-ecological systems. The main problem of adaptive forest management is that the stands should suit not only the future expected climate but also the current climate (Broadmeadow and Ray 2005). Canadian Forest Service (2009) defines adaptive forest management as “a dynamic approach to forest management in which the effects of treatments and decisions are continually monitored and used, along with research results, to modify management on a continuing basis to ensure that objectives are being met” (Canadian Forest Service, 2009). Two variations of adaptive management are known from literature: active and passive (Gregory et al. 2006; Linkov et al. 2006; McAfee et al. 2006; Bell et al. 2008). Lawrence and Gillet (2011) define the two forms as follows:

- **Active adaptive management**: managers typically seek to define competing hypotheses about the impact of management activities on ecosystem functions and, in turn, design management experiments to test them. In this way, systems are deliberately tested through management interventions, often with several alternative types of management activities attempted in sequence or in parallel so as to observe and compare results. Active adaptation for example includes the active transformation of forest in order to replace or admix tree species sensitive to climate change with tolerant species (native as well as introduced species or provenances) that are potentially better adapted to future climate conditions.

- **Passive adaptive management**: managers typically use historical data, from the specific area under consideration or from areas considered to be ecologically comparable, to develop a 'best guess' hypothesis and to implement a preferred course of action. Outcomes are monitored and new information is used to update the historical dataset and, if necessary, the hypotheses and management action. Bolte et al. (2009) suggest that passive adaptation deliberately uses spontaneous adaptation processes in terms of natural succession and species migration. This minimizes drastically the input efforts, but eliminates many possibilities to control the stand dynamics that are important for future forest composition, stand structure and forest functioning. Criteria for the use of this option are (i) low importance of the forest stand for economic and ecological functioning, (ii) no adequate
measures for active adaptation, and (iii) better cost-benefit ratio than other strategies.

Adaptation measures refer to adjustments in forestry in response to actual or expected climatic changes or their effects in order to reduce the impact of a particular risk or to exploit possible beneficial opportunities (Lindner et al. 2008, Kolström et al. 2011). They are required to ensure that the forest ecosystem services of a particular forest at a particular site are maintained also under future climate (Seppälä et al. 2009). Due to the long-term perspective of forestry, “adaptation measures need to be planned well in advance of expected changes in growing conditions because the forests regenerated today will have to cope with the future climate conditions of at least several decades, often even more than 100 years” (Lindner et al. 2008). Their intensity and priority depends on:

- Anticipated intensity of climate change, which can however be derived only in a broad context of future trend.
- Vulnerability of forest stands to other than climatic factors, e.g. air pollution, nutrients exhaustion, poor site matching, etc. Cumulative effect of non-climatic and climatic stressors may induce rapid decline and increased attention should be paid to such species, communities or regions.
- Experience obtained from the projections of climate change impact on forests.
- Experience obtained from similar conditions in other parts of Europe or world. Adverse climate-related effects on forests have been observed and documented worldwide. Pest outbreaks, emergence of new species or drought induced decline observed elsewhere can be used to guide the hazard rating and focus the adaptation on specific ecosystems or regions.
5.3.3.1. Slovakia

The principal legislation document specifying forest management in Slovakia is Act on Forests No.326/2005. This act distinguishes three categories of forests depending upon the primary use of their functions as follows:

- **protective forests** – are forests usually situated on extreme sites (screes, steep slopes, etc.), forests at timber line, and forests with prevailing soil protection function
- **special purpose forests** - their main function is to ensure specific needs of society or individuals that require specific forest management regime
- **commercial (management) forests** – are forests with the primary production function, while they also need to fulfil non-productive functions.
- **Protective and special purpose forests** have to be declared by state administration. Currently, there are about 68% of commercial forests, 17% of protective forests and 15% of special purpose forests in Slovakia.

Forest management plan represents an executive tool for forest management. Since 2011, forest management plans are called care programs for forests (following Act 117/2010). They define management models for a management unit. According to Anfodillo et al. (2008), the present system of forest management used in Slovakia is one of the most detailed and sophisticated systems worldwide due to:

- A very detailed spatial division of forests into basic management units
- High quality of forestry maps
- Country wise data gathering
- Complex and unified site survey
- General obligation to follow forest management plans
- Close link between site survey and forest management.

The plans are prepared by professional mensurationists (cruisers, taxators) with regard to the actual state of forest stands, while a so called “degree of threat” is used as a measure of forest stability in near future (i.e. in next 10 years). The mensurationists follow the field survey methodology prepared by the workers of the National Forest Centre, who attempt to apply the newest scientific results including forest adaptation to climate change in the suggested methodology. Hence, climate adaptation measures are primarily included in framework plans, which form the basis for creating forest management plans of individual stands. The cruisers discuss all the issues included in the care programs with the forest owners and managers and search for a consensus between what is needed from the point of forest sustainability and what is feasible for a forest owner. Unlike before, care programs are no longer binding for forest owners and managers, the only obligatory measure is the volume of allowable cut per decade. Nevertheless, the personal communication with forestry practitioners from several private forest enterprises revealed that in many cases the prepared forest management plans (care programs) are still considered to be important and helpful tools for forest managers, which they attempt to follow.

**Awareness issues and cross-sectoral cooperation**

The Ministry of Environment of the Slovak Republic (MoE) is responsible for the implementation and coordination of climate change policy including the adaptation to adverse impacts of climate change. The Slovak Republic does not have a complete adaptation strategy, it is being developed under the auspices of MOE. The Working Group for the preparation of the National Adaptation Strategy (NAS) within the MoE is preparing the first draft of the NAS based on all relevant documents and outcomes of projects which focus on this issue. The basis for the NAS is partial analyses of climate change impacts and a proposal of proper adaptation measures...
in various sectors. The Fifth National Communication of the Slovak Republic on Climate Change issued in 2010 (MoE and SHMU 2009) summarises main findings of climate change impacts and adaptation measures in water management, agriculture, forestry, biodiversity, transport, and tourism.

In the water sector, Water Act 2004 and the EU Water Framework Directive at the national and international level are important drivers of adaptation. Adaptation is also included in the "Concept of Water Management Policy" of the Slovak Republic in force until 2015, which defines the principles of the state water policy for competent authorities and organisations (EC-EEA 2013). Recommendations from this concept have been included in other strategic documents dealing with water management (e.g. Flood risk management concept, Water plan of Slovakia). On October 27, 2010 the Government of the Slovak Republic approved the Landscape Revitalisation and Integrated River Basin Management Programme (Government resolution no. 744/2010). The main objective of this programme is to build a system of preventive flood-protection measures to reduce flood risk. One project of this programme has been already implemented for 24 towns around Slovakia (EC-EEA 2013).

The long-term project on the National Climate Programme of the Slovak Republic was developed in 1994. In the period 1994 – 2010, it was funded by the MoE and focused on trends and projections of the climate system of Slovakia, climate change scenarios and climate change impacts on various social and economic sectors. The most recent study of projection of climate change impacts, complemented with proposals for adaptation measures, was prepared within the project "Climate Change Impacts and Possible Adaptation Measures in Various Sectors in Slovakia". This project was co-coordinated by the Slovak Hydrometeorological Institute (SHMU) and its outcomes will provide input for the NAS (EC-EEA 2013).

Several international (e.g. CC-TAME, CECILIA, WATCH, BurnOut, CLIVARGI (MoE and SHMU 2009)), national EU funded, and national projects focusing on climate change adaptation have been solved in Slovakia since the end of the last century. Some non-governmental organisations and public associations also focus their activities on climate change issues and help to increase public awareness, e.g. Strom života (The tree of life), Za matku Zem (For mother Earth), Priatelja Zeme (Friends of the Earth Slovakia). However, education and public awareness activities with respect to climate change are neither legally not institutionally supported. New information and communication technologies are used to disseminate knowledge on climate change, e.g. via film festivals (Envirofilm, Ekotopfilm) or web portals, e.g. Information System of Monitoring (www.iszp.sk) and Enviroportal (www.enviroportal.sk). Slovak Agency of Environment Protection (SAŽP) operates centres of environmental education (MoE and SHMU 2009). In general, public awareness can be thought as moderate.

Cross-sectoral cooperation is on relatively low level; relationships between state administration on the environment and nature conservation and agriculture and forestry are antagonistic; collaboration with water management administration is more-less declarative. NGOs usually take critical attitudes to presently applied resource management, and fruitful collaboration with state administration is not obvious. Low level of awareness in cross-sectoral cooperation substantially limits progress in this area. Various initiatives of awareness increase have been launched, but the transfer to practice is obviously limited by insufficient sources.

**Adaptation measures**

As presented above, the current legal documents do not directly address the issue of forest adaptation to climate change. From the defined forest management systems, the special purpose cut can be considered to be an adaptive forest management measure per se, since its aim is to increase the ecological stability of forests (Regulation 453/2006). National Forest Programme (NFORESTPORTAL 2008) published in 2007 (National Forest Programme 2007) included climate change in Strategic Objective 2: Improvement and protection of the environment under
Priority 4: To mitigate consequences of climate change and to support adaptation of forests to impacts of climate change. Although NFORESTPORTAL 2008 considers the expected climate change to be one of the most serious threats to sustainable development with adverse impacts on the environment, it does not specify any adaptive forest management strategies. NFORESTPORTAL 2008 only recommends the adaptation of present forest management, identifies available funding, and emphasizes the importance of proper usage forest genetic resources. The main problem of adaptive forest management is that the stands should suit not only the future expected climate but also the current climate (Broadmeadow and Ray 2005).

Management systems

First broader proposals of adaptive measures for Slovakia can be found in the research report of Minďáš and Lapin (1996), Čaboun et al. (2008) and Hlásny et al. (2009), who addressed an array of impact of climate change on Slovak forests and options for adaptation. The authors suggested applying finer forms of management systems, particularly small-scale shelterwood and both forms of selection systems in order to create structurally diversified forest stands that are considered to be more stable and more flexible to anticipated changes. The reports suggested increase of the share of close-to-nature forest management because of its long-term sustainability that results in the forests that are stable, healthy and able to fulfil a range of forest functions (Čaboun et al. 2008). The practices that minimally disturb, replace or maintain the original forest structure are most likely to be sustainable in the long-term (Sajwaj et al. 2008).

From the scientific point of view, selection forest management system represents the most close-to-nature system (Saniga 2008). According to Čaboun et al. (2008), selection management system can be applied at more than 18% of forested area of Slovakia, although currently its proportion is only 3%. It is considered to be the best and the most stable system for protective forests and multifunctional forest management. However, Saniga (2008) points out that its efficient application is restricted to coniferous and mixed broadleaved-coniferous forests of montane and subalpine areas of Slovakia. Most commonly it is applied in the natural forests of shade-tolerant tree species, particularly silver fir and Norway spruce with beech admixture (Saniga 2008).

For broadleaved tree species, the small-scale form of the shelterwood system is the most suitable system that also respects ecological and economic requirements on forest management (Saniga 2008). Under the expected climate change, Čaboun et al. (2008) suggests applying this system particularly in oak and beech forest stands in the colline belt, while the main aim should be to achieve and/or to maintain two- or more storied mixed forests. The stability of spruce, beech and mixed forest stands was also found to increase by applying the method of future crop trees.

Tree species composition

Continuous change of current tree species composition is a main tool of adaptive management. Such change needs to be approached separately at lower (drought induced) and upper (temperature induced) distributional limit of zonal tree species; while management near the lower limit should aim at increasing forest drought tolerance; and management near the upper limit should aim at taking benefit of prolonged vegetation season, increased nutrient input, etc.

The change in tree species composition will be particularly needed in the regions situated near the lower ecological limit of the current main tree species. The measures should focus on the increase in the share of drought tolerant species, and reduction of the share of water demanding, mechanically and biotically vulnerable species such as Norway spruce. Change of species composition should also result in the increase of species, genetic and structural diversity to support the inherent adaptive capacity of stands.
Climatic sensitivity of beech has been reported by various authors. Projections and observations imply drought induced decline of beech, which can be followed by biotic damage (Mátyás et al. 2010) resulting in beech mortality. Beech production was projected to decline in Central Europe at elevations up to 500 m a.s.l., while 5% of present beech stands are situated at the sites where drought induced mortality may occur (Hlásny et al. 2011a). In contrast, in some studies oaks (Quercus sp.) were found insensitive to climate change and oak-suitable climate conditions are supposed to expand to higher elevations. Thus, the increase of the share of oak species to the detriment of beech and spruce is a promising adaptation measure. Notably oak species that are currently at the northern distribution limit in the Central and Eastern Europe – Quercus pubescens, Quercus cerris, Quercus frainetto – appear to be the sound alternative for climatically exposed sites. Scattered species with similar climatic ranges similar to oaks, e.g. Fraxinus ornus, Acer campestre, Sorbus torminalis, Tilia cordata and T. argentea, have a significant potential for adaptation to changed climate; while the use of this species can also support stand diversity.

Norway spruce is expected to suffer from drought stress at lower to middle elevations, where it has been planted artificially, and thus the species should be replaced by other tree species more tolerant to drought stress. In addition, secondary biotic damage of stands growing in suboptimal sites is presently the most serious threat to spruce forests in Slovakia. Spruce forests outside their natural range are not only susceptible to drought stress, but they are also under the threat of Spruce bark beetle attack, which can have up to three generations in one growing season at these elevations (Hlásny and Turčáni 2009, Hlásny et al. 2011b). Experiments from Bavaria, Austria, Czech Republic, Poland, Serbia and Slovakia suggested Douglas fir, white fir and larch as suitable surrogate species for vulnerable spruce stands in middle to higher elevations. Mainly Douglas fir has recently received a great deal of attention because of its good production, drought tolerance, absence of insect pests and pathogens causing substantial damage, and its good soil-ameliorative effect; this implies the suitability of this species for use in adaptive changes in present species composition. European beech is considered as important surrogate species, mainly in middle to higher elevation, where beech sensitivity to drought should not hamper its use. Increase in the share of currently less abundant species, such as Black walnut (Juglans nigra), may increase adaptive capacity of stands by supporting biodiversity.

An absolutely paramount adaptation measure concerning species composition is the reduction of secondary spruce forests at elevations below 800 m above sea level, and their replacement with mixed and broadleaved forests. Conversion of such stands is however rather slow due to the fact that nowadays the price of spruce timber is high, and it is problematic to find market for other species. To cope with this, activities focusing on the increase of awareness of all stakeholders, and broader public discussion are needed to pay more attention to the unsustainability of management in unstable secondary spruce forests (Hlásny et al. 2013) in Central Europe. An important presumption is that despite a global increase of bark beetle activity, the pest preferentially attacks trees older than 60 years, what provides opportunity to use Norway spruce with short rotation. In fact, 40-60 year-old stands in the vicinity of the outbreaks occurring in older stands at elevations below 400-500 m a.s.l. were heavily damaged by bark beetles in the Czech Republic in 2009, thus this presumption may have to be reconsidered in the future. Spruce could be preserved below 800 m a.s.l. in the commercial forests with sufficient water supply, but the management must dynamically respond to potential changes in climate and related forest disturbances. Recent spruce decline regions in the northern and eastern Slovakia (Hlásny and Sitková 2010) (transboundary SK-CZ-PL region), which were subjected to long-term air pollution and commercial overuse in the past, must receive an increased attention, and their radical conversion to more stable ecosystems must start immediately.
Scots pine and Austrian black pine, which used to be planted at the sites of former coppice oak stands at lower altitudes, should be used with caution due to increasing occurrence of their damage by *Sphaeropsis* and *Dothistroma* (Diplodia). Despite the fact that black locust (*Robinia pseudoacacia*) is sometimes considered in forest adaptation, it should be treated cautiously. The species has remarkable climatic tolerance and outstanding regeneration capacity. It should be able to maintain forest canopy and while appropriate cultivars are available, to produce valuable timber. Several other properties raise concerns about it for both ecological and economical reasons. First of all, it is probably the most invasive tree species in Central-Eastern Europe. Its aggressive expansion, exceptional regeneration by sprouting and strong allelopathy suppressing other tree species makes this species a serious threat to the integrity of native forest ecosystems. Once established, it expands at the expense of economically more valuable trees of oak-dominated woodlands. With its tendency towards strong dominance and suppressing of other tree species, hardly any other management alternative exists than recurrent coppicing in the long-term.

**Forest regeneration**

Natural regeneration of forests should be fostered because it enables natural selection of those individuals which are most vital, and best adapted to local site and climate conditions. In case planting has to be applied, the selection of provenances suitable for particular site conditions should be performed a priori. Combined natural and artificial regeneration (so called enrichment planting) proposed by Lindner et al. (2008) also seems to be a suitable adaptation measure as it can positively increase genetic diversity of forest stands and hence its inherent adaptive capacity. Enrichment as well as underplanting are useful measures to change tree species composition, forest structure and forest conditions to adequate state (Čaboun et al. 2008).

In some regions, specific game management methods should be applied to reduce the limited success of natural regeneration because of overpopulated game that has recently become an important factor in Europe. This mainly concerns reforestation after large-scale calamity events (windthrows, fire, etc.)

In Slovakia, certified stands for seed collection represent common sources of reproductive material. Climate change, however, represents a risk of loss of these sources, hence measures are needed to preserve valuable gene pools. Ex-situ sources, i.e. seed orchards and seed stands, should be used and established at sites with suitable site and micro-climate conditions even from the long term perspective to conserve the natural genetic diversity. The ex-situ network of seed orchards and generative reproductive plantations should be extended. Progeny tests are necessary to improve our knowledge about climatic tolerance of forest tree species.

**Tending, thinning, harvesting**

Adaptive measures related to silviculture should aim at reducing the impact of disturbance agents via the change of species composition and increasing static stability of forest stands. Thinning treatments should be diversified with regard to the exposure to biotic disturbances. This means that in the regions with higher activity of biotic pests the treatments should be less intense than in those with a low risk of biotic damage. However, such a type of management can have negative impact on static stability of forest stands, which can increase the risk of abiotic disturbances. Due to this, a balance between biotic and abiotic impacts with regard to applied treatments must be sought. From this perspective, the use of models for stand hazard rating seems to be useful to guide this process. The same principle holds for harvesting operations. When necessary, thinning treatments should also aim at excluding undesirable tree species, e.g. invasive tree species like black locust and keeping their expansion under control.
In beech dominated forest stands, thinning from above seems to be the best alternative (Čaboun et al. 2008). Positive selection from above is optimal, because this approach promotes stronger individuals with big symmetric crowns that form the frame of the whole stand. Hence, positive thinning from above efficiently increases the stability of forests which is crucial under the conditions of climate change since it is expected that the amount of incidental felling will increase.

Harvesting operations should be performed in such a way that the susceptibility of forest stands to disturbance agents will not be increased. The main condition is to eliminate activities that create open forest stand edges which are exposed to prevailing wind or strong direct sunlight, mainly in Norway spruce forests. The size of regenerated elements should be kept small. The interventions should emulate natural dynamics of forest stands.

It is suggested to reduce rotation period and prolong regeneration period to increase the flexibility of forest adaptation; reduction of rotation period should however be applied only for the species, the vulnerability of which increases with age. For example, Kulla et al. (2012) suggest that the increase of the present rotation period of oaks can be beneficial from the view of timber production and this profit is not compromised by increase in risk of damage.

Reduction of rotation periods should reduce the risk of forest damage by episodic events such as windthrows and forest fires, and reduce the extent of age classes susceptible to biotic or abiotic damage. At the same time, this kind of reduction allows more flexible forest management in the period of climate changes that outpace the inherent adaptive mechanisms of species. This measure is applicable mainly in coniferous stands at middle to higher elevations.

In addition, anticipated increase in the production of mountainous forests could allow for reaching the dimensions of mature stands at lower ages, thus shortened rotation along with improved growth could partly compensate the losses in forest production at lower to middle elevations due to drought.

**Forest protection**

The following measures are recommended to support the rule of forest protection in the adaptive forest management:

- Develop, test and implement new methods of forest protection, including biological control, to increase the efficiency of presently applied measures
- As pests and pathogens need to be thought of as critical climate change driven agents in forests, increased funding is needed to support and enhance the present systems of forests protection including personell, infrastructure, legislation
- Improve the national monitoring programs and integrate them into supranational or European schemes, which should focus on newly emerging species and changes in population dynamics, virulence
- Focus on regions where drought stress could induce changes in the dynamics, distribution, food preferences, etc. of pests and pathogens
- Pay increased attention to species which have been of marginal importance and for which some evidences of their increasing importance exist. For example, Larix decidua and Pinus cembra, which had been considered as pest free tree species, have been recently heavily attacked by Ips cembrae, Pityogenes chalcographus and Ips amitinus; these attacks resulted in degradation of some mountainous forests. Increased attention needs to be paid to Ips duplicatus and Taphrorychus bicolor for which the evidences on substantial damage to forest exist.
- Important factor, which has been recently observed, is the change of food preferences of some species, such as above mentioned bark beetles on Larix decidua and Pinus cembra; or Lymantria dispar on beech.
- Account for the risks associated with the expansion of new fungal agents and changed dominance of the existing ones. Climate-related stresses combined
with continuing acidification and eutrophication of forest soils, are mentioned as predisposing factors of gradually more serious problems with Armillaria sp., Phytophthora sp. needle blights caused by Sphaeropsis and Dothistroma (Diplodia), Chalara fraxinea, etc.

- Control of invasive tree species to prevent their further expansion under warmer and drier climate, should be strengthened. In the southern parts and at lower elevations of Central and Eastern Europe, several invasive tree and shrub species spread at the expense of native forest ecosystems. Although it may not be viewed as core forestry activity, control of Robinia pseudoacacia, Negundo aceroides and Fraxinus species coming from North-America is to be done for ecology, landscape but obviously also economical reasons.

- Increased attention should be paid to continuous education and awareness increase of employees of Forest Protection Service, who are the first experts that have to cope with newly emerging species or changes in population dynamics and virulence of resident species.

**Conservation**

The applicability of adaptive measures needs to reflect the conservation status of forests. While in managed forests adaptive measures may be more intense, e.g. by planting suitable tree species, in protected areas stress should be laid on the inherent adaptive mechanisms of species and communities. Generally, nature protection will be strongly influenced by climate change and can follow one of the directions:

- to leave the protected areas to self-development and self-regulation, i.e. passive nature protection is applied,
- to conserve the actual status of forests by various interventions, i.e. active nature protection is applied,
- to transform forest stands, or ecosystems in order to minimise the losses of biological diversity by creating corridors and stepping stones for species migration and expansion.

Enhancement of present forest monitoring systems should receive increased importance in the period of environmental changes, especially in protected forests with limits on active adaptation through forest management. This measure takes special importance in forests under the highest level of conservation, where present legislation implies no-management regime. We recommend adopting the following measures to support the adaptive capacity of protected forests:

- Improvement of present institutional, national and European systems of forest monitoring, with special emphasis on monitoring of pests and pathogens, and adverse effects of drought.
- Development of strategies for disseminating the information on processes in protected forests under no-management regime to secure the information transfer to broader public, scientists, decision- and policy-makers to promote the value of these ecosystems, ecological and social assets of supporting no-management regime under changing climate, as well as pointing out the threats (climate change related and others) to these ecosystems. The later point can also provide a basis for broad discussion on re-considering the present no-management regimes, if some ecosystems or processes may become critically vulnerable, and human assistance may support their persistence or adaptation.

Though forest monitoring and information dissemination cannot be thought of as direct adaptation measure, knowledge on ecosystems responses to changing climate and increasing awareness of all stakeholders are critical presumption for taking any measure.
Other adaptation measures and supportive activities

Landscape scale measures should support the connectivity of ecosystems, mainly in the directions of lower climatic variability, to support the natural migration and enhance species and genetic diversity. Forest fragmentation at landscape scale should be avoided, and large-scale forested areas should be preserved. These measures should promote the natural migration of species that can enhance species adaptive response and genetic diversity.

Potential measures in infrastructure include the improvement of forest road network. Due to higher risk of disturbances in future, it will be necessary to ensure operational management even in nowadays inaccessible sites. Increased density and better quality of forest roads will also stimulate small-scale management which can subsequently reduce overharvesting in currently accessible locations. However, this measure has to be applied with caution, since there is strong evidence that compressed soil on forest slopes is one of the main reasons for floods and droughts, drying up of watercourses and forest areas, and decreasing groundwater levels (Vaľo 2013). This author suggests reclaiming forest roads that have not been used for a long time, as well as logging tracks and forest ground degraded by heavy machinery, as soon as possible after completed logging.

As already stated, continual forest monitoring represents an important part of adaptation management. It is required in order to obtain feedback on applied measures, and to detect any negative trends in forest development early enough so that the management can be promptly adapted to current conditions. The following measures are suggested to improve the present forest monitoring schemes and programmes and to provide better support to forest adaptation to climate change:

- Improvement of present institutional, national and European systems of forest monitoring, with emphasis on monitoring of pests and pathogens, and adverse effects of drought. Mainly present crisis in the financing of European forest monitoring may negatively affect the availability of continuous and consistent time series of forest status indicators, which have potential to reveal forest responses to changing environment on national to European scales.
- Since field monitoring is time and cost-demanding, integrated monitoring schemes based on terrestrial data and readily available remote sensing data should be developed and used to provide consistent information on changes in forest cover and changes in tree physiological performance indicating the effect of stress factors.
- Increased attention should be paid to monitoring of forest status and development in regions exposed to non-climatic stress, such as air pollution, soil deterioration, etc. which may act complementary to climate change. The need for consistent knowledge on processes in such regions may be critical for hazard rating and adaptation.
- Increased attention should be paid to collecting information on forest disturbances through accidental felling data. System for data collection, their keeping and further statistical processing should be optimized to make reliable national data on forest disturbances on annual basis available
- Increased attention should be paid to statistical evaluation of forest monitoring data in relation to climate factors, and to the transfer of this information to decisions- and policy-makers to provide them with adequate support for taking efficient decisions concerning needs for forest adaptation to climate change.
Conclusion

The current forestry legal documents of Slovakia (Act on Forests No.326/2005, Regulation 453/2006) do not directly address the issue of forest adaptation to climate change. National Forest Programme (NFORESTPORTAL 2008) published in 2007 included climate change in Strategic Objective 2: Improvement and protection of the environment under Priority 4: To mitigate consequences of climate change and to support adaptation of forests to impacts of climate change. Although NFORESTPORTAL 2008 considers the expected climate change to be one of the most serious threats to sustainable development with adverse impacts on the environment, it does not specify any adaptive forest management strategies. NFORESTPORTAL 2008 only recommends the adaptation of present forest management, identifies available funding, and emphasizes the importance of proper usage of forest genetic resources.

Research aimed at studying the impact of climate change on Slovak forests and the options for their adaptation has been on-going since the end of the last century. Several broader proposals of adaptive measures for Slovakia can be found in the research reports of Minďáš and Lapin (1996), Čaboun et al. (2008), Hlásny et al. (2009) etc. Several national EU funded and national projects focusing on climate change adaptation are on-going now, and the capacity of researchers to join international research consortia is increasing. However, the transfer of knowledge from research to forest management is generally unsatisfactory. In general, practitioners usually face and try to solve the consequences of the on-going changes of forests caused by a complex of factors, which may be induced by climate change. Hence, they do not deal with climate adaptation separately. The application of suggested adaptation measures in practice is performed via forest management plans, which prescribe specific management measures in individual stands. These measures should already encompass the issue of climate change as they are based on the methodology prepared by the research organisation National Forest Centre, who attempt to transfer and promote the application of the newest scientific results to practice by their inclusion in the methodology of forest management planning.

Nowadays, the strongest emphasis is paid to the reconstruction of vulnerable secondary spruce forests, where the efforts towards more natural species composition and more diverse forest structure can be thought of as important part of adaptive forest management. Generally, forest conversion does not keep up with forest decline, and large scale deforestations occur at a national scale.

Cross-sectoral cooperation is on relatively low level; relationships between state administration on the environment and nature conservation and agriculture and forestry are antagonistic; collaboration with water management administration is more-less declarative. NGOs usually take critical attitudes to presently applied resource management, and fruitful collaboration with state administration is not obvious. Low level of awareness in cross-sectoral cooperation substantially limits progress in this area. Public, decision and policy-makers awareness can be thought of as moderate. Various initiatives of awareness increase have been started, but the transfer to practice is obviously limited by insufficient sources.
5.3.3.2. Poland

In Poland, several key legal documents were introduced or amended over the past two decades (Pogorzelski 2010). The documents supporting pro-climatic activities are: the Forest Act (1991), the State Forest Policy (1997), National Program for the Forest Area Enlargement (1995), as well as the internal regulations of State Forests - National Forest Holding (NFH), in particular Order #11 (1995). All these policy and legislation documents promote ecological values in forest management. They also emphasize the need for the balance between the economic demands and multiple functions that forest ecosystems provide to society, including environmental and social functions. A good example is Article 8 of the Forest Act, an overarching legislation document; it explicitly names the principles that guide country’s forest managers. The four principles are: to protect all national forests, to maintain and manage forest resources sustainably, and to continuously enlarge the forest area (Pogorzelski 2010).

Following the regulation from 28-09-1991 (Dz.U. 1991 Nr. 101 poz. 444), sustainable forest management is conducted according to a forest management plan or a simplified forest management plan by taking the following points into consideration:

- to preserve forests and its effect on climate, air, water, living conditions and human health and on natural environmental balance.
- to protect forests and ecosystems comprising natural fragments of forests that are especially important for:
  - biodiversity conservation
  - conservation of forest genetic resources
  - landscape values
  - scientific needs
  - conservation of soils and areas especially exposed to danger from environmental pollution or damages and with special social status.
  - protection of surface and ground water sources, protection of retention especially in the areas of ground water supply.
  - production with rational forest economy, wood and non-wooded forest products.

Some problems result from the structure of forest ownership in the Polish Carpathians. In the Carpathians the share of private forests is substantially larger when compared to the whole country average, and equals about 30.8 percent, thus the share of the state and municipal forests is 69.2 percent. Forest management plans are prepared for State Forests, while a lot of private owned forests do not have actual if any forest management plans. This seems to be one of the most important difficulties for the coordinated adaptation of forests to climate change at the scale of the Polish Carpathians.

Awareness issues and cross-sectoral cooperation

Activities to restore forest productivity potential weakened by natural disasters are directly financed by EU EFRROW fund. The objectives of the post-disturbance ecosystem productivity restoration activities are:
- to revive damaged stands of all age classes and precious forest nature sites.
- to prepare forest seeding material.
- to integrate fire prevention systems in forested areas.

The program is implemented in two schemes:

- Restoration efforts undertaken in the areas affected by natural disasters. The areas are selected by the Ministry of Environment. The implementation of
activities and restoration of destroyed forest potential pertains only to the forest areas damaged by natural disasters (e.g. windthrows) or biotic factors;

- Introduction of preventive measures in the areas with the highest risk of forest fire.

Project PROZA – concentrated on the multi-disciplinary use of meteorological data and numeric weather prognosis on the area of Poland. This project started in 2009 and it is currently in progress. There are four main tasks:

- Task 1 – Development of operational system of weather forecast
- Task 2 – Development of expert systems for energy industry
- Task 3 – Use of the results of numerical weather forecasts in forestry and fruit farming
- Task 4 – Use of the results of atmosphere and ocean modeling in transport and engineering

Project ISOK – A Computer System Country Protection – the main purpose of this project is to protect the territory of Poland before floods, however much more environmental aspects are also taken into consideration. This project started in 2010 and it is in progress. The main aim of the project is to develop maps of flood risk, maps of meteorological and other threats and the hydrological map of Poland. These products should be shared with the society. The products should mainly improve crisis management in the case of floods and generally in the case any of environmental threats. System ISOK should be open for development and it should be possible to use it in different fields. It should be possible to develop it in dependence on newly formulated expectations.

Management systems

As already stated above, the existing legal documents promote ecological values in forest management and emphasize the need for the balance between multiple functions of forest ecosystems. The above legal documents are critically important for forest practitioners especially in justifying expenses not directly contributing to economic gain. In practice, this means an increase and consolidation of the forested areas as well as the incorporation of multiple silvicultural activities that result in greater forest ecosystems resiliency (Pogorzelski 2010).

Ecosystem management options for adaptation were suggested by Brzeziecki (2008). According to Brzeziecki (2008) forest management must account for the fact that change is unavoidable. Ecosystems are the subject of continuous changes considering species composition, and population dynamics. Forest management should take this fact into consideration. Causes of changes result from inside and outside, representing human world, natural and physical environment. They are the source of large uncertainty and many surprises. Traditional forest disturbances play an important role in functioning ecosystems and therefore should be also considered as a part of natural processes. Ecosystem management should have adaptive character in order to predict and use such changes. It is important to maintain caution in taking decisions, which exclude some options of possible course of events. However, nowadays decisions aiming at mitigating the effects of long-term changes resulting from climate changes should be taken. According to the rules accepted in ZHL (2012):

- Dispersion risk in forest management should be attained by the use of possibly large number of tree species adapted to local site conditions.
- Schematism should be avoided.
- Conversion of the stands consisting of a small number of species and with a simple structure should be strengthened and promoted.
- The risk of forest management should be reduced by:
  - supporting natural regeneration everywhere, where it is possible;
• supporting forests natural processes, which favour increasing biological diversity;
• promoting dynamic character of stands – changing in time by accounting for the biological characteristics and ecological requirements of individual species;
• orientation of tending felling of the stands to stability, vitality and sustainability of stands and improvement of production quality;
• preferring tree species and individuals with adaptive ability to changing site and climate conditions.

In the Polish Carpathians selection management system is applied on 16.1 % of forested area (NFI Report 2011). Possibility of using selection management system at a larger scale seems to be restricted by economical aspect. For example Regional Directorate of State Forests in Krosno, with relatively large share of selection (17.6) and small scale shelterwood (64.0 %) system needs to be supported by central funds from General Directorate of State Forests. From the ecological point of view, selection system could be considered to be the most stable and close-to nature system of forest management. However, this system is recommended in Poland only for Silver Fir and mixed stands with large proportion of silver fir and montane Norway spruce stands situated at high elevations. As it was stated by Davies and Kerr (2011) the economic effect of management in complex continuous cover forestry structure is only about 34 % of the effect in clear felling, whereas economic effect in the case of simple continuous cover forest structure may attain even 98 % of economic effect with the management by clear cutting. In this context, simple continuous cover structure results from typical shelterwood and group cutting as defined in Chapter 2.1. Complex continuous cover forestry structure results from the selection management system, i.e. single tree selection cutting or selection method.

Generally, tree species composition is a critical factor in the western part of the Polish Carpathians, whereas in the Central and the southern Polish Carpathians tree species composition is relatively good adjusted to natural site conditions. Change of current tree species composition is a main challenge and a tool of adaptive management in the Western Beskidy Mountains, where Norway spruce currently dominates. This change needs to be approached particularly at the lower (drought induced) distributional limit of Norway spruce. Silver fir was due to air pollution in 70's and 80's strongly weakened and decline symptoms were observed. However, in the last decades substantial improvement of its vitality and natural regeneration of Silver fir stands was observed.

Forest regeneration

Due to the dominance of shelterwood and selection or purpose cut systems in the Polish Carpathians, natural regeneration takes place in a large share of the Polish Carpathians. This good practice was slightly worsened in the areas with large-scale Norway spruce decline in the Beskidy Mountains, where clearcutting system connected with artificial regeneration had to be applied. In the areas with the dominance of Norway spruce, a combined method of natural and artificial regeneration was used for many years especially at lower elevations. This method of regeneration seems to be the most appropriate especially for lower and middle elevations.

Considering possible changes in site conditions presented above, the certified stands for seed collection representing common sources of reproductive material should be verified. In practice these stands were selected on the base of growth characteristics and wood quality. As a result of such selection, best productive populations growing in relatively good conditions were selected as certified stands. In an era of changing climate and increasing drought events best growing populations with short crowns and large h/d ratios, do not seem to be appropriate for the production of the reproductive material for the uncertain future conditions.
Therefore, “valuable gene pools” should also be verified by making progeny tests of the adaptability of trees to changing conditions, natural immunity and resistance to illnesses and drought stress.

**Tending, thinning, harvesting**

From the experience obtained from Norway spruce stands in Poland it seems that in stands vulnerable to biotic and abiotic factors better practice is to use heavy thinning starting from first stages of stand development (Zajączkowski 1991; Socha 2008). In the Beskidy Mountains, dense stands were dominated especially at lower and middle elevations. Such stands were strongly exposed to drought stress which was one of the most important factors causing fast spruce decline in the middle of the first decade of XXI century (Bruchwald, Dmyterko 2010; Hlásny, Sitková 2010). According to Gebhardt et al. (2012), thinnings reduce stress from drought, at least for some years, but long- term effects and the impact of long droughts have to be clarified by further measurements. However, thinnings might be one of the rare silvicultural options for the adaptation of young stands to climate change and for the reduction of drought- and heat-induced tree mortality.

Nitrogen inputs to the atmosphere and raising CO₂ concentrations improve growth conditions, due to which altered growth is observed across Europe. Accelerated growth of forests leads to accumulation of growing stock. This requires that prescribed cuts be raised in order to avoid forest stands with too high densities and unstable structure concerning h/d ratio. The increased growth performance should enable more flexibility regarding the length of rotation periods. In the case of selective felling methods, dominant trees will reach exploitable diameters within shorter periods of time (Wermann 1999). Therefore, reduced rotation period should be first applied to coniferous monocultures, since their vulnerability increases with age. Apart from other factors, increasing vulnerability results from the reduced plasticity of trees to changing site conditions, increasing risk of forest damage by windthrows, other abiotic and biotic factors.

**Forest protection**

According to Forest Protection Instructions (2012), in order to prevent forest decline due to the outbreaks of pests and pathogens it is necessary to:

- recognize processes of population dynamics of pests as the element of forest diseases in order to rationally interfere into forest ecosystems using appropriate prophylactic and rescue methods.
- improve the methods of environmental assessment and the level of hazard by:
  - preparing appropriate short- and long-term prognoses concerning the outbreaks of harmful insects;
  - inventory of losses caused by insects
  - periodic large scale inventory in order to assess health and sanitary state of forests;
  - initiating biological monitoring of insects
- increase biological resilience of forests to harmful insects by:
  - the enrichment of biological diversity using biocenotic admixtures;
  - protecting forest vegetation cover and other elements of forest biocenosis;
  - using natural regeneration;
  - continuous conversion of coniferous monocultures, which are in many cases centers of gradations;
  - using complex methods of biological forest protection in practice;
  - applying selection for natural resilience in forest silviculture
- respecting designated hygiene and prevention in forest silviculture, forest utilization and forest management;
stop destructive processes in forest ecosystems and prepare forest ecosystems to changing environment.

Nature conservation

As they are constituted at present, protected areas are often not able to buffer against broad-scale shifts in the distribution of species or ecosystems, which presents us with a serious dilemma (Lee and Jetz 2008). Protected areas as such do not migrate, even though some of their components (species) do, either within the area or outside it, nor can they be moved (Heywood and Culham 2009). Even assuming that viable ecological assemblages are established in the areas into which migration has taken place, in many cases they will no longer have any protection status, so that the whole legal, social, political, scientific and financial process of reserve establishment will have to be initiated again (Heywood and Culham 2009).

In addressing the likely consequences of climate change both mitigation and adaptation strategies are essential elements of our response but the main conservation strategies are concerned with planned adaptation. The main planned adaptation options that have been proposed are to (Heywood and Culham 2009):

- Reinforce, enhance and expand the existing protected area systems
- Strengthen measures for biodiversity conservation outside formally protected areas
- Ensure that there is as a wide a representation as possible of the genetic variation in the populations of target species in protected areas
- Facilitate the possibility of gene flow through the populations of species
- Increase the implementation of in situ conservation at the species level through conservation management/recovery plans
- Inter situs conservation/re-introduction of species
- Strengthen ex situ approaches such as seed banks, botanic gardens
- Habitat rehabilitation

In addition, some more innovative approaches such as plant micro-reserves and human assisted migration and the adoption of a bioregional or landscape approach have been proposed.

Other adaptation measures and supportive activities

Water retention and hydrological balance enhancement program was established by the Polish State Forests at the end of the last century (Pogorzelski 2010). The program aims to restore degraded and drained peat lands, increase water retention potential of damaged peat soils and to counteract floods and droughts in forest ecosystems. It involves hundreds of individual country-wide projects run by forest districts annually. Improving hydrologic conditions and stabilizing groundwater levels leads to healthier ecosystems, greater vitality and resilience of forests, and increased forest production which could also be associated with increased carbon sequestration levels. Restoration of rare wet and boggy sites reduces water stress at a national scale, improves fire resistance of ecosystems and increases the productivity of agriculture and forestry. Restoration and maintenance of peat lands result directly in a) reduced greenhouse gas emissions and b) increased carbon storage. All hydrological activities in forests comply with Polish Water Law and other regulations (Pogorzelski 2010).
Conclusion

In Poland, several key legal documents were introduced or amended over the past two decades (Pogorzelski 2010). The documents supporting pro-climatic activities are: the Forest Act (1991), the State Forest Policy (1997), National Program for the Forest Area Enlargement (1995), as well as the internal regulations of State Forests - National Forest Holding (NFH), in particular Order #11 (1995). All these policy and legislation documents promote ecological values in forest management. They also emphasize the need for the balance between the economic demands and multiple functions that forest ecosystems provide to society, including environmental and social functions. A good example is Article 8 of the Forest Act, an overarching legislation document; it explicitly names the principles that guide country’s forest managers. The four principles are: to protect all national forests, to maintain and manage forest resources sustainably, and to continuously enlarge forest area (Pogorzelski 2010). In practice, this means an increase and consolidation of the forested areas as well as incorporation of multiple silvicultural activities that result in greater forest ecosystems resiliency (Pogorzelski 2010). Hence, adaptation to climate change is primarily made indirectly by promoting ecological values in forest management.

Ecological values in forest management are promoted by:

- Establishing more resilient stands by adjusting species composition;
- Continual conversion of coniferous monocultures;
- Establishing multi-layered, uneven-aged stands by applying shelterwood, special purpose and selection management systems instead of clearcutting (in the Polish Carpathians, clearcutting system is reduced to below 1%);
- Enrichment of biological diversity using biocenotic admixtures;
- Promoting natural regeneration;
- Using complex methods of biological forest protection;
- Respecting designated hygiene and prevention in forest silviculture, forest utilization and forest management.

There are no economic problems with the introduction of adaptive measures to climate change in Poland, and sufficient national funding is available. A more problematic issue is considering climate change as an important issue. Nevertheless, applied actions aimed at strengthening the ecological values of forests should be able to meet climate change adaptation needs.
5.3.3.3. Romania

The Forest Code (Law no. 46/2008) stipulates main characteristics of Romanian forest management: functional groups, maintenance of natural species composition in forests, utilization of natural regeneration, maintenance of high-level rotation age for native forest species, utilization of adequate treatments to maintain the ecological balance, evolution towards multi-use forests. According to the present forest regulations (Law no. 46/2008), two kinds of forests are distinguished in Romania:

- Functional Group I, which includes forests with special protection function for water, soil, climate and objectives of national interest, forests for recreation, forests for biodiversity protection and forests declared as national monuments and reservations;
- Functional Group II, which includes forests with production and protection functions, aiming to achieve high quality timber and other forest products, but in the same time to ensure the protection of environment.

From all Romanian forests, 54% of the forests have special protection functions and 46% have production and protection functions (Stoicescu 2006).

In Romania no specific forest management systems as presented in Chapter 1 are legally defined, although they are applied in forest planning, particularly when referring at integrated operations in the forest exploitation.

The allowable cut is calculated for each administrative unit following the traditional sustained yield approach. It takes into account rotation length, average species composition, forest structure according to site indices and the existing distribution of age classes. Rotation length is calculated according to the maximum rent principle, and has been set according to the average increment of the target dimensional class, reflecting a very conservative policy (WWF 2005). The annual allowable cut at the country level is obtained by cumulating the allowable cut for each forest district (both state-owned and private forests), based on the data from the informational system for Romanian forests, taken from the management plans developed for all forest districts (WWF 2005).

Forest management is regarded as wide scale, regional and local. Effective management aims at optimizing specific ecosystem functions, such as economic, ecological, social and cultural functions, and ensuring them for future generations based on ensuring forest management planning (Report regarding status forests in Romania, 2010). National forest management is based on forestry regime. According to Law no. 46/2008 (Forest Code), it refers to all forests at national level. Forest regime is defined as a uniform system of technical forestry, economic and legal rules regarding spatial planning, culture, exploitation, regeneration, protection and security of national forest fund in order to ensure sustainable management of forest ecosystems, regardless the ownership. Depending on the regeneration type, three fundamental forest regimes are defined:

- High forests i.e. forests regenerated from seed following either natural or artificial regeneration. This type of regeneration uses the following regeneration cutting: successive cuttings, progressive cuttings, garden cuttings and clear cuttings. The types of cutting are specified in technical standards, such as MWFEP (2000). In Romania, this forest regime is applied at an area of about 93%, particularly in the forests of coniferous species, mixed softwood and hardwood, mixed deciduous forests, hybrid black poplar crops.
- Coppice forests (term “grove forests” is used by National Institute of Statistics in official documents) based on vegetative regeneration – forests are regenerated naturally from shoots of stumps or roots. This forest regime is typical in native poplar stands, willow, acacia, and in groves. Before the Second World War coppice forests accounted for over 30% of the forest area.
of Romania. After 1948, their proportion decreased continuously, and now they occupy only 3% of the country forests. Coppice-with-standards with both generative and vegetative regeneration. Although this type of regime had occupied rather large areas in the past, after 1948 all former coppice-with-standards forests were converted to high forests. At present, such forests occupy 4% of the country’s forests. Sometimes, coppice-with-standards is considered just an intermediary stage between the first two states.

Following the Forestry Code high-forest regime is to be promoted to ensure sustainable forests. The coppice regime is allowed only in poplar and willow forests (Borlea 1998).

At a local level, management of national forests (both state and private forests) is established through forest management plans. Forest management plans are multidisciplinary scientific works that comprise a system of indicators and measures for the organization and management of forests in order to fulfill the appropriate socio-economic and ecological functions. They are elaborated at the level of forest districts (Law no. 46/2008). For most of the forests, forest management plans are valid 10 years. In case of fast-growing species like poplar, and willow, the plans are valid from 5 to 10 years. Every 10 years, the situation of forestry fund is assessed based on management measures implemented during last 10 years. Forest management plans should follow four fundamental principles:

- the principle of the sustainability of wood production and hence, of harvests (to ensure such management conditions and use of forest ecosystems that maintain biodiversity, productivity, regeneration capacity, vitality, health and hence, ensure present and future capacity of forests to perform multiple ecological, economic and social functions);
- functional effectiveness principle (with the aim to increase production capacity and protection of forests, making the best use of forest "products", ensuring timber production continuity on short term (10 years) and on medium term (40-50 years);
- the principle of ensuring the conservation and enhancement of biodiversity;
- economic principle.

According to Borlea (2008), the main goal of present-day management plans is to achieve natural tree species composition. Following Law no. 46/2008, the approved forest management plans are also a part of the management plans for PAs (Protected Areas) if the forests are included in PAs. An important aspect in forest management is the level of detail – stand or subplot as an elementary unit for forest management. The stand represents a homogeneous area from the structural, functional, and ownership points of view. In general, it is up to 0.25 ha (Bozga et al. 2009).

The four above-mentioned forestry tools are aimed at sustainable management of forest resources and promoting fundamental natural forest types. In accordance with sustainable management principles established in the Forest Code (Law no. 46/2008 with subsequent amendments), forest management:

- promotes practices that ensures sustainable forest management;
- ensures the integrity of forest fund and forest permanence;
- increases forests areas;
- stabilises long-term forestry policies;
- ensures continuity of adequate legal, institutional and operational forest management;
- promotes environmental objectives of forestry;
- increases the role of forestry in rural development;
- promotes fundamental natural type of forest and biological diversity of the forest;
harmonizes relations between forestry and other fields;
- supports forest owners and stimulates their association;
- prevents irreversible degradation of forests due to human activities and destabilizing environmental factors.

The long-term continuity of wood vegetation can be achieved either by natural regeneration through long-term treatments or artificial planting on the lands, where cuts were applied or on the lands without forest vegetation. Romania uses silvicultural systems based on natural regeneration (61,000 ha/year) and clearcutting (maximum 3 ha) usually followed by artificial regeneration (5,500 ha/year). The total surface area that is reforested artificially is between 10,000 and 16,000 ha/year. Over the last 10 years, natural regeneration treatments have increased. Logging activity should not damage the forest ecosystem beyond a certain limit (although the Forestry Code/1996 does not clearly specify this limit). Natural regeneration or forestation of these areas needs to be secured within a maximum of two years, while the seed and planting stock used in forestry must be certified. The health of forests must be assessed annually (Borlea, 1998).

A major problem affecting forest management is forest restitution to private owners. In 2011, state public ownership (including public ownership of administrative – territorial units) was about 63.2%. This represents 6.6% decrease in comparison to 2008 and 16.4% decrease in comparison to 2005 (World bank, 2012, Report regarding forest status in Romania, 2005, 2008). Knot et al. (2012) presented the main problems after the restitution to new forest owners:

- Most of the restituted forests are immediately cleared to gain short-term profits.
- New forest owners often lack the capacity and the knowledge of sustainable forest management, sustainable harvesting principles (UNDP, 2004), nature conservation principles and legislation.
- They often doubt the permanence of their newly gained property rights.

In consequence, widespread logging and over-harvesting has been documented after the restitution laws in 1991 (Nichiforel and Schanz 2011), 2000 and 2005 (Ioras et al. 2009). Long-term goals for the state-owned forests focus on the maintenance of the integrity and development of the public forest estate; and the preservation of private forests. Ecological objectives aim at the conservation of biodiversity of natural forest types; the extension of the present-day forest area; the ecological and economic reconstruction of degraded forests; the intensification of forest protection and safeguarding activities; the provision of sustainable forests through forest management planning (Borlea 1998).

**Awareness issues and cross-sectoral cooperation**

The national framework on which awareness issues related to climate change are based or could be based consists of the following documents, which however focus on awareness issues only marginally. The first document was the National Strategy on Climate Change 2005-2007 approved by Governmental Decision no. 645/2005. This document contains detailed aspects of adaptation to climate change in several sectors: agriculture, forestry, water management, settlements. In response to the EU Green Paper “Adapting to climate change in Europe - options for EU action”, the Ministry of Environment and Forests developed the Guide on the adaptation to the climate change effects (approved by Ministerial Order no 1170/2008). The National strategy on Climate Change 2013-2020 is currently underway. The document comprises two main directions: reduction in concentration of greenhouse gases and adaptation to climate change. The adaptation component of the strategy “aims to provide an action framework and guidelines to enable each sector to develop an individual action plan in line with national strategic principles” (http://climate-
adapt.eea.europa.eu/countries/romania). Among actions regarding the “adaptation to climate change” at national level, the action referring to developing and implementing a campaign to increase the awareness of all stakeholders, and society is stated.

From the implementation point of view, a number of national and international research projects (e.g. CECILIA, for the list of projects see http://climate-adapt.eea.europa.eu/countries/romania) have been on-going and can provide underlying information on impacts and vulnerability of ecosystems to anticipated climate change. In addition, the activities aimed at increasing the society awareness of the climate change effects have been launched. During August 2010 – July 2011, Terra Mileniul III Foundation coordinated the project: Adaptation to Climate Change, in partnership with Climate Action Network – Romania. The purpose of the project was to increase the awareness about the effects of climate-change of local and national authorities by meeting non-governmental communities from Romania and Europe, and on-line communities. This project addressed the groups unfamiliar with climate change topic through brochures, photos, videos, but also national and international networks, seminars, caravan movies, websites, mass-media, and events at schools. A documentary film about climate change perception in Romania: “Plus 2 Celsius” was made in collaboration with Terra Incognita from Cluj-Napoca Association.

Another project entitled “The forest as a factor for reducing the greenhouse gases – study case Topoloveni [2012 – 2013]”, coordinated by the same organization, is under implementation in partnership with Alma-Ro Assoociation and Topoloveni UAT. The project is co-financed mostly by another project „Education for sustainable and responsible management of world’s forests”, financed by EuropeAid and implemented in 19 other cities from Romania, Malta, Italy, Spain, Poland. In this project Terra Mileniul III foundation and Alma-Ro foundation are partner organizations. The main objectives are:

- To increase the level of education and awareness of the local communities in the projects which reduce greenhouse gas emissions through management forest conservation activities.
- To increase the awareness level of local decision makers regarding the efficient use of forest resources and durable forest management.
- To increase the capacity of civil society representatives in implementing and monitoring an integrated plan of forest management.
- To increase the promotion and dissemination of good practices aiming at sustainable forest utilisation from the level of communities in Arges County to national level (http://terramileniultrei.ro).

Adaptation measures

Governmental Decision no. 48/2013 regarding organization and functioning of the Ministry of Environment and Climate change states the development of following documents:

- National Forestry Strategy and Action Plan;
- National Strategy and Action Plan in Forestry;
- National Action Plan for the expansion of forest area.

These documents seems to be very similar, first two even identical and moreover, no deadline is established for preparing these documents. Adaptation measures to climate change in the forestry sector should be based on scientific research and technological progress which support the sustainable development of forests. Also, these measures should be accompanied by adequate monitoring of forest health and their development. The importance of forests, especially in the context of climate change should be well explained to all stakeholders and the public to encourage forest protection and defense.
Further, we present general information about adaptation measures to climate change according to National Strategy of Romania regarding Climate Change 2013-2020. The main indicators of adaptation to climate change are:

- forest area (percent of afforestation);
- national timber production;
- usable wood volume;
- forest health, expressed as a percentage of trees degradation (loss of foliage, fallen trees, broken trees);
- distribution of tree species in appropriate areas.

The main disturbances are related to: drought, fungi, pests, snow, wind, insects, fire, and game. The most appropriate adaptation measure to climate change is to maintain forest vegetation and to intensify reforestation. This would not only help to maintain the stability of forest ecosystems against the pressure of external factors, but would also decrease soil erosion, prevent landslides and floods, and encourage tourism. From the point of adaptation, the forests should consist of less vulnerable tree species (e.g. grey oak (*Quercus pedunculiflora*), downy oak (*Quercus pubescens*), ash (*Fraxinus*), silver lime (*Tilia tomentosa*) etc). Resistant tree species (fir (*Abies*), white fir (*Abies alba*), larch (*Larix decidua* etc)) to climate change must be particular resistant to new types of pests.

**Management systems**

To ensure the continuity and sustainability of forests and their functions, it is necessary to adopt intensive treatments that utilise natural regeneration, selective garden cuttings, or so called quasi-gardening cuttings, which are intermediary cuttings between garden and progressive cuttings used repeatedly during a longer time period, and irregular cuttings that are promoted by Pro Silva Europe.

Garden cuttings (specified in technical standards, e.g. MWFEP 2000) have the advantages from the ecological point of view by creating stands with high stability, and from the economical point of view by ensuring the existence of crops for an indefinite period. This approach is preferred to other treatments such as clear-cuttings, successive or progressive cuttings.

It is advisable to extend the application of garden cutting to forests such as spruce (*Picea abies*) stands, sessile oak (*Quercus petraea*) - beech (*Fagus sylvatica*) forests, sessile oak (*Quercus petraea*) forests, mixed broadleaved forests dominated by sessile oak, mixtures of sessile oak with other oak species, oak - mixed broadleaved forests, mixtures of pedunculate oak (*Quercus robur*) with other oak species, and the forests with production and protective functions (Duduman 2011).

**Tree species composition**

The choice of species for afforestation or stand regeneration requires special attention in order to achieve harmony between their site requirements and environmental conditions changed by global warming. In this direction, research is still needed (Giurgiu 2010). From the point of tree species composition, forests should consist of tree species less vulnerable to climate change and resistant to new types of pests. Since compositional and structural diversity is a fundamental condition for the stability of stands under the conditions of climate change, the conversion of even-aged pure forests to multi-staged mixed stands should be performed where possible. To increase the functional effectiveness of the stand, some changes are needed with regard to the composition of natural forest type by promoting valuable species (e.g. Spruce (*Picea abies*), fir (*Abies*), sessile oak (*Quercus petraea*), beech (*Fagus sylvatica*), pedunculate oak (*Quercus robur*)) in terms of economic, aesthetic and cultural value. The species can be mixed in the main layer or can create a sub-layer. Percentage of these species should not exceed 20% of stand composition.
Promoting non-native species instead of native species should be treated with caution. Their application can be recommended only after long-term experiments. In case of severe climate change, promoting of mezoxerophilous species (e.g. grey oak (*Quercus pedunculiflora*), Caucasian ash (*Fraxinus coriariaefolia*), elm (*Ulmus procera*)) should be carefully considered within the forests of sessile oak, and mixtures of sessile oak with beech. In the mixtures of beech with coniferous species the proportion of beech should be increased, while beech and fir should be promoted in spruce stands at lower altitudes, and subalpine spruce stands. Juniper and Swiss pine (*Pinus cembra*) could be used at the bottom of the Alpine area, but their utilization needs to be tested in long-term experiments (Giurgiu 2010).

Based on the experience to date, the usage of species with high potential to adapt to water and temperature stresses is recommended (Untaru 2010). Especially the following species are recommended:

- grey oak (*Quercus pedunculiflora*) and downy oak (*Quercus pubescens*) shall be incorporated in the resorts which favor the development of forest vegetation with normal soil conditions ensuring gradual transition to natural ecosystems. The establishment of such stands will improve stationary conditions by reducing the amplitude of temperature, increasing soil and air moisture, reducing wind speed, and decreasing the intensity of land degradation processes;
- ash (*Fraxinus*), which is resistant to drought and calcium carbonates shall be planted on plain land, plates and low slope, with moderate soil depth and favorable moisture regime;
- Turchestan elm (*Ulmus pumila celer*) characterized by high resistance to drought and low demands on soil may be placed on eroded soils, shallow to moderately deep, poorly to moderately humic soils, predominantly on sunny slopes;
- Silver lime (*Tillia tomentosa*) shall be planted on the land with at least moderately deep soil and favorable moisture regime.

The composition and mixing schemes (species proportion, arrangement and combination of species) will be established by accounting for the biological characteristics of the species and the role they are to perform.

Fir, due to its morphological-physiological peculiarities, is a supporting species of complex biodiversity and poses no significant hazard to harmful biotic gradations / insect invasions that are more common in other stands of coniferous species (spruce (*Picea abies*), pine (*Pinus*), larch (*Larix*)). Thus, this tree species is required for maintaining the stability against the pressure of external factors, maintaining biodiversity, and increasing the amount of sequestered CO2 of mixed natural forest ecosystems. Only complex compositional diversity can actually meet the challenges of unpredictable climate change. Preferential extraction and wasteful use of fir trees generates several problems such as:

- reduction of compositional diversity of natural forests resulting in increased vulnerability to the pressure of external factors (windthrow, snowbreakage, insect invasions, etc.)
- changing the structure of forest ecosystems with implications for biodiversity;
- reducing the amount of CO2 sequestered in the forests of the Carpathian mixture, because fir trees have greater dimensions, and consequently biomass production;
- decrease of the landscape / recreational forest value.

Climatic sensitivity of beech has been reported by various authors (Linder et al. 2008, Bolte et al. 2009). Projections and observations imply drought induced decline of beech, which can be followed by biotic damage (Mátyás et al. 2010) resulting in beech mortality. In contrast, in some studies (Lindner et al. 2008) oaks (*Quercus sp.*) were found insensitive to climate change and oak-suitable climate
conditions are supposed to expand to higher elevations. Thus the increase of the share of oak species at the expense of beech and spruce is a promising adaptation measure. European beech (*Fagus sylvatica*) is considered an important surrogate species mainly in middle to higher elevations, where beech sensitivity to drought should not hamper its growth. Increase in the share of currently less abundant species, such as Black walnut (*Juglans nigra*), may increase the adaptive capacity of the stands by supporting biodiversity.

Norway spruce is expected to suffer from the drought stress at lower to middle altitudes, where it was planted artificially. Thus, the species should be replaced by other tree species that are more tolerant to drought stress. Spruce forests outside their natural range are not only susceptible to drought stress, but they are also under the threat of Spruce bark beetle attack, which can have up to three generations in one growing season at altitudes of 650 -1700 m) (Hlášny and Turčáni 2009, Hlášny et al. 2011b). Experiments from Bavaria, Austria, the Czech Republic, Poland, Serbia and Slovakia suggested Douglas fir (*Pseudotsuga menziesii*), white fir (*Abies Alba*) and larch (*Larix decidua*) as suitable surrogate species for vulnerable spruce stands in middle to higher elevations. Within the regions characterized by small-scale variations of site factors (mosaic arrangement of microsites, especially depending on slope and aspect), it is advised to plant seedlings of various forest species in groups. At homogeneous sites, the mixtures can be regularly alternated in rows or bands.

The application of technical solutions for the establishment of forest crops results in the following (Untaru, 2010):

- using a large number of species, i.e. creating mixtures of grey oak (*Quercus pedunculiflora*) and downy oak (*Quercus pubescens*), ash (*Fraxinus*), Turkestan elm (*Ulmus pumila celer*), Silver lime (*Tilia tomentosa*) and shrubs (hawthorn (*Crataegus monogyna*), horn (*Cornus mas*), lilac (*Syringa vulgaris*), while respecting their requirements for ecological factors, is likely to lead to increased biodiversity, resistance to biotic and abiotic pests factors and thus to increased stability and functional efficiency of future stands;
- avoiding planting in rigid arrangements and placing the species with regard to micro-site conditions allows better use of their productive potential;
- in addition to careful composition and cultivation technology at the time of forest establishment, success and proper development of young forest stands requires special attention to maintenance and guarding and protecting crops against various harmful factors;
- using healthy seedlings of the highest quality (i.e. vigorous and suitable with well developed root system raised in polythene bags or other containers) in most difficult site conditions improves the success of works and efficiency of established crops.

Planting species that will benefit from the new environmental conditions and will achieve higher total biomass accumulation throughout the production cycle (e.g. beech at higher altitudes, for which biomass accumulation may reach 30-40% surplus or oak that can have a greater biomass accumulation by 10-20%, etc.) is also a measure of adaptation to new climatic conditions.

**Forest regeneration**

The choice of species for afforestation or stand regeneration requires special attention to achievement of harmony between their site requirements and environmental conditions changed by global warming. In this direction, research is still needed (Giurgiu, 2010). In general, natural regeneration of forests enables natural selection of those individuals which are most vital and best adapted to local site and climate conditions, and thus, should be fostered. In case planting has to be applied, the selection of provenances suitable for particular site conditions should be performed a priori. Combined natural and artificial regeneration proposed by
Lindner et al. (2008) also seems to be a suitable adaptation measure as it can positively increase genetic diversity of forest stands and hence its inherent adaptive capacity. Valuable natural species (oak (*Quercus robur*), beech (*Fagus sylvatica*) maple (*Acer campestre*), lime (*Tilia*)) should be promoted depending on the site, avoiding the plantations of conifers and other species at the sites appropriate for oak (*Quercus robur*) forests, except for improving degraded lands or for landscape interests. It is forbidden, however, to plant poplars and acacias at sites suitable for oak species.

Care and treatments of a newly established forest is carried out following forest continuity principle by installing and maintaining forest vegetation, promoting composition and mixture schemes, and using establishment technologies of plantations according to the specific technical rules. Compositional and mixture schemes (proportion, arrangement and combination of species) shall account for the biological characteristics of the species and the role which they have to fulfill (Untaru, 2010).

Romanian foresters have a long experience with promoting natural regeneration. The forestry methods with shelter regeneration were first used in the second half of the 19th century. Depending on the complex way to intervene in the forest structure, the Romanian forestry defines three fundamental regeneration forms:

- Shelter regeneration in high forests performed with uniform and slow thinnings distributed in the periodic block in rows, aiming at installing and developing the new generation in a uniform and slow way, too.
- Shelter regeneration in high forests performed with non-uniform and progressive thinning in the mature stand, aiming at installing and developing the new generation in a non-uniform way, within the time corresponding to the regeneration period. The main concern is opening of small areas in the places most favorable for the seedlings in each fructification year. These gaps are elementary plots for the regeneration process and they can have different sizes and shapes, according to the requirements of the species that should form the future stand. As the seedlings grow and develop, the gaps are progressively thinned until they connect each other when the seedlings reach the biological independence.
- Shelter regeneration in high forests based on continuous removals, characteristic for the uneven-aged stands. The mechanism for this regeneration system is characterized by the fact that it keeps the forest in the same dimensional structure, as it follows continuous exploitation-regeneration process. These interventions result in the most favorable conditions for the seedlings to install in and in the continuous integration of the existing young growths with the stand.

Application of shelter regeneration technologies and introduction of some native valuable tree species appropriate for stationary conditions by planting or direct seeding under shelter, leads to optimal recovery of the potential of degraded land, avoiding the exposure of soil to erosion or other degradation processes. Sheltered regeneration and reforestation with valuable species represents an efficient method for increasing the stability of reforested stands on the degraded land. In this way the degradation process can be stopped and the vegetation can be reinstalled. For example by stabilizing the land affected by various forms of degradation and by improving site conditions, in many forest areas proper conditions were created for the natural regeneration of a new generation. Under the massive forest plantations naturally develop species with lower economic value such as: manna ash (*Fraxinus ornus*), Turkish cherry, ash (*Fraxinus*), american maple (*Acer negundo*), etc. Thus, application of these regeneration technologies (shelter regeneration and introduction under shelter) will lead to the development of viable stands and increase their operational efficiency, especially in terms of erosion protection and hydrological protection, while promoting valuable deciduous species (alder (*Alnus glutinosa*), maple (*Acer pseudoplatanus*), ash (*Fraxinus*), manna ash (*Fraxinus*...
In terms of ensuring the continuity of degraded forest lands (Costandache, 2004).

In terms of climate change, the afforestation of degraded lands requires the application of appropriate technologies that secure the retention of soil water from precipitation through dissipation, avoid leakage, and reduce surface evaporation at maximum (Untaru, 2010):

- on land with slopes greater than 15 degrees, with pronounced deficiency of moisture, it is recommended to use terraces with counter slope platform;
- on excessively eroded slopes there is a very strong need to create terraces supported by masonry fences with stone benches;
- on stable land with slopes less than 15 degrees it is efficient to divide the soil into strips of 0.8m to 1.5 m wide and alternate them with grass strips.

**Funnel pits**, used for the afforestation of degraded land also improve water retention on slopes, where significant quantities of water would run out.

**Wave ditches** can be applied under the conditions of degraded land in different versions: continuous wave, with interrupted wave (with layout in triangles (chincons)) high profile (depth of 75 cm and effective height of wave 25 .. 35 cm) and low profile (depth of 50 cm and effective height of wave 20 .. 30 cm).

Mulching with grass obtained from the maintenance work around the seedlings is a particularly important measure for the reduction of soil water evaporation. However, it must be specified that terracing and ditches with wave can be applied only at sites with high stability against landslides or other forms of gravitational movement.

The inventory of the afforested lands, of the growths and of the sequestered carbon amount will be performed each year by Romanian foresters; after five years an independent body will verify and validate the data collected.

The expansion of the Romanian forests (including the forests from the Carpathians region) up to 35% of the total surface of the country is a long-term objective. The afforestation works will be carried out wisely, by site-specific analysis of the regeneration solutions according to the site conditions, the social impact of the works and the need to preserve the existing biodiversity.

At present, the inventory of the lands which require works for ecological rehabilitation is being performed at the level of the entire national forest area. In addition, the criteria for stand classification on the base of the comparison of their structure to the optimal structure (i.e. the structure that is able to restore soil functions necessary to ensure the proper requirements of sustainable land use) and according to the emergency of the interventions are being established. These criteria will be in agreement with the levels of biodiversity, complexity, stability and eco-protection and productive functions, characterizing those stands.

Ecological rehabilitation, a difficult and a long term process, understood as a component of the sustainable forest management, calls for “close to nature” specific technologies and methods. Here are some of the methods successfully applied in the Romanian forest area:

- Methods based on natural regeneration of beech stands, mixed beech and coniferous stands and oak forests.
- Methods that use the shelter of the remains of the damaged stands and the existing shrubs, and mixed regeneration which leads to a better preservation of the population biodiversity.
- Methods based on artificial improvement of site conditions with the help of irrigations, drainage, fertilization, etc. Their application is recommended on small areas.
- The increase in the forested area and the afforestation of agricultural lands damaged by different degradation processes represent priorities of the forestry policy in Romania. Creating new forests, without wood production
profit, becomes more and more important. The protection, biodiversity and even the recreational functions become priorities in these cases.

Tending, thinning, harvesting

While species choice in the regeneration phase has long-term impact, practices taking place after stand establishment that promote target species composition, stand stability, quality, and structure as well as enhancing the growth of crop trees have the effects on shorter timescales. Proposed adaptation measures aim mainly at modifying frequency or intensity of tending and thinning activities, but may also include altering tree species composition by targeted stand tending operations.

Adaptation measures in tending and precommercial thinning should support mixed stands of well-adapted tree species, inter alia to distribute risk via diversification. Tending and thinning can also help to manage increasingly mal-adapted stands in a changing environment (Felton 2010). However, since canopy openings affect stand integrity and increase surface roughness, intensified thinning might be limited by increased short-term susceptibility to abiotic and biotic damages such as windthrow or insect infestation. Improved individual tree stability increases stand flexibility in the regeneration phase, thus balancing the negative effects of increased surface roughness through higher stability in partial regeneration cuts. Similarly, in over-mature structurally uniform forests, standing stocks have to be reduced by adapted thinning regimes focusing on increasing and maintaining structural diversity.

Clearcuttings should be avoided because after such interventions, erosion and landslides occur and a large amount of soil organic carbon is lost. Faster mineralization of organic matter releases more carbon dioxide, which is integrated in the global carbon cycle, thereby increasing the greenhouse effect. For the same reasons aggressive timber exploitation technologies are not suitable. Instead, greening logging technology based on modern skylines (used in Switzerland, Austria, and Slovenia) can be understood as an effective means of adaptive forestry to climate change.

“Small-scale harvesting interventions and promoting harvesting systems which support natural regeneration of suitable species are recommended to increase spatial heterogeneity and biodiversity. However, small-scale cutting may induce loss of light-demanding tree species, which are often also more tolerant to water stress and high temperatures because they are typically pioneer species. Yet, this might be balanced by intensifying disturbance regimes under climate change. Recently, continuous cover forestry and variable retention systems have been proposed as robust strategies under climate change, but their overall benefits in this context remain poorly investigated” (Kolström 2011).

Forest protection

The health of forests plays an important role in absorbing CO₂ from the atmosphere. Forest health is ensured by appropriate protection, which aims to prevent attack by pests and diseases and their control. In general, we can say that Romanian forests have proper health status. Nationally, the state of the health of forests for all species was broadly regressive between 1990 and 1994 and has been improving since 1995.

Lately, important steps have been performed for the implementation of a large-scale integrated control method, which blends silvicultural measures with biological and bioactive treatments, using increasingly less chemicals against insects and diseases. The aim of the method is to restore the balance of forest ecosystems in a broader context of sustainable forest management.

To reduce the damage caused by harmful factors and to maintain proper forest health, forest protection measures with a preventive and curative character are realised annually by forestry divisions. Out of all works performed, 99.2% were oriented at trees, 0.5% at forest nurseries and only 0.3% represented sanitary
works (Simionescu 2001). More than a half of forest protection measures were preventive ones (54.4%), aimed at the prevention and control of coniferous bark beetles, avoiding damage caused by mammals by applying repellents, preventing damage caused by *Hylobius abietis* and treatments to prevent attacks caused by plant parasites (Simionescu 2001).

Main applied measures were against bark beetles (49.3%), defoliating insects (42.5%), various insects damaging wicker (*Salix spp.*) plantations (1.5%), plant parasites of root, stem and branches (*Fusarium*, *Glomerella cingulate*, *Rosellinia quercina*, *Cytospora chrysosperma*, *Pseudomonas juglandis*; plant parasites of leaves - *Microsphaera abbreviate*, *Fusiladium saliciperdum*, *Capnodium quercinum*) (2.2%) and *Hylobius abietis* (1.5%). *Salix* family includes trees, shrubs and sub-shrubs with deciduous leaves and elastic stalks. Willow species grow abundantly in Romania, and is spread primarily on moist soils on the banks of rivers, ponds and lakes in cooler areas.

Technical means used to detect and control bark beetles (especially *Ips typographus*) and xylophagous are Atratyp pheromone traps for *Ips typographus*, Atralymon for *Lymantria monacha*, Atrabayou for *Rhyacionia buoliana*, etc. and trap trees (classical or primed with pheromones).

Atratyp and Atralymon pheromones were widely used in Romania. Atratyp pheromone began to be widely used as a result of the experiments conducted since 1980, which proved that the outstanding qualities of this pheromone to detect and prevent propagation of *Ips typographus* beetle. Besides these pheromones, trap trees are also used because Scolitidae family includes also other important species such as *Pityogenes chalcographus* and *Ips amitinus* in spruce, *Pityokteines curvidens* and *Cryptophalus piceae* in fir, etc.

Generally, the control of *Hylobius abietis* pest was performed by placing toxic spruce bark in young coniferous plantations, from 75 pieces of toxic bark per ha in case of very weak infestation up to 400-600 pieces of toxic bark per ha in the case of strong infestation. In early years (probably between 1986 and 1998) carpets were treated with organochlorine insecticides, which were gradually replaced with less polluting insecticides based on dimethoate. In 1998, a trap funnel was approved that was primed with fagoattractant synthetic pheromone. This method gave excellent results in practice using a small number of funnels (4-6 pieces/ha) to lower populations of *Hylobius abietis* below acceptable damages.

For the prevention and the removal of threats caused by wood pests *Romsilva* acted for the removal of the timber from the affected areas, while applying necessary phytosanitary measures:

- efficiently turn the affected wood mass into cash, followed by auctioning, exploitation and extraction of this mass from the forest;
- placing a sufficient number of trap trees, selected from the snow- or windthrown, monitoring of their infestation and peeling off at the optimum time in order to destroy bark beetle in larva and pupa stage;
- placing of pheromone baits to trap and destroy bark beetles in hardly accessible areas;
- in situations where it was not possible to extract all affected trees, the timber was peeled off or chemically treated;
- permanent monitoring of forests affected by wind and snow, as well as those adjacent to take expeditious measures against pest outbreaks in the surrounding of disturbed areas.

In order to prepare and conduct the campaigns to combat defoliator caterpillars (*Lymantria dispar, Tortrix viridana, Operophtera brumata* and several species of *Geometridae*) in optimal conditions, concrete measures and responsibilities are annually established as a result of cooperation between foresters and forest protection related specialists from the central administration of RNP-*Romsilva* and ICAS. Here are some of the measures that are undertaken on an annual basis:
procurement of plant protection products from import and domestic production according to the needs;
- obtaining permits necessary for the flyover of forests in the adjacent area or where there are special objectives;
- equipping surveillance aircrafts with spraying equipment;
- checking insect populations of defoliators after hatching out in the forest surveillance zone or in the control area in order to determine the opportunity to control and the optimal time for treatment applications;
- widespread promotion of biological control methods other than those based on microorganisms by stimulating breeding of insectivorous birds and ants;
- inform society through the media about the period of treatment application, about the nature of the products used and measures taken to protect bees and silkworms;
- experimental treatments with new biodegradable and selective products, in order to prevent the occurrence of the resistance to pesticides.

According to the Forest Code, measures to prevent and combat forest vegetation pests shall be based on projections prepared annually for the entire forest. In order to protect fauna and flora, we apply biological and integrated methods for controlling pest diseases aiming not to harm the ecological balance.

The actions to be taken to improve the health and stability of forest ecosystems and to increase their functional effectiveness are as follows:

- Promote natural regeneration, the correct choice of treatment, the use of biotechnology to produce seedlings of valuable species that cannot be regenerated naturally, etc.
- Optimization of forest composition and other parameters of forest structure in order to keep their environmental, economic and social functionality, promoting stable and valuable native species.
- Identify inappropriate forests in relation to the potential of forest sites (derived by comparing values of different forest sites with similar soil structure) and prepare programs for their rehabilitation.
- Reconstruction of forests affected by disturbing factors or forests with inappropriate structure and function (affected by windthrow and snow breakage, insect outbreaks, etc.).
- Selection and promotion of biotypes resistant to disturbances and extending utilisation of these biotypes for forest regeneration.
- Protect forests through proper control of pests and diseases (biological control methods etc.) and ban or severely restrict grazing in forest by law.
- Further test and register new insecticides that are biological and biodegradable, selective and with low impact on the environment.
- Further promotion of integrated control methods by combining combat microbiological and chemical methods with other natural factors, such as insectivorous birds, useful ants, parasites and predators, and application of silvicultural measures etc.
- Carry out a close analysis and the implementation of specific treatments against biotic pests (Hylobius abietis).
- Improve monitoring of forest health in conjunction with aspects of forest soil quality.
- Protect quality of forest soil, prevent deforestation or exclude inappropriate technologies (clear cuts).
- Site mapping of all the surfaces and planting, using different species composition which shall lead to the creation of stable stands with beech and larch playing a special role.
- Further endowment of forest local offices with advanced equipment for land application of warm and cold aerosol treatments.
- More intensive coverage of all actions which ensure appropriate health state of forest vegetation encompassed in the national forest fund.
Nature conservation

Adapting forests to changing climate conditions will not be possible without increasing the stability of forest ecosystems by conserving and restoring biodiversity. All types of biodiversity: genetic, species, ecosystem, ecosystem complexes, will have an indispensable role in this process (Giurgiu 2010).

We recommend protection of, where appropriate, conservation of natural, virgin and quasi virgin forests (quasi virgin forests are natural forests, which suffered visible anthropic changes in the past that are not significant for the structure, resorts and ecosystem processes) within the system of protected areas or within the gardening forest management units (managed using selective harvesting of trees or small groups of trees in order to create and maintain the uneven-aged structures) and special conservation units, to sustain their high biological diversity, ensuring high stability against disturbing factors, including climate change.

We recommend also the establishment of new protected areas aimed at forest biodiversity conservation based on specific management plans of protected areas.

An important role is also to identify natural forests in areas most exposed to climate change and select a special conservation regime for them, especially as these have a genetic background adapted to severe drought, vital for the production of material necessary for afforestation of the areas in question. Particular reference is made to gray oak forests (Quercus pedunculiflora), downy oak (Quercus pubescens), oak (Quercus) etc. (Giurgiu 2010).

It also envisages the involvement of researchers in genetics and forest tree enhancement, which, using modern investigative methods will be able to select species, subspecies and other intraspecific units resistant to specific adversities of climate change.

Excessive fragmentation of forests on small properties is incompatible with the need for sustainable management. It is therefore necessary to ensure that forests exposed to climatic hazards are managed by state forest districts or state licensed bodies, which encompass both production and protection, regardless of the ownership, cost planning, management and their management should be largely supported by the state budget.

Here are other measures related to reducing pressure on forest ecosystems and reducing actions that may adversely affect biological diversity:

- Identify types of forest ecosystems and habitats valuable in terms of biodiversity, to be subject to a suitable management system.
- Restoration of damaged forest habitats.
- Identify and create connecting corridors to prevent habitat fragmentation, highlighting their forest planning.
- Inclusion of all types of representative forest ecosystems in the system of protected areas.
- Application of treatments and intensive care technologies and such management of stands that favor natural regeneration and maintain and enhance biological diversity of forest ecosystems.
- Inventory and protection of rare, endemic, threatened or endangered species.
- Protect wildlife by developing and implementing appropriate - bio-conservative and hunting management programs.
- Restoration of land with mountain pine junipers (Pinus montana) and inclusion of these forests in the national forests for preservation.
- Include a chapter on biodiversity of forest ecosystems into forest management plans, with special measures regarding conservation.
- Integrating information system and monitoring of forest biodiversity issues and management of protected areas.
- The ecosystem approach to management of all types of forests and application of expanded work program on forest biological diversity, adopted by Convention on Biological Diversity (CBD) Decision VI/22.
Other adaptation measures and supportive activities

Adaptation measures to climate change in the forestry sector should be based on scientific research and technological advances which support sustainable development of forests, taking into account the environmental and socio-economic context. These measures should also be accompanied by adequate monitoring of forest health and their development. Finally, the importance of forests, especially in the context of climate change should be well explained to all stakeholders and to the public to encourage forest protection and defense.

Considering the geographical location and the current state of Romanian forests we can state that the forests are and will become increasingly affected by climate change. At the same time, this fact considerably increases the role of forestry to mitigate the impact of global warming. Preparing forests and forestry to these challenges is absolutely necessary (Giurgiu 2010).

As the implications of climate change modify, the strategy, legislation, technical standards in forestry programs, and forest management will have to be adapted to these new conditions. In order to implement the adaptation measures to climate change an assessment of the damage caused by climate change should be made in the forestry sector. According to experts in forestry, at present there are no such estimates due to the lack of proper monitoring (MPP 2012).

Other proposed measures relating to forests in Romania are as follows:

- zoning of forests in relation to their vulnerability to climate change;
- subsidies, at least in part, from the state budget, for private forest management in the areas exposed to climate change;
- classification of forests that are situated in the areas strongly affected by climate change as forests for climate protection. The recognition of forests as protection functional areas is a result of implemented actions within the soil and forestry monitoring system and it is achieved by evaluating forests health status, identifying the presence of certain types of injuries affecting trees (insects, fungi, abiotic agents - wind, snow, frost, fire, pollution, etc). Currently, only 3% of country forests were assigned climatic function.
- development of methodology for national forest inventory that will respond to the implications of climate change requirements;
- test forest classification typology developed by the European Environment Agency if it can be used in Romania, including monitoring the impacts of climate change;
- development of advanced methodologies, unchallenged in commercial transactions and international confrontations, to assess forest carbon stock (in biomass and soil) and carbon content in wood products;
- enhancing and deepening of basic scientific research, much lagging behind (Allen 2009), on the impact of climate change on forest ecosystems; forest and forestry adaptation to these impacts; and mitigation of global climate change through forestry activities within many international and interdisciplinary programs funded primarily by foreign funds. Only in this way, scientific uncertainties and gaps in this area can be removed. It is also necessary to institutionalize a national monitoring system of forest health in the long term, integrated into an international system correlated with national forest inventories;
- creating a national system for monitoring endangered species, supported by public and private funds, using national programs and civil society participation as a result of research activities;
- assess monitoring system to determine its effectiveness under development of the effects of climate change and identify the opportunities to modify it;
- extending the use of monitoring data by extrapolating results obtained using mathematical simulations;
• development of specific management plans for preventing and limiting degradation of natural habitats as a result of climate change impacts;
• reducing agricultural activities in areas directly affected by climate change, and implementing adequate measures to protect natural and semi-natural habitats near existing agricultural areas, including identification of compensatory measures necessary for the survival of the affected population;
• reducing the impact of industrial activities on groundwater and air quality by insulating forest stripes;
• expanding the network of forest roads used for permanent timber transport (bridges, culverts, consolidation works, cross and return stations, signalling indicators), and the reconstruction and strengthening of the existing roads;
• increasing the accessibility by creating a network of so called collection routes (i.e. non-permanent forest pathways: slip roads, paths reinforced with wood, winding paths, unimproved or unmanaged pathways), aimed at reducing the average distance and the use of eco-protective methods and technologies.

Conclusion

The current Forestry Code adopted by Romanian Parliament in 2008 (Law no. 46/2008 with subsequent amendments) does not directly address the issue of climate change. However, the rules and the principles stated in the code primarily support and promote long-term sustainability of forests and forest land. In accordance with the management principles established in the Forest Code, current forestry tools are aimed at sustainable management of forest resources and promoting fundamental natural forest types. The central competencies within the field of climate change adaptation are assigned to the Ministry of Environment and Forests through the Directorate for Climate Change and Sustainable Development. The first National Climate Change Strategy was drawn up for the 2005-2007 period and approved by the Governmental Decision No. 645/2005. Climate change adaptation of several sectors including forestry was highlighted in the chapter "Impact, Vulnerability and Climate Change Adaptation". The present National Climate Change Strategy (2013-2020) concentrates upon mitigation and adaptation. The adaptation component of the current strategy aims to provide an action framework and guidelines to enable each sector to develop an individual action plan in line with national strategic principles. From the point of its implementation, a number of national and international research projects have been on-going and can provide underlying information on impacts and vulnerability of ecosystems to anticipated climate change. In addition, the activities aimed at increasing the society awareness of the climate change effects have been launched. It is accepted that adaptation measures to climate change in forestry should be based on scientific research and technological progress, which support the sustainable development of forests. These measures should be accompanied by adequate monitoring of forest health and their development. Reforestation and maintenance of current forest vegetation are considered to be primary measures. Large scale afforestation of Romania is a long-term objective until 35% forest cover of the total area of the country is achieved. Although practitioners do not perceive climate change as having a significant impact on forests, they usually couple the existing problems with this issue. Adaptations strategies are considered as context dependent, and therefore, issues such as political influence in forestry administration, incoherence of forest legislation, and illegal logging should be addressed first.
5.3.3.4. Ukraine

State forest management is carried out by a number of authorities, including a specialized authority - the State Forest Resources Agency of Ukraine (managed by the Minister of Agrarian Policy and Food of Ukraine but with high level of independence in the sphere of decision-making) and governmental authorities which have forests under their management (the Ministry of Agrarian Policy and Food of Ukraine, the Ministry of Defence of Ukraine). Some functions, related mainly to environmental protection, are given to the Ministry of Ecology and Natural Resources of Ukraine. Administration structure consists of the following levels:

- National level – State Forest Resources Agency of Ukraine, Ministry of Agrarian Policy and Food of Ukraine – Department of Licensing and Forestry, Ministry of Defence, Ministry of Ecology and Natural Resources of Ukraine
- Regional level – Committee of Autonomous Republic of Crimea of Forestry and Hunt, 24 Regional Administrations of Forestry and Hunt, territorial bodies of the Ministry of Ecology and Natural Resources of Ukraine and State agrarian forestry enterprises (in the regions where they exist)
- Local level – State Forestry Enterprises and municipal forestry enterprises. State forestry enterprises as well as municipal enterprises are responsible for a wide range of forestry activities, from forest planting to final felling, some being also engaged in milling.

In Ukraine, forest management of each forestry enterprise is based on a forest management plan (FMP). It results from forest inventory, which is normally realized every 10 years. Materials of the inventory contain qualitative and quantitative characteristics of each forest plot, and a complex evaluation of forest management in the stand. Forest management plan is an obligatory document for every forestry enterprise. It contains main information about forest enterprise and forest management (for example, the fact whether the enterprise have mainly protected or recreation forests is reflected in FMP) and directions of development of forest enterprise on the ecologically balanced basis and should account for economic and social development of the region.

The materials of the plan include:

- explanatory note;
- mensurational descriptions of lands of forest enterprise;
- compartment maps;
- forestry sections with information about forest stands that represent basic forest management units;
- map of the enterprise;
- list of forestry measures etc.

All the materials must be approved by forestry authority at the regional level with the consent of regional environmental protection authority. There are many legal documents that regulate forest management system in Ukraine. The most important of them are as follows:

- The Forest Code of Ukraine (1994)
- Law of Ukraine on Natural Protected Areas of Ukraine (1994)
- State Specific Programme Forests of Ukraine for the years 2010-2015 (2009)
- Rules of Final Felling (2009)
Since 90s of the last century, the increase of volumes of sanitary and others regeneration cuttings has been observed (Popkov, http://www.lesovod.org.ua/node/8402) when compared to final cuttings, which currently produce only 43% of marketable wood. Intensive sanitary cuttings may lead to the loss of biodiversity losses due to the destruction of biotopes, particularly of species connected with dead wood. Moreover, the actual volume of sanitary cuttings is often substantially higher than the volume assigned by forest survey, because sanitary cuttings are frequently misused to increase timber harvesting. Legal documents that address the issue of enhancing forest structure are also often misused to get permission for felling. This approach is called “pharisaic” cuttings, because they do not follow the law they refer to, and have in reality an adverse effect on forests, since their only goal is to make profit. They are usually carried out in protected forests where commercial logging is normally prohibited (e.g. forests near rivers, in the protected areas).

Such ungrounded sanitary and “improvement” cuttings have caused unbalance in the age structure of forests. Due to this, current forest area of mature and over-mature stands is much lower than normative (50-60 % of normal or optimal forest stand structure). Young and middle-aged forest stands prevail especially in spruce forests, but also in oak, beech, hornbeam and maple forests.

Another important issue of national forestry is unbalanced spatial distribution of cutting areas. The areas are mainly concentrated on easily accessible territories that generate the lowest costs for cutting processes and transportation. Thus the reported forest crop increases, while forestry in the areas of intensive cuttings is not sustainable from either ecologic or economic points of view.

**Awareness issues and cross-sectoral cooperation**

Key factors and mechanisms of climate change impact are studied by scientists and academic institutions (Oliynik 2008; Tsaryk 2008; Stojko 2009; McCarthy 2010; Bukscha 2010; Stojko 2011 etc.). However, there are still some gaps in the climate change studies and its impact on Ukrainian forests. Due to the lack of some practical recommendation necessary for forestry and the slow transfer of research results to practice, practically no adaptation measures are currently implemented in practice. Nevertheless, there are some projects aimed at the transfer of the results of modern forestry studies to forest management of the Ukrainian Carpathians, but the practical use of this knowledge is concentrated mainly in the few pilot areas. An example of such projects is FORZA that also includes some issues related to climate change adaptation and mitigation, such as multifunctional close-to-nature forestry to be performed in Zakarpatska region. In general, forestry enterprises are reluctant to any changes in forest management systems especially if they address commercial forests, except for those addressing the most “visible” issues, such as replacement of declining secondary spruce forests with native species, growing of species resistant to storm on the slopes subject to windfalls etc.).

Climate change issues are included in university courses for foresters. They focus mainly on the general issues such as global climate changes and the impact of climate changes on the global ecosystems. Practical aspect of climate change and its impact on the Ukrainian forests are either not considered at all or considered...
only marginally in general description of the results (such as decline of secondary spruce forests in the Carpathians).

**Adaptation measures**

In Ukraine, National Plan for CC Adaptation 2011 - 2013 is prepared, but it has not been adopted yet. The plan includes only a list of preparatory activities to be carried out by different actors, but not concrete measures necessary for adaptation.

A number of research studies have been performed to examine the impact of climate change on forests in Ukraine, e.g. McCarthy 2010, Bukscha 2010, Tsaryk 2008, Stojko 2011, Oliynyk 2008, Stojko 2009, etc. Bukscha (2010) analysed several climate change scenarios that were developed using CCCM (Canadian Climate Centre Model; sensitivity to doubled atmospheric CO2 concentration = 3.5°C), GFDL (Geophysics Fluid Dynamics Laboratory model; sensitivity to doubled atmospheric CO2 concentration = 4.0°C), GISS (Goddard Institute for Space Studies model; sensitivity to doubled atmospheric CO2 concentration = 4.2°C), and UKMO (United Kingdom Meteorological Office model; sensitivity to doubled atmospheric CO2 concentration = 3.5°C). According to the simulation results, a temperature increase is forecasted for all seasons of the year on the premise of doubled CO2 concentration in the atmosphere. It is expected that the air temperature will increase most significantly in the winter or spring (according to GFDL and UKMO). The last two scenarios suggest that the warming in Ukraine will increase from south to north. Under all the tested scenarios, the amount of precipitation will increase, and during certain seasons this increase could exceed the current level by 20%. The reaction of forests and forestry to climate change showed that the borders of the forest growth regions and areas would change, and so would species composition (Bukscha 2010). Stojko (2009, 2011) presented both positive and negative impacts of climate change. Positive impacts (Stojko 2009) include possible expansion of thermophile tree species and increase of biodiversity; increase of the growth and productivity of forest stands due to prolonged vegetation period; intensification of soil-forming in the mountains; restoration of the upper timberline and improvement of water and soil protective role of forests at the timberline. Negative impacts include increase of precipitation and risks of floodings; increase of intensity and frequency of biotic and abiotic disturbances (erosion, avalanches, landslides, mudslows, wind- and snowbreakage of trees). Stojko (2011) also proposed a program of ecological monitoring for further investigation of the development of forest formations.

**Management systems**

On the base of the study aimed at the water-protective role of the mountainous forests in the Ukrainian Carpathians, Oliynyk (2008) suggests the increase of shelterwood and selective cuttings with corresponding decrease of clearcut. Close-to-nature forestry is assumed to be the method which can be used as a measure of adaptation to climate change in the Carpathians. This approach is supported by many scientists. However, it is mainly spread among scientific society. There are few pilot projects in the forest of Zakarpattya region where methods of “close to nature forestry” are applied on practice by forestry enterprises.

In general, it is expected that the shift of forest management from growing spruce monoculture forests to mixed fir-beech forests (natural) will result in increase of resistance of forest ecosystems to climate change.

**Tree species composition**

It is expected that Carpathian forests will have enough resistance to the expected climate change. Bukscha (2010) presented that the species with large ecological amplitude will expand, while poorly adapted species with narrow ecological amplitude will diminish and possibly become extinct. Together with the
changes of the areas covered by Ukraine’s main forest-forming species, the changes in the forest-growth regions will determine the regional character of the changes in forest ecosystem structures and their biological productivity. At the forest ground vegetation level, replacement trends of dominant species will be seen. Spruce forests are considered as a weak component so in unnatural conditions they are to be replaced by mixed fir–beech forests. According to Stojko (2009) possible expansion of thermophilic tree species may be expected, i.e. possible expansion of oak and oak-beech forests (with sessile oak) to higher elevations. The prognosis of Stojko (2011) suggests that beech will replace sessile oak (*Quercus petraea*) in beech-oak forests as well as spruce in secondary spruce forests planted on fir-beech sites. He also assumes that their species composition will be enriched by thermophilic exotic trees such as sweet chestnut (*Castanea sativa*), Weymouth pine (*Pinus strobus*), Black walnut (*Juglans nigra*) etc. (Stojko 2011), and that warming will be favourable for natural regeneration of spruce on pasture lands, which will result in natural restoration of the upper timberline (Stojko 2009). Mixed uneven-aged forest stands should be promoted because they have higher water-protective capacity than even-aged monocultures (Oliynyk 2008).

**Forest regeneration**

There are discussions between scientists and foresters on the efficiency of forest regeneration in the Ukrainian Carpathians (natural regeneration versus planting) but they are related mainly to economic efficiency and biodiversity protection not the climate change adaptation measures.

**Tending, thinning, harvesting**

The only change in individual forest treatments which are mentioned in relation to the adaptation of forestry in the Carpathians are gradual refusal from clear cut to others types of cut which are less destructive in relation to the forest environment (selection cut and shelterwood cut as well as methods of close to nature forestry (the last within pilot projects only). Oliynyk (2008) proposes to reduce final felling and to ban felling at elevations above 1,100 m a.s.l. The results of his study also justify the prohibition rule of cuttings which may lead to the decrease of forest cover of water streams basins below optimum level (65%).

**Nature conservation**

It is expected that adaptive forest management will allow to improve the issues related to nature conservation (natural composition of species in their natural conditions, more natural habitats for rare and threatened species, less areas with fully removed forest cover (less clear cuts).

Adaptive forest management practices are considered to be fully compliant with international obligations of Ukraine in the sphere of natural conservation. They also comply with national nature conservation legislation and are expected to contribute to the establishment of environmental network and protection of endangered and rare species of plants and animal.

There are thoughts that some types of adaptive forest management can adversely affect protection of endangered and rare species taking into account plans of massive construction of forest roads which are necessary for the access to cutting areas and intensification of forestry. These forest roads can be a factor of disturbance for wildlife and ways for poachers to enter remote areas.
Other adaptation measures and supportive activities:

- Organisation of long-term monitoring on the basis of natural protected areas (over autotrophic and heterotrophic and soil blocks);
- Support of researches on the issues related to adaptation of Ukrainian forestry to the climate change.
- Seminars and trainings for personnel on the climate change issues and best practice in the sphere of adaptation to climate change (taking into account low level of understanding of the problem and insufficient knowledge of management of Ukrainian forestry)
- (Oliynyk 2008) - use of nature protective technologies of skidding (skyline and aerial).

**Conclusion**

In Ukraine, National Plan for Climate Change Adaptation 2011 - 2013 was developed. However, it has not been adopted yet. The plan includes only a list of preparatory activities to be carried out by different actors, but not concrete measures necessary for adaptation. Key factors and mechanisms of climate change impact are studied by scientists and academic institutions. However, there are still some gaps in the climate change studies and its impact on Ukrainian forests. Due to the lack of financial resources, as well as practical recommendations necessary for forestry and the slow transfer of research results to practice, practically no adaptation measures are currently implemented in practice. Nevertheless, recently some projects aimed at the transfer of the results of modern forestry studies to forest management of the Ukrainian Carpathians have been launched, although the practical use of this knowledge is concentrated mainly in the few pilot areas. In general, forestry enterprises are reluctant to any changes in forest management systems especially if they address commercial forests, except for those addressing the most “visible” issues, such as replacement of declining secondary spruce forests with native species and converting these stands to mixed beech-fir or beech-fir-spruce stands. Another change related to adaptation is gradual movement from clearcut to other less destructive types to forest environment, particularly selection cut and shelterwood cut. Similarly to Romania, illegal cutting seems to be the most important forestry issue at present.
5.3.3.5. Hungary

In Hungary, forest management systems are specified by Act 2009 - XXXVII on Forest Conservation and Forest Management. The main items included in the Hungarian Forestry Law are the following (Csoka and Somogyi 1996):

- forests can be converted to other land use only after authorized approval;
- forest property exceeding 400 ha should employ a professional forester;
- forest management plans should be approved by the Minister of Agriculture;
- management plans are financed by the State and are provided free of charge;
- forest owners should follow the plan's recommendations, and the State inspects the owners' activities through State Forest Inspectorates;
- the forest owner/user must contribute a sum (determined by the logging involved) to a special Forest Maintenance Fund;
- logging sites must be reforested; the cost of regeneration is covered by the Forest Maintenance Fund on a normative basis; this subsidy is intended to include some profit to encourage faster regeneration;
- afforestation, as well as furnishing existing forests for welfare services, are considered as special investments of national interest and therefore are financed by the state budget;
- primary management objectives are defined by law; management of protective and nature conservation areas is controlled by the Minister of Environment and its local authorities;
- forests are open to the public for recreational purposes;
- hunting rights are controlled by the State, which is subject to renting, with the renter responsible for wildlife management and for damages caused by game;
- grazing domestic animals in forests is prohibited;
- forestry is subject to the Ministry of Agriculture.

In the new regulation approved in 2011, the Ministry of Rural Development ordered the application of so-called continuous cover forestry measures on 10% of the state forest land within the next 10 years. The ratio has to increase further in the next 10-year period. It is considered as beneficial for mitigating climate change – however there are no research/experimental findings supporting this.

The main objective is to diversify pure and even-aged stands by small-scale gap cuttings.

Majority of forests is covered by broadleaved species in Hungary. Conifers are mainly considered as introduced species, but a fairly high proportion of the broadleaved forests also consists of introduced species, such as black locust and improved poplars (Csoka and Somogyi 1996).

Almost all forests in Hungary are considered even-aged. They are established artificially. Stands of coppice origin represent 40 percent of the area. After felling, the natural regeneration process is preferred wherever practicable. The rate of stands regenerated in a natural way (coppice and regeneration cuts) amounts to about 50 percent. The age structure of Hungarian forests has been improving as a result of regulations to achieve sustained yield (Csoka and Somogyi 1996).

Forest management planning includes periodical mapping, inventory and planning management of forests. It is a concept, as well as some kind of organization, that has been operating in Hungary for more than 200 years. The basic philosophy, strategy and principles of management planning remained relatively unchanged through these many years and are based on the sustainable management theory. Naturally, the methods, intensity, concepts, funds, devices and principles, as well as the organizational structure, have been developing since without any serious setbacks (Csoka and Somogyi 1996).

The main characteristics of the present management planning are as follows (Csoka and Somogyi 1996):
in accordance with the Forestry Law, the total forested area of the country, regardless of ownership, is under the regulation of management planning;

- while mapping, inventory, planning and yield regulation are done every ten years (i.e., one-tenth of the forest area is covered annually), the supervision of management is done on an annual basis;

- management planning as a whole is in the interests of society, thus 100 percent of the operational costs for all owner/user is covered by the state budget;

- the output, including maps, reports, plans and statistical tables, is supplied to owners, agencies and supervising bureaux free of charge;

- a dynamic approach is applied to process information on forests and forest management. This includes using data on stands and operations (cut, reforestation, thinning, etc.), and other matters. Through the use of sophisticated simulation programs, management planning is able to update the database, as well as plans (e.g., the allowable cut) for all Hungarian forests on an annual basis.

Both management planning and supervision are required to be objective. Therefore to avoid biased, unfeasible management plans, planning and supervision are made separately. The Forest Management Planning Service is responsible for nearly all aspects of forest management, excluding supervision. The latter is done by ten independent local State Inspectorates (Csoka and Somogyi 1996).

**Awareness issues and cross-sectoral cooperation**

Water management strategy in Hungary is changing slowly. In the past, fast drainage of floods and high level of excess surface waters from the Carpathian basin was the principle of water management following the primacy of human safety and agriculture production. Lowland forestry has always been in favour of retaining the waters. Climate change effects seem to support the forestry approach. Plans to retain more water in the country are on the table and actions especially along the Tisza River are going on.

Accumulating new research results on climate change effects have strongly contributed to a growing awareness in the forestry community.

Forest companies directly confronted to climate change effects such as large-scale mortality, diseases and pests cooperate with research teams to find appropriate answers to these challenges. These initiatives are parallel with the trend to apply close-to-nature technologies in silviculture (Pro Silva movement). Much of the program also serves the aims of climate adaptation as well, as it supports and promotes maintenance of closed forest cover, natural regeneration, increasing species diversity, creating more structured forest stands, etc.

**Adaptation measures**

Planned forestry means that the structure, species composition and demography conditions of forests are determined by current management concepts, strategies and laws. Spontaneous processes are suppressed or tolerated only if they fit into the accepted strategies. Planned, sustained harvesting methods determine the applicable techniques for regeneration of forest stands.

Operational plans for forest management therefore imply that spontaneous forest cover changes determined by climatic shifts may be balanced by human actions, if principles of forest policy are oriented towards adaptation to the effects of such change. Consequently, goal-oriented forest policy and management should be seen as effective measures to serve climate adaptation.
Policy level

In spite of a large variety of research results and initiatives to prepare forest management practice for climate change (Berki et al. 2007; Führer-Jagodics 2007; Mátýás et al. 2007; Németh et al. 2007), no specific concept or strategy to buffer effects of projected climatic changes currently exists in Hungary. National Climate Change Strategy was approved by the Parliament in 2008. Development of its implementation is going on. However, in the strategy forests are only marginally mentioned as a source of biomass and areas to conserve biodiversity. Long-term forestry strategies were formulated in the National Forestry Program (2006). However, climate change adaptation was not thematically considered in the program. In the new forest law from 1st July, 2009 known as XXXVII. Act of 2009 on forests, forest protection and forest management, there are first signs of awareness of global warming. The primary function of the forest is considered to be the mitigation of climatic changes. However, no specific measures are included in the act.

The reason for this state might be a very strong acceptance of a conservative approach in dealing with active interferences in climatic adaptation. According to the prevalent approach of official forest policy, natural adaptation and succession processes can efficiently deal with the changes, and the artificial interference in species and genetic diversity conditions is not advisable.

Indirect policy measures that can mitigate climate change impacts are change of forest management system and afforestation. In 2011, The Ministry of Rural Development published the regulation, which requires the application of so-called continuous cover forestry measures on 10% of the state forest land within the next 10 years. The ratio has to increase further in the next 10-year period. The main objective is to diversify pure and even-aged stands by small-scale gap cuttings. It is considered as beneficial for mitigating climate change – however there are no research/experimental findings supporting this. The National Agricultural Program, accepted in 1997, declared that large scale afforestation in Hungary should continue until forest cover reaches 27%. The current forest cover of Hungary is 20.6%.

Presently running research projects address most of the problems coupled with climate change in Hungary (TÁMOP Agroklima: concentrating on proper management technologies in future climates, and on decision support system development, TÁMOP Folyamatos Erdőborítás: analysing conservation and production aspects of applying continuous cover technology). From among the investigated themes the following should be mentioned at this point:

- improved forest monitoring to better support the assessment of climate change caused damages and pests
- analysis of effects of biodiversity on buffering the extent of damages
- genetically set limitations to tolerance of extreme events
- early detection of climatic stress
- water regime and nutrient cycle components of buffering climate stress
- effect of continuous-cover forest management on species level processes, demography and stability.

The scientifically founded results will be adopted in a decision support system for climate change adaptation that is being developed by a cooperation of several institutions: University of West Hungary (Faculty of Forestry), Forest Research Institute, Szent István University, National Food Chain Safety Office (NFCSO). The

---

1 only a sample is given from the very extensive „grey” literature in Hungarian. Scientific publications of the authors are accessible in domestic and foreign professional journals, including Acta Silvatica or Erdészettudományi Közlemények (latter in Hungarian with Eng, summaries)
system should be set up by the end of 2014. It is intended that the system will provide the data on projected climate and extreme risk until the end of the 21st century (2100), providing yield information and applicable forest management approaches on a geoinformatic basis. This means that information will be available locally, at a compartment level. This decision support system, if introduced, might strongly improve risk assessment and local mitigation of climate change effects and contribute to a deeper sensibilisation of foresters for the available options of adaptation.

Management systems

Considering the above-mentioned policy situation in Hungary, current climate-change adaptation in forest management covers methods and approaches that support actual close-to-nature conditions allowing for natural species composition change but excluding artificial interferences to assist species and genetic migration of non-autochthonous origin. So-called „continuous cover forest management” aims at creating a network of gaps which will promote the development of uneven-aged, mixed forest stands.

The successive introduction of the continuous cover method has been prescribed for all state forests under close to nature management system, irrespective of species. Total area of close-to-nature forests in the Carpathian region of Hungary is 363.642 ha (76%), approximately 85% of it is state property. In the present decade (2011-2020), 20% of the total forested area should be converted into the mentioned management system, and the work should continue further. It seems that this decadal goal will be attained, while mostly beech stands have been selected for „continuous cover forestry”. The main argument against the binding introduction of this system is the fact that no scientific analysis of the consequences in a changing environment has been carried out. Such investigations were initiated only now. It is assumed that the planned long term discontinuation of crown closure may lead to the prolonged change of microclimate, which may create unfavourable conditions for natural regeneration in extreme years. A serious threat to this adaptation approach is the generally admitted but less publicised extreme level of game density in Hungary.

Tree species composition

Contrary to general belief, the trend of raising temperatures and declining summer rainfall will not result in a “mediterranisation” in Hungary, because the regulating effect of the distant sea is weak and the predicted climate anomalies will be different from general trends assumed for Central Europe (Gálos et al. 2008). The shifts in drought frequency may cause drastic changes in lowland forest regions. Even a relatively minor shift of temperature and precipitation may profoundly affect the available climatic niche of dominant forest species. Mass mortality may appear at the rear edges, especially on sites with unfavourable water regime. On edaphically extreme sites, such as e.g. south facing slopes with shallow and sandy soils with no surplus water, the eventual loss of permanent forest cover and the development of forest steppe vegetation is accepted and tolerated. The extent of these sites may reach up to 20% of the total area of forests in the Carpathians. Many of these sites are prone to invasive species (both woody and herbaceous), such as tree of heaven (Ailanthus altissima) or Solidago virga-aurea.

In general, mixed multispecies stands are promoted due to their higher resistance to abiotic as well as insect and disease attack. Non-autochthonous species on landscape level are banned. The support of immigration of potentially better adapted species (and genes) is facilitated only if their presence is locally considered as natural. Oak species (Qu. petraea, robur and pubescens) should play a central role in climate change adaptation of Hungarian forests. Sessile oak should be considered in beech zone (defined by dominant tree species and climatic constraints), together with hornbeam and maple. In Sessile oak zone, introduction
of Turkey and pubescent oak should be considered. Similarly, in hornbeam-oak zone, Turkey oak may be a suitable species together with cherry and other wild fruit species, maples etc. However, the migration and natural regeneration of oak species is menaced by extremely high population of deer and wild boar.

Forest regeneration

Generally, natural regeneration is favoured in all stand types. Following the answers of the Ministry of Agriculture to survey of EU 27 Member states to promote adaptation to climate change in forestry performed in 2009, there are two on-going adaptation measures in Hungary:

- Increased application of natural regeneration
- More careful selection of main species of regeneration during management planning considering possible local effects of climate change.

The other measures, such as e.g. decrease of the number of seedlings in plantation forests, more frequent sowing in artificial regenerations are not applied yet, and are considered only in long-term.

The survey was coordinated by the DG Agriculture and published as „Impacts of Climate Change on European Forests and Options for Adaptation AGRI-2007-G4-06“, Report to the European Commission (EU Directorate-General for Agriculture and Rural Development, 2009).

Nevertheless, on approximately 70% of the Hungarian forest area (and 95% of close-to-nature forests), artificial regeneration methods will still be applied in the future because of ecological and economical considerations. This implies stronger application of directed genetic interventions primarily through utilising reviewed directives for reproductive material. It is the result of recent genetic analyses (Mátyás 2007, EVOLTREE 2009) that

- genetic response to climatic changes is strongly species-specific
- generally, response depends on the ecological distance from the limits of tolerance
- populations exposed to extreme climate stress need special consideration both in risk management and conservation.

Artificial regeneration together with forest protection measures may effectively buffer the spontaneous effects of climatic shifts; needless to say, this is only until the physiological and genetic limits of the species are reached.

Tending, thinning, harvesting

Selective cutting should be promoted and clear cutting methods should be reduced. In mature or close to mature stands small scale gap cuttings are prescribed in state forests. In natural forest types, forest canopy should be kept closed, tending and thinning should be less frequent leaving more room for natural processes. Shortening of the felling cycle is seen as a proper countering method to increasing frequency and intensity of damage caused by biotic disturbance factors.

A specificity of Hungary is the combating of drought effects in forests. Beech is the species most exposed to extreme droughts. A method to naturally regenerate beech by considering orientation to insolation, maintaining of suitable microclimate, has been developed and named as microclimate-saving regeneration cuts (Török 2007).
**Forest protection**

Forest stands under extreme weather conditions are predisposed to increased insect and disease attack. The number of immigrating species is continuously growing, but also “traditional” consumers (*Lymantia, Ips* et.) are increasing, and so are the frequency and the intensity of damage. Management practice is modified to improve the stability of stands to both biotic and abiotic factors. The promotion of natural regeneration, mixed and uneven aged stands composed of more native broadleaves, selective cutting and shorter felling cycle are seen as proper countering methods. The continuation of national forest condition monitoring including monitoring of damages is assured.

**Nature conservation**

The legislative influence of nature conservation in forest management of state forests is overwhelming, without available scientific proofs for prescribed adaptive measures. Genetic aspects are left unconsidered (marginal populations, provenances).

**Conclusion**

The present *Forest Law* (2009) considers global warming marginally, as it mentions forest effect on climate change mitigation. However, no specific measures are included in the act. Long-term forestry strategies have been formulated in the *National Forestry Program* (2006). Climate change adaptation, however, has not been considered. The *National Agricultural Program* was accepted in 1997. This program declares that large scale afforestation should be continued in Hungary to reach 27% forest cover (as compared with present 22.4%). Research activities on climate change impact assessment are well developed throughout all sectors. Such activities have contributed to a growing awareness in the forestry community. Private sector in forestry starts considering the climate change related threats intensively, mainly as response to recently observed climate related tree mortality and pest outbreaks. Principles of continuous-cover-forestry and management supporting climate change adaptation became inherent part of forestry planning.
5.3.4. Task 4: Observed and projected shift of forest tree species in the Carpathians

Effect of climate change on the shift of forest tree species and communities, including evaluation of ecological, environmental and economic impacts, has received great deal of attention during the recent decades. Despite this effort and growing body of literature, the complex processes behind the anticipated climate change-induced species shift are not completely understood.

Inability of species to follow the shifting climate may cause population decline and, in some cases, extinction. Species shift may represent threat to biodiversity, which is especially pronounced in mountain areas, where species have limited options to migrate or adapt.

Species shift concerns a variety of processes changing across scales with different level of their understanding. Drought induced decline at species lower range limit, species northward and upward expansion at upper range limit, invasion of alien species, colonisation after disturbances, alteration of species competitiveness or effects on biodiversity are some of the most pronounced processes. Some of these effects have already been reported from the Carpathians, and will be described in this report.

Shifts in the geographic ranges of plant species occur as a consequence of a combination of population expansion at the leading edge of their distribution and retraction at the trailing edge (Jump et al. 2009); these two processes are most distinct manifestations of species shift. Altitudinal upward shifts of species’ ranges have occurred across a wide range of taxonomic groups and geographical locations during the twentieth century in response to current climate warming (Peñuelas et al. 2007). However, actual data on plant species’ altitudinal shifts are still scarce and not always clear. Observation of processes related to drought induced retraction of lower range limit are even scarcer, though some evidences has been provided from various regions where xeric forest limit occurs (e.g. Hungary, Spain, Portugal).
5.3.4.1. Used methods of species shift modelling

Additionally to the overview of species shifts observed in Carpathian countries, we used the environmental envelope modeling-based approach (e.g. Pearson et al. 2002; Pearson and Dawson 2003) for projecting the future shift of species bioclimatic space. This approach can be used as proxy of species shift assuming the tendency of vegetation to follow the shifting climate, and to decline after suitable climate changes critically. As such approach is strongly simplified, and it does not consider the mechanisms such as dispersal and biotic interactions, the following assumptions need to be adopted to allow for the interpretation of outputs of the presented modeling:

- Present climatic amplitudes of species can be interpreted as bioclimatic limits of species occurrence; i.e. species survival beyond these limits is limited. In case of species with substantially altered distribution, such as Norway spruce, bioclimatic limits derived from species distribution needs to be adjusted by other data, for example by limits of species natural distribution which are, for some species, reported in literature.
- Presented projections describe the projected shift of species bioclimatic space not the shift of species themselves. Species shift is further affected by dispersal, competition, landscape fragmentation, physical barriers hampering the shift and various biotic interactions.

The projections can be used to describe the change in species-specific climatic conditions towards improvement of growing condition near to upper distributional range, and worsening of growing condition close to lower range limit; such processes are the most distinct features of projected species shift, and have support in literature.

Proper interpretation of presented climatic projections in terms of species shift need to be backed up by observed species shift; therefore this deliverable contains information on both observed and projected species shifts.

We used the following approach to modeling the shift of species climatic envelopes:

- Climatic amplitudes of tree species distribution have been derived using the data on species distribution described in the previous chapters. To consider the spatial variability of climate in the Carpathians and varying control of climate over vegetation distribution, the amplitude of each species was identified independently for three subregions of the Carpathians:
  - Western sub-region containing Outer and Inner Western Carpathians (Czech Republic, Hungary, and parts of Poland and Slovakia)
  - Eastern sub-region containing Inner and Outer Eastern Carpathians (parts of Slovakia, Ukraine and Romania).
  - Southern sub-region containing part of Romania, including Transylvannian Plateau and Serbia (Figure 21)
- The 50 km transitional zone was designated around each sub-region border, and this zone was used to secure the smooth transition between species environmental envelopes calculated for the sub-regions (Figure 21).
- Species lower and upper distributional limits were modeled independently. Based on the literature overview, mean annual air temperature was used as limiting for the upper range limit, an Ellenberg climatic quotient for the lower range limit. Use of the the same variables for all addressed species needs to be thought of as simplification.
- In oaks, only the upper tree limit given by temperature was considered. Considering oaks’ drought tolerance, though differing between oak species, we did not expect that future drought would limit oaks persistence in the Carpathians. Potential substitution of temperate oaks by Mediterranean oaks is discussed, but not modelled.
- Specific approach was applied in case of spruce. Lower range limit was specified by climatic limit of highest abundance of beech, as biotic interactions, such as competition of beech, are expected to shape lower range limit of spruce rather than the climate. Upper range limits was modelled as in the case of other species, using mean annual air temperature limit.

Figure 21 Subregions of the Carpathians for which functions describing response of tree species abundance to climatic gradients have been calculated. The displayed zone around subregion borders wide 50 km is used to secure smooth transition between subregion-specific functions.
5.3.4.2. Results of national literature overview

We performed detailed literature overview on observed or projected forest tree species shift in Carpathian countries. We used evidences reported in scientific papers, project reports and also some personal communications. This information is described in detail in Deliverable SR2.T5.D1 produced by SR2. Here we compile the main findings.

SLOVAKIA

Diverse geomorphology and intensive elevation gradient implies that the most remarkable signs of species shift, i.e. tree line upward expansion in the mountains, and retraction of lower range limits of species distribution, may be present in this region. Intensive south-north climatic gradient driven by elevation also implies increased forest dynamics at contact of zonally arranged forest communities due to climate change induced changes in species competitiveness. Generally, competitive relations between various oak species, oaks and beech, and oak-beech and spruce are supposed to shape the future of forests in this region. Frequent disturbances, mostly related to windthrows followed by bark beetle outbreaks, may support species shift by colonization of deforested areas by both species migration from lower elevations and by human assisted colonization of such areas in order to enhance stands resilience to changing climate.

On the other hand, forests in Slovakia are intensively managed, and present species distribution differs from that original. Mainly the share of Norway spruce has been artificially increased to the detriment of native broadleaved, and its present share reaches 26.4% (510,000 ha); the estimated share of spruce in natural species composition makes up 6%. These factors hamper substantially the assessment of climate change induce species shift as such process can be largely covered by changes in forest management induced for example by changes in ownership, or natural ingrowth of broadleaved in artificially planted spruce forests. Inherent forest dynamics related to stands maturation, and effect of disturbance makes such assessment even more difficult.

In addition, lack of observation evidences and present low economic and ecological importance of species shift caused that species shift has not yet been recognized as scientifically sound topic, and it has been investigated only rarely. On the other hand, various modeling exercises, based mostly on the concept of environmental envelope modeling, have been produced to guide the development of adaptive forest management strategies.

Long-term change in species composition of forest tree, shrub and herb layers

We present here result of investigation based on approximately 20,000 permanent forest plots which were established within the frame of forest typology survey in the period 1951-1977. During the period 2005-2007, repeated measurements were conducted in 2,250 plots. This dataset was used for the investigation of long-term changes in species composition, forest stand structure and other parameters, including evaluation of climate change effects on species shifts (Vladovič et al. 2008). Shift of species optima along elevation gradient has been addressed. Elevation minimum, maximum and optimum of selected indicator species have been identified for both addressed periods (past and present). Only taxa with frequency of occurrence above 30 in both time periods were considered.

The authors found out that distribution of species under the present-day conditions remained, on average, the same as under past climate, thought variability of species elevation shifts was high, ranging from -300 to +250 m a.s.l. (Figure 22). Species showing significant upward or downward shift have not possessed any common traits, thus not allowing the inference of specific response of some functional group of species.
The authors assume that increased precipitation compensated the evaporative loss increased by raised temperature, and thus the availability of soil water remained unchanged. Hence, species distribution has not been affected. In the same time, temperature itself did not acted as limiting factor, as may be the case of montane ecosystems, and no significant upward shift was recorded for some group of species. Observed high variability of species can be attributed to natural forest dynamics related to stands maturation, succession-related processes, and inherent dynamics of biotic interactions.

Figure 22 Distribution of differences between past and present elevation optimum of surveyed species. Column height indicates frequency of species (a) and relationship between past and present elevation optimum of surveyed species (b).

**Indication of tree line shift**

Mountain dwarf pine (*P. mugo*) creates the upper tree line in highest mountain crests. Therefore, dwarf pine upward expansion use to be studied as first signs of climate change effects, which can however be confounded with land abandonement in highest elevations.

Solár (2013) and Solár and Janiga (2013) found out that mountain pine cover in the Western Tatras Mts. was permanently increasing in the period 1965–2002. The total surface area covered by mountain pine increased from 8,173,812 m² in 1965 to 10,141,505 m² in 1986 and 11,394,461 m² in 2002. The percentage of total surface area covered thus increased from 41.8% in 1965 to 51.8% in 1986 and 58.2% in 2002. The mean increase of mountain pine surface cover was in all periods about 0.4 percent per year. From 1955 to 1986, mountain pine cover probably increased mainly in areas that were subject to grazing.

The authors identified an apparent shift and densification of *Pinus mugo* scrubs at higher altitudes. The authors claim that this shift correlates with recent climate change. Longer growing seasons, milder winters, shorter duration of snow cover create favourable conditions for the growth of mountain pine.

Though authors tend to claim that observed shift has been induced by climate change, this conclusion is rather questionable considering the former management of sites above the tree line. In the past, intensive removal of dwarf pines by felling and burning out was applied. Later, planting and natural recovery occurred. In addition, there are areas in the High Tatras Mts. where the range of dwarf pine has not showed any shift during the last 50 years, as can be seen in historical photographs. The period of maximum shift reported by authors was observed till 80th of the last century; this period corresponds with most intensive planting at tree line was conducted, being a rule of Tatras National Park Administration. In addition, period up to 1980 cannot be thought as period with changing climate, potentially inducing tree line shift. After the restriction of grazing in some national parks, progressive long-term trends in secondary succession and patterns of plant
establishment driven by climate was observed this could be confounded with climate-change induced species shift.

**Colonization after disturbances**

Extent of forests damaged by windstorms and subsequent bark beetle outbreaks has been substantially increasing, and it follows the general trends in forest disturbances in Europe. Deforested areas, mainly in mountains (High Tatras Mts., Low Tatras Mts., Beskids Mts., etc.) (Figure 23), provide opportunity for enrichment of mostly spruce dominated forest stands by other tree species. Damaged soil cover also provides opportunity for establishment of new species, including invasive. Except for natural regeneration, also human-assisted introduction of new species is often applied.

We mention here the results of forest regeneration monitoring after large scale wind calamity which stroke forests in High Tatras Mts. in 2004. The research was conducted in several cycles at number of forest monitoring plots. We present here only the results of natural regeneration monitoring, this however coincided with artificial planting.

Spruce along with pioneer species such as birch (*Betula* sp.), mountain ash (*Sorbus aucuparia*) and goat willow (*Salix caprea*) dominated, and these species constituted 80-90% share in individual height classes. Surprisingly low share of pine (*Pinus sylvestris*) and larch (*Larix decidua*) was recorded. Species with low abundance were fir (*Abies alba*), European ash (*Fraxinus excelsior*), javor horský sycamore (*Acer pseudoplatanus*), Swiss pine (*Pinus cembra*) and aspen (*Populus tremula*) (Šebeň and Bošela 2011).

Concerning species shift, an important finding is that no species typical of warmer climates appeared in the regeneration in mountain location of the study area. Regeneration pattern was similar to previous large scale disturbances, though series of warm and dry years followed the event.
Figure 163 Example of the comparison between aerial photographs: changes between 1965, 1986, and 2002 (Source: Solár 2013). Upward shift of dwarf pine in High Tatras Mts. can be seen.

**Projection of species shift using growth simulations along elevation gradient**

Hlásny et al. (2011) performed an assessment of climate change effects on growth, mortality and carbon cycle of oaks (*Quercus* sp.), European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*). This report is study is complemented by project reports Hlásny et al. (2010) and Hlásny et al. (2012), where additional information on Scots pine (*Pinus sylvestris*) is given. Changes in tree growth also indicate changes in species competitiveness, and can be interpreted in terms of species shift.

The SIBYLA growth simulator (Fabrika and Šurský 2005, 2006) was used to model climate change impacts on tree production and natural mortality. SIBYLA is an individual-tree, distance-dependent model. It is an empirical, ecological niche-based model that simulates the growth of individual trees and in doing so, evaluates inter- and intra-specific competition among trees.

The following quantities were investigated:

- total volume production, calculated as the sum of growing stock at the end of the simulation period and mortality during the simulation period;
- change of growing stock, calculated as the difference between the growing stock at the end and beginning of the 30-year simulation periods; and
- cumulative volume of dead trees, calculated as the sum of naturally dying trees during the simulation period. This quantity has not been presented here, and can be found in Hlásny et al. (2011).
Relative change between the growing stock at the end and beginning of the 30-year simulation periods was calculated as the difference between final and initial stock relative to the initial growing stock (%). Because the initial growing stock was uniform for all 30-year simulations, the temporal evolution of the relative change of growing stock can be directly translated into absolute growing stock (stem and root) increment. The final analysis examined the differences in mean values of total volume production, change of growing stock, and cumulative volume of dead trees at the end of simulation periods in all plots within the respective VZs. This design allowed us to include a large part of the variability in natural conditions for each VZ. To allow for broader use of the results, we investigated relative changes rather than the absolute changes.

**Oaks** - As expected, the current study indicated that oak production was almost insensitive to climate change in Central Europe. Production equal to that in the reference climate, and even decreasing mortality in elevations up to ~300 m a.s.l. (not presented here, see Hlásny et al. 2011), suggest sustainability of oak forests in this region. Increasing production in elevations above 400–500 m a.s.l. by up to 10% in the future suggests potential expansion of oak distribution upwards. Generally, projected changes are highly variable, though remaining in the future on the same level as in the reference period. Climate change is not expected to negatively affect the receding edge of oak forests in Central Europe provided that resident pests and pathogens (e.g. defoliators such as *Lymantria dispar* L. or tracheomicotic fungi such as species of *Ceratocystis* and *Ophiostoma*) do not increase their outbreak ranges (Hlásny and Turčáni 2009) and virulence, and provided that newly emerging species (Bolte et al. 2009) do not substantially alter the present forest disturbance regime. The presented results imply the persistence of oak species in the zone of their present distribution, stable or improved production in this zone, and potential expansion upwards. Such expansion may be efficient especially on nutrient-poor and drier stands, where oak can successfully compete for resources with the resident species.

**Beech** - In the reference period, the production optimum for beech was in VZs 3 to 5. The simulated change in growing volume in VZs 7 to 8 was negative, indicating that mortality was greater than the increment. This corresponds with the current beech-free status of these zones. In the near future, beech production was projected to decline by 5 to 10% in VZs 1 to 2, where various oak species naturally dominate (mainly *Quercus cerris*, *Q. robur*, and *Q. petraea*). A decrease in beech production by as much as 10% was also projected in VZs 3 to 4, which is presently the ecological optimum for beech. Production in the 5th VZ remained similar to that of the reference period, while an improvement of 15 to 40% was projected in VZs 6 to 8. The change in growing stock in the 8th VZ was zero (versus – 150% in the reference climate); thus, the climate was projected to continue to critically limit the growth of beech in that VZ (without consideration of edaphic limitations). The small gains in VZs 6 to 7 prevented the increase from compensating for the reduced production in the dominant VZs 3 to 4. Beech production response in the distant future corresponded to that of the near future, except that it was more pronounced. The 1st and 2nd VZs were critical, because the differences between the final and initial stock volumes turned negative. Reduction in the growing stock by as much as 50% compared to the beginning of the simulation period, along with an increase in natural mortality by up to 30%, indicated a radical, drought-induced reduction of beech distribution in the distant future. The mortality significantly increased (20 to 40%) in VZs 1 to 6, while it decreased in the marginal VZs 7 to 8 (not presented here, see Hlásny et al. 2011).

**Spruce** - The spruce growth simulations indicated a generic response pattern of declining production at lower elevations and increasing production in spruce’s ecologically (but not productively) optimal 7th VZ (1250–1550 m a.s.l.) by the end
of the century. Compared to the reference period, production was projected to decline in VZs 4 to 5 (which represent spruce’s production optimum in the reference period) but increase in VZs 6 to 8 (8th VZ is however presently spruce free dwarf pine zone). This trend was projected to be more pronounced in the distant future than in the near future. Increased production in VZs 6 to 7, which are the VZs with the highest proportion of spruce, could positively influence regional forest production. The production optimum for spruce was projected to shift in the distant future from the 5th VZ to the 6th to 7th VZs. In contrast to beech, the change in spruce growing stock remained positive, even at its present lower distribution range (4th VZ). The simulations indicate possible spruce expansion to dwarf pine zone, which has already been reported in several studies from the Carpathians. Direct effect of changing climate on the retraction of lower range limit cannot be expected, as spruce occurs in Europe in much southern and arid location as compared with the lower elevations of the Western Carpathians. Spruce retraction can be however substantially supported by drought induced increase in activity of pests and pathogens, and by increased competitiveness of beech penetrating to present distributional zone of spruce.

**Pine** - Response of pine production to changing climate is similar to spruce, though it is less distinct, i.e. production decline in lower elevations and increase in higher elevations are not as intensive as in case of spruce. This fact can be interpreted as lower climatic sensitivity of pine’s production, and supposedly also weaker tendency to shift. The simulations indicate that pine’s production optimum was in 5th – 6th vegetation zone under the reference climate. This corresponds well with outputs of national forest inventory conducted in Slovakia in the period 2004-2005 (see Hlásny et al. 2012). In the near future, production optimum was projected to shift to 6th – 7th vegetation zone. Substantial decrease in production was projected to occurring in 4th vegetation zone in the distant future (15% less as compared with reference period), where presently lies 26% of pine forests in Slovakia. Production ca. equal to reference period was projected for 6th – 7th vegetation zone (±5%), what is key information, because 66% of pine forests are distributed here. Production increase by 12-15% in 7th vegetation zone was projected for both near and distant future, and such increase can compensate, in minor extent, anticipated losses in lower elevations. Production increase in 8th vegetation zone needs to be thought of as hypothetical, as pine is presently not occurring there.

**CZECH REPUBLIC**

Most of the Czech part of the Carpathians is covered by managed forest with high share of secondary Norway spruce stands, therefore indications of species shift in such environment is difficult to identify. No systematic research of climate change induced species shift has been conducted in such environment as inherent forest dynamics is supposedly suppressed by forest management. Upper tree line is not present in this region, therefore its shift cannot be evaluated. There are two protected areas NPA Beskidy and NPA Bílé Karpaty which contain more natural forest communities, however, empirical studies evaluating the changes in species composition of forest and other plant communities are, up to our knowledge, not available. There are however some studies on projection of forest vegetation zones in the Czech Republic under climate change, which can be also used to describe the anticipated changes in the Carpathian.

**Projected shift of forest vegetation zones**

The area with the conditions of the 1st vegetation zone was projected to be the most widespread in the Czech Republic in 2030, and will cover almost a third of the country (29.44 %) (4.19). The area with the conditions of 2nd zone will increase to 17.11 %, and the area with the conditions for 3rd zone will increase to 27.40 %. The area with of vegetation 4th zone, the most extensive vegetation zone nowadays, will decrease from the present 43.07 % to 20.07 % in 2030. The area with the
conditions of 5th zone will decrease substantially to 4.77%. The area of 6th vegetation zone (spruce-fir-beech), 7th vegetation zone (spruce), and 8th vegetation zone (dwarf pine) will decrease from the present 3.68% to only 1.22%.

The projected shift may feature a substantial improvement in conditions for xerothermophilous Ponto-Pannonian biota. The area with climatic conditions of present-day vegetation zones 1 and 2 will increase from the present-day value of 15.51% to 46.55% in 2030. There will be a reduction in the area with conditions for Central European broad-leaved deciduous forest species. The area of the territory with the climatic characteristics of vegetation zones 3–5 will decrease from the present 80.80% to 52.24% of the country’s total area. There will be a substantial reduction in the size of the territory with conditions for the occurrence of boreal forest mountain species, related to a colder and moister climate, as the area with the conditions of vegetation zones 6–8 will decrease to a third of the present-day values.

Similar research as described in the previous chapter was conducted by Vahalík and Klimánek (2013). The authors modelled the climate change induced shift of forest vegetation zones in the Czech Republic using different approach as was used in the previous study. Altitudinal zones modeling were performed by using two different methods: Maximum Likelihood Classification and discriminant analysis. Results of simulation are presented in Figure 24. The authors did not provide detailed information on results of their analysis.

![Figure 174 Climate change induced shift of forest vegetation zones in the Czech Republic proposed by Vahalík and Klimánek (2013).](image)

Kupka (2006) elaborated critical evaluation of climate change impacts on forest of the Czech Republic, including notes on anticipated species shift. The author suggests that pedunculate oak (*Quercus robur*) is expected to dominate in lowlands and lower montane zone, where it will occupy heavier and moister soils and alluvia. Based on extensive distributional range of Pendunculate oak, stretching even to Scandinavia, the species is expected to withstand severe winters as well as benefit from the oceanic climate. The author assumes that Pedunculate oak may dominate in low to middle elevations. Drier sites could be occupied by Sessile oak (*Quercus petraea*), which may presently occur up to elevations of 500-600 m a.s.l. Oak forests may be enriched by hornbeam, lime, mapple and elm. Especially the share of sycamore maple and lime could be increased as compared with present-day,
mainly in nutrient-rich stands. Unless tracheomicotic disease affects oak forests, the share of aforementioned species could be even higher.

Warmer climate with mild winters could favoure species sensitive to early and late frosts; hence share of beech and fir could be substantially increased. Present climatic optimum of beech is in the zone with mild winter and sufficient precipitation. Present optimum in the elevation 300-500 m a.s.l. could shift under changing climate to higher elevations, where presently beech stretches on warm calcacerous bedrock. Similarly, fir absent in areas with severe winters, and moist summers with mild winters represent typical fir climate. Present optimum of fir is at annual precipitation totals of 750 mm. Spruce is expected to remain mountain species with sparse distribution at climatically suitable sites.

**POLAND**

The topic of climate change inducted shift of main forest tree species in Poland is relatively new. Information about the shift of main forest tree species in Western Carpathians and the outputs of various modeling exercises comes mainly from the papers of Socha and Suchanek (2011), Socha and Durło (2012), Socha and Szydłowska (2013) and presentation from IUFRO Conference in Edinburg 2013 by Socha and Lesiński (2012).

**Climate change effects on site suitability for beech and spruce**

As was mentioned in the simulation experiment performed in Slovakia in the chapter 4.2.1, productivity is important indicator of trees vitality and competitiveness, and thus its changes may imply the anticipated species shift. The objective of this study was to identify the relationship between present climatic conditions and the growth of Norway spruce and European beech, and to simulate the effect of anticipated changes in temperature and precipitation in Poland.

The case study were carried out in the Western Beskids (18°48'50” E and 19°58'58” E longitude and 49°23'52” N and 49°41'3” N latitude) in the Western Carpathians region, the southern Poland.

Authors used historical meteorological data from the period 1956-2008, present climatic data from 43 meteorological stations and scenario data for 100 years ahead. In order to simulate the effect of climate change on site conditions, models describing relationships between the potential site productivity, expressed by means of site index, and the basic climate indicators were developed.

The observed trend of increasing mean annual air temperature undoubtedly will modify site conditions for Norway spruce and European beech. When adopting the scenario assuming the doubling of CO₂ concentration in the atmosphere, the mean annual temperature projected under this scenario would increase by about 2.7° C and the rainfall during the growing season would decrease by about 70 mm. Such changes would result in a significant deterioration in site conditions for Norway spruce and improvement of site condition for European beech in major portion of forests in the Western Carpathians, especially in higher elevations. In these new and altered site conditions Norway spruce could maintain a dominant role among tree species at the highest locations, i.e. above 1 000 m a.s.l., only. Under this scenario, the species composition of stands at the lower altitudes should change. At the same time, improvement of site conditions for European beech and vertical expansion of this species can be expected.

The difference between the current and future potential site productivity was used to map changes in site productivity for the projected level of carbon dioxide concentration. The consequence would be the reduced site index, particularly apparent in elevations up to 800 a.s.l. and significantly increased site index for European beech, especially in higher elevations.

A slightly better prospect for the growth of Norway spruce in the Western Carpathians was projected under the scenario assuming a 30% increase in CO₂ concentrations in the next 50 years. The scenario implies the increase in mean annual air temperature by about 0.7 °C while maintaining the mean annual
precipitation at their current level. In the same time, a slight reduction in rainfall during the growing season is projected. These changes would cause slight deterioration in site conditions for Norway spruce up to an altitude of about 800 m a.s.l., and secure optimal growth conditions for Norway spruce within the zone between 850 and 1,000 m a.s.l. In the same time, improvement of site conditions for European beech in the all analysed area can be expected, however the magnitude of increase in site index for this species is smaller than in previous scenario considered, and it varies along the elevation gradient. On the lowest elevations, only slight improvement of site conditions for European beech can be expected, and magnitude of site conditions improvement for European beech may increase with increasing elevation.

The presented analysis indicated that even a slight increase in mean annual temperature may adversely affect the growth and development of the Norway spruce and European beech stands over a large area of the Western Beskids. Such results can be used as a basis for decisions concerning the future role of addressed species in optimisation of future species composition.

The presented projections indicate trend in potential change in species composition, which is obviously reported from such studies, i.e. improvement of growing conditions in higher elevations accompanied with potential expansion, and growth and vitality decline in lower elevations. The authors expect that spruce forest can move to higher altitudes under warming climate, site conditions improvement for European beech may result in spruce substitution in the contact zone of these species.

In the Polish part of the Carpathians, however, substantially changed species composition towards increased share of Norway spruce needs to be considered (mainly in the western part, the Western Beskids region). Such changes may induce increased forest dynamics related to disturbances, and faster substitution of spruce by broadleaved. Forest management supporting climate change adaptation, including assisted colonisation of deforested areas, may largely modify the future species composition of these forests.

Changes in treeline

In the northern Carpathians in Poland a slow decline of mountain agriculture has started since the peak of agricultural expansion around the middle of the 19th century (Kozak 2003). Throughout the 20th century the decline of agriculture resulted in a steady increase of forest cover – forest transition in the sense proposed by Mather (1992) – strengthened in some regions by re-settlement actions and depopulation processes (Kozak et al. 2007). Especially in the sub-alpine and alpine areas depressed anthropogenic timberlines were gradually expanding up. This expansion has led to the removal of many mountain pastures and re-establishment of spruce communities in the formerly deforested areas (Sitko and Troll 2008).

Treeline analysis in the Polish part of the Tatra Mountains was performed by Czajka et al. (2010). Relatively low portion of old trees in treeline suggested that treeline in the studied region was established in last 50 years. Previous treeline boundary was changing and adjusted to past climate changes from the beginning of glacial period. However, the largest changes in forest range in Western Tatras Mts. are connected to decline in grazing by sheep. Trees growing on the area of past grazing lands show higher diameter increment.

The growth of Norway spruce is controlled by climatic factors and it is observed that individuals occupying higher elevations in the period from early 80's of the 20th Century form wider increments, while trees in the area of older ecoton, shows comparable tendencies to regional chronology for Tatra Mts.

HUNGARY

Hungary covers 5.1% of the Carpathians, and Hungarian Carpathians contains 4,336 km² of mostly broadleaved forests. Hungary, along with southern planar to
colline parts of Romania, represent specific region of the Carpathians with ecosystems significantly vulnerable to climate change. High climatic exposure presented in the maps in Chapter 3.3 implies that mainly east of the Hungarian part of the Carpathians may face substantial temperature increase. In the same time, two out of four RCM used in this study imply that Ellenberg climatic quotient may increase the value 40, what implies occurrence of severe droughts with adverse effects on forest vegetation.

The shifts in drought frequency may cause changes in lowland forest regions. Even a relatively minor shift of temperature and precipitation may profoundly affect the present climatic niche of dominant forest species. Mass mortality may appear at the rear edges, especially on sites with unfavourable water regime. Effects of drought on Hungarian forests, specifically on forest growth, mortality and distribution, have been subjected to long-term research which was, among other factors, initiated by need for development of adaptation measures.

**Present and forecasted xeric climatic limits of beech and sessile oak distribution in Hungary**

Sessile oak and European beech form extensive zonal forests distributed throughout the Central Europe and reach their xeric distributional limits within the forest-steppe biome transition zone of Hungary. The rise of temperature, and especially summer rainfall deficits expected for the 21st century, may strongly affect both species. Experimental studies and field survey data suggest increased mortality rates following prolonged droughts. Mass mortality and range retraction are potential consequences, which have been already sporadically observed in field survey studies (Berki et al. 2009; Jump et al. 2009).

Beech and sessile oak forests of Hungary are to a large extent the “trailing edge” populations, which should be preferably modelled using specific modelling strategies. In general, most of modelling studies do not differentiate between leading and trailing edges, and rely on assumptions and techniques which are intrinsically more appropriate for “leading edge” situations. Further, we present the results of study by Rasztovits (2011), who strived to address some methodological caveats of such modelling.

The results show that climate change may lead in Hungary to drastic reduction in macroclimatically suitable sites for both beech and sessile oak forests (Figs. 40-41). Applying the calculated thresholds to the probabilistic projections reveals that 56–99% of present-day zonal beech forests and 82–100% of sessile oak forests might be outside their optimal bioclimatic niche by 2050. Potential area reduction is highest for scenario HadCM3-A2, and lowest for CSMK3-A2. CSMK3 scenarios are generally milder than all other scenarios projecting lower summer warming and no significant decrease in precipitation during either half year.

Such findings imply dissapearence of beech suitable climate by 2050 for most of Hungary, and potential substitution by drought more tolerant species. Interesting finding is also substantial reduction of climatically suitable sites for sessile oak, though projection implies oaks` persistence in the future.
Figure 185 Actual distribution of beech-dominated zonal forest stands in Hungary (a), consensus projection maps for the probability of presence (b-e) and their uncertainty (f). Time horizons for the mean projections: 1975 (b); 2025 (c); 2050 (d); 2085 (e). The intensity of shading indicates the probability of the location to be above the xeric limit for stable zonal stands. Tile (f) demonstrates uncertainty by the standard deviation of the ensemble runs for the 2050 time horizon.
Case study 2: Changes in species composition at the Síkfőkút forest stand

The research was carried out at the Síkfőkút site established in 1972 by Jakucs (1985) for the long-term study of forest ecosystems. The experimental site of 27 ha is located in the south part of the Bükk Mountains in North Eastern Hungary at 325 m altitude. The forest is a semi-natural stand (Quercetum petraeae-cerris community) without forest management.

In Hungary, the annual average temperature increase was 0.68 °C, while the annual average of precipitation decrease was 83 mm, during the last century.

During the last few decades the long-term meteorological data of the Síkfőkút Forest indicated similar changes in climate, and regional forests became drier and warmer (Szalai 2004, Jolánkai et al. 2004). Due to this change, forest structure and species composition have changed. Since 1972, 68% of Quercus petraea and 16% of Q. cerris trees died and new tree species (Acer campestre, A. tataricum, Cerasus avium, Carpinus betulus) have grown up in the gaps from the shrub layer into the canopy layer (Bowden et al. 2006; Kotroczó et al. 2007). The new species created a second canopy layer.

Decline affected two main oak species present in the stand - sessile oak (Quercus petraea) and Turkey oak (Q. cerris); however sessile oak was affected considerably stronger. Higher vitality of Turkey oak under progressive drought can be explained by its better adaptability to warming and drying of climate. The adaptability is presumably connected to the higher water storage capacity which was pointed out inside the trunk of this submediterranean oak species.

As compared to the survey which was carried out in 1973, no regeneration of oak appeared on the study area during the last few decades, although game damage could have contributed to this situation. Mass regeneration and spreading of common maple characterizes the canopy level. Gaps in the canopy level accelerated the warming and aridification of the forest.
Case study 3: Drought induced damage to forest

The gradually growing moisture deficit in Hungary has led to health problems in Hungarian beech forests since the 1990s, first of all in the Southwest of the country where climatic changes were the strongest, and where the stands are at low elevation and close to the xeric limits (Mátyás et al. 2010). The weakened trees became more sensitive to secondary pests and pathogens and showed symptoms of health deterioration (early leaf abscission, sparser crowns, etc.). The extent of climate damages of the drought years 2000–2004 has been investigated in two West Hungarian state forest companies. In 460 damaged forest compartments (total area: 3900 ha) 87.7 thousand m$^3$ of damaged timber was harvested. The damaged stands were mostly above 60 years. The area most damaged was the Zalaegerszeg forest district (Zala county), where mass mortality was triggered in mature beech stands after regeneration cuts, when the canopy closure was opened up. This led to the outbreak of the otherwise harmless beech buprestid (Agrilus viridis). Damage of Biscogniauxia nummularia disease and of the beech bark beetle (Taphrotychus bicolor) occurred together with the buprestid damage. As a consequence close to 70,000 m$^3$ of sanitary felling had to be executed in 2005 in that forestry district alone. The type of damage supports the observation of forest protection experts that disturbance of the closed canopy increases the risk of climate damage.

Figure 197 Percentage of compartments in West Hungarian forest companies damaged by drought events 2000-2004 (vertical axis) in relation to their climatic position (climate worsens toward lower tolerance index values, horizontal axis).

A close correlation was found between the climate classes and the percentage of stands damaged to various degrees (Figure 27). Extrapolating this information on the national scale, 23% of the 104 thousand ha of beech forests may be assumed as threatened with 9 million m$^3$ of total standing volume. For year 2065, a tripling of these figures was extrapolated (76%, 29 million cu.m.). To avoid further increase of damages, a faster rotation (lowering of rotation age) is proposed by silviculturists.

Case study 4: Drought induced tree mortality close to beech xeric limit

For the closer definition of extreme weather effects leading to the “mortality syndrome” in beech, threatened stands have been selected in different parts of the country. Criteria of selection were: at least medium-age, zonal site (primarily climate dependent site, at least medium deep soil with no defects, no hydrological influence) and position as close to the xeric limit as possible. Weather conditions and mortality events in the stand in the recent past were reconstructed. For the
analysis on annual basis, Ellenberg quotient had to be modified to be suitable to characterise individual years’ weather. Mean temperature of the 3 summer months was used for the annual EQ index instead of just July’s, to avoid random effects of individual months.

Investigation of mortality frequency has shown that single drought events did not threaten the stability of populations. The recurrent drought period lasting up to five years in some areas, has however resulted in very serious mortality in the investigated beech stands, in one case the population went extinct.

The stand has been selected at the edge of the xeric limit which is indicated by the frequency of droughty years. Years with Ellenberg quotient significantly above 30 have been considered as drought events. Mass mortality started in 2003, in the fourth year of consecutive drought, after an extremely dry summer. Observations at other locations have confirmed that in case of beech, recurrent drought events of 3 to 4 consecutive years (depending on severity) lead in general to irreversible mass mortality and local extinction (Berki et al. 2009). It was also found that not only the number of consecutive years, but the severity of drought period has an influence on the decline. Data of selected observation plots near the xeric limit (Figure 28) confirm a direct, causal link between health and drought. Mean summer drought severity above Ellenberg quotient value 40–42 seem to trigger a mass mortality syndrome.

![Figure 208 Average Ellenberg quotient value of the drought years 2000-2004 (vertical axis) and the health condition of selected mature beech plots at the xeric limit, at the end of the period (percentage of healthy individuals, horizontal axis).](image)

**UKRAINE**

Ukraine Carpathians spread over 11.9% of the Carpathians (27,354 km²). The region contains mountain crest of Chornohora with highest elevation 2,061 m a.s.l. (Hoverla Mt.). The estimated forest cover is 40.0 – 42.0% (Chernyavskyy et al. 2011; Svyrydenko et al. 2005). European beech and Norway spruce dominate in forest tree species composition.

Only sparse and indirect information exist on climate change induced species shift in the Ukrainian Carpathians. Because of higher elevation of the region and presence of tree line, mainly processes related to tree line shift, and increased dynamics at contact zone of higher elevation zonal tree species such as beech, spruce and dwarf pine, have been investigated (e.g. Sitko and Troll 2008; Martazinova et al. 2011; Shandra et al. 2012).
**Preliminary observations from long-term forest monitoring plot**

The network of permanent research/monitoring plots established in the 1930s by Zlatník in the current Transcarpathian Ukraine provide unique data for the investigation of climate change induced species shift. Repeated measurements on forest plot in the Father Ivan Mt. in the Maramures mountain range led to the conclusion that a change is being manifested in the altitudinal shift of tree species. Specifically, the European Beech (*Fagus sylvatica*) and European Silver Fir (*Abies alba*) were found to expand to higher altitudes (Buček et al. 2008). These results need to be thought of as preliminary, they however draw attention to this experimental design.

**Tree line shift**

Project “Climate and Tree Line Dynamics in the Carpathian Mountains” supervised by University of Nevada, and supported by USDA, National Institute of Food and Agriculture (NIFA) ([http://www.reeis.usda.gov/web/crisprojectpages/0220743-climate-and-tree-line-dynamics-in-the-carpathian-mountains.html](http://www.reeis.usda.gov/web/crisprojectpages/0220743-climate-and-tree-line-dynamics-in-the-carpathian-mountains.html)), focused on the investigation of tree line dynamics in Ukraine. The main findings are the following:

- The current treeline in the Ukrainian Carpathians is much lower than its climatic approximation, which suggests that tree line position is strongly influenced by land-use practices, and therefore that mountain forest responses to land-use change may largely obscure potential responses to climate change.
- Considerable net forest increase has occurred near the treeline, indicating that substantial changes are happening at this ecotone, similarly to other European mountains.
- Coniferous timberlines have risen in elevation, while deciduous ones have remained stable. At treeline, conditions are advantageous for the invasion of coniferous species throughout the whole Carpathian Mountains.
- Changes in forest cover mainly happened during 1940-2000; there had been little change in forest cover during 1880-1940.
- During 1880-2000, forest cover in the Ukrainian, North Romanian, and South Carpathians has declined at lower elevations, which can be attributed to widespread illegal logging in post-socialist times. At higher, less accessible elevations forest cover has mostly increased. In the West Carpathians forest cover has evenly risen at all elevations.

Complementary information was provided by Martazinova et al. (2011), who conducted research on land-cover changes above the upper forest limit in the Ukrainian Carpathians. The authors found out that grass cover significantly decreased at sites with conifers. Spruce moved to higher altitudes, mainly on the northern slopes, whereas beech stands on the southern slopes in the same area, did not show any significant shift. Apparently, the greatest changes were recorded at those sites where upper forest limit was marked at higher elevations. The mountain pine area has been reduced because of expanding spruce forests. This has been observed mostly at southern slopes, where the natural timberline is higher.

Martazinova et al. (2011) examined climate change and treeline dynamics of the Ukrainian Carpathians Mts. during the 20th Century. Comparison of treeline positions in 1930s and 2000 reveals a decrease of area above the treeline and a general rise of treeline elevation, mostly in places where the treeline is formed by coniferous species. However, at locations with predominantly deciduous species there is little or no change. The magnitude of change is spatially heterogeneous. The authors consider warmer temperatures, among other relevant factors, to have impacted the observed treeline changes.

Concerning spatial distribution of tree line shift, the authors state the following. The Beskid region comprises low-elevated mountains proximate to settlements. It is
probable that human disturbance has impeded further treeline advance at these locations. The Gorgans, remote high elevated mountains with limited human access, have experienced the most significant treeline rise. On the contrary, the treeline of the Poloniny mountain ridge, located in the beech forest zone, was lowered during the study period. Treeline altitude of the Chornogora and Marmarosh, the highest-elevated mountain ridges of the Ukrainian Carpathians, has risen but to a somewhat smaller extent than on the Gorgans. Spatial variability of described tree line shift is presented in Figure 29 and 30.

Figure 21 Spatial distribution of tree line advance coefficient imposed over geobotanic map of Ukraine (Source: Martazinova et al. 2011).

Figure 30 Changes in treeline position on Svidovets mountain ridge (Source: Martazinova et al. 2011).
**Invasion**

The Ukrainian Carpathian Mountains are a prime example of a temperate mountain range that is experiencing increased rate of invasion by alien plant species established for over a century in the adjacent lowlands and spreading to the interior of the mountains, including existing and proposed conservation areas (Simpson and Prots 2012).

There is a range of drivers which induce alien species expansion to new areas. In Ukrainian Carpathians, anthropogenic disturbances to natural ecosystems, changes to land use in the post-Soviet era and agricultural mismanagement, climate change, etc. are the main drivers. Invasive plant species are found at high densities in close proximity to urban centres, major highways and riparian habitats in the Carpathian foothills and mountain valleys, and disperse into protected areas along the frequently disturbed linear corridors.

Predictions of habitat suitability were projected under two scenarios depicting increasing rates of climate warming and anthropogenic disturbances in 2050 and 2100.

Under current climate and disturbance patterns, the models predicted suitable habitats for invasive species establishment to be aggregated in the south-west, east and north-east of the Ukrainian Carpathians, along major rivers and roads at altitudes of up to ca. 700 m a.s.l.. Eight per cent of the total area within protected areas was predicted to be potentially susceptible to invasion by at least one species, with 13% of these susceptible habitats being suitable for all 11 species (Figure 31).

![Projected spatial distribution of suitable habitats for establishment of at least one or nine invasive plant species/genera by (a, b) 2050 and (c, d) 2100 within the study area and within protected areas and ecological network assuming (a, c) climate change (CL) and (b, d) climate change and high economic development (CLandHED). Source: Simpson and Prots (2012).](image-url)
ROMANIA

Romania contains the largest area of the Carpathians, and forms the eastern and southern boundaries of the region. The Romanian Carpathians are divided into three units: Eastern Carpathians, Southern Carpathians and Western Carpathians. The highest peaks are in the Southern Carpathians – Moldoveanu (2,544 m a.s.l.) and Negoiu (2,535 m a.s.l.).

The 55.2% of the Carpathian region is located within Romania, while 47.4% of Romanian territory is part of the Carpathian mountain range. Forests occupy 26.7% of the country, and 60% of “forests are located in the Carpathians, 29% in pre-Carpathian hills and 11% in lowland areas. The most deforested area is the Western Plain (3.2%), Baragan Plain (3.5%), Moldavian Plain (4.1%) and Oltenia Plain (5.3%). Forests in Romania are mainly made up of deciduous species. The remaining 30.7% of the forested areas are made up of resinous species (Cuculeanu et al., 2002). Mountain forests make up 58.5 %, hills forests 27.3 % and plain and riverside forests 6.7 % of total forest in Romania. The total forested area is 6.249.000 ha, and there is also about 328,000 ha of forest vegetation outside the forest land. Forests are formed by spruce (Picea abies), fir (Abies alba), beech (Fagus sylvatica), sessile oak (Quercua petraea), and other broadleaved species (Tilia sp., Carpinus sp., Ulmus sp., Aces sp., Sorbus sp.), Pedunculate oak (Quercus robur), Hungarian and Turkey oak (Quercus frainetto, Q. cerris), alder, poplars, willows (Alnus incana, A. glutionosa, Populus nigra, P. alba, Salix alba, S. fragilis, etc.) and other species of minor extent.

Tree line shift

In a study of alpine, subalpine, and forest landscapes in the Iezer Mountains (Southern Carpathians, 1,800 – 2,470 m a.s.l.). Romanian Carpathians, the Iezer Mountains are notable for their “high and middle mountain” land-scape and their environmental features (Muica et al 1981; Patroescu and Nancu 1995). The vertical zonation of their vegetation includes all the zones of the Carpathians. Dwarf pine (Pinus mugo) subalpine associations developed and gradually covered subalpine meadows and barren land (Figure 32).

Abandonment of pasture will allow invasive expansion of P. mugo scrubs to new areas. In recent decades, dwarf pine forest has generally lost total surface area as the result of pressure from lower vegetation communities and even secondary pastures (Mihai et al. 2007).

Mihai et al. (2007) described how mountain pine–subalpine associations developed and gradually covered subalpine meadows and barren land (between 1986 and 2002, colonization averaged 0.14 km²/y). However, the mountain pine area has lost some lower stands because of spruce forests, which increased in elevation.

Between 1986 and 2002, dwarf pine colonization averaged 0.14 km²/year. This might be important in the context of the surface of the subalpine and alpine zones in the Iezer Mountains, which is 116 km². Dwarf pine area declined because of spruce forests expansion (ca 8 km²/decade), and such expansion increased with elevation. This is largely a feature of southern aspect slopes (sunny), where the natural timberline is, under some local conditions, higher than 1,850 m a.s.l., as in the Fagaras Mountains, situated in the northern neighbourhood (Voiculescu 2002). By comparison, colonization of barren land by dwarf pines took place at a rate lower than 0.06 km²/year. The coniferous forest zone has a general tendency to increase in elevation. This belt has won the competition against dwarf pines, with an average growth of 6.2 km² in 16 years. Dwarf pine forest actually lost a total surface area of 27.4 km² under pressure from lower vegetation communities such as mixed beech, spruce, and silver fir forests, beech forests, and even secondary pastures.
Evidence of spruce forest move to higher altitudes was provided by Mihai et al. (2007) in the Southern Carpathians in Romania. The scattered observations confirm the replacement of spruce communities by beech communities, a common process in the Romanian Carpathians. The most remarkable feature of coniferous forests is their gradual replacement by mixed forests, which increased by 28.1 km².

Beech forests are the most dynamic in comparison with spruce forests (6.3 km²/decade) and mixed forests (3.4 km²/decade), and in comparison with barren areas and secondary meadows (together representing 3.6 km²/decade). This might be related to general natural recovery of beech on deforested slopes, as has already been observed in other mountain areas (for example in the Postavaru Mountains, 1,799 m a.s.l., Mihai 2005).

In summary, beech forests have recently shown quite high dynamics. Beech is well adapted to mountain pedoclimatic conditions, and follows a large “recovery corridor” along slopes. Small glades and timber harvesting areas within the forests and along slopes have disappeared as a consequence of such expansion. Area pf coniferous forests is increasingly declining, and beech reaches, at some locations, almost the upper tree limit (e.g. Voievoda Ridge).
5.3.4.3. Results of species shift modelling

Projection of present bioclimatic space of oak species

Oaks (Quercus sp.) are favoured by relatively warm and dry climates (Lorimer 1993). Hence, most studies on oak responses to climate in Europe come from southern regions (e.g. Sabaté et al. 2002), while knowledge from the temperate zone is rather incomplete (Berki et al. 2009; Czúcż et al. 2011). Oaks are generally expected to take advantage of anticipated drier climate, and expand over large areas of the temperate zone (Czúcż et al. 2011; Hlásny et al. 2011, Hanewinkel et al. 2012). Some authors also suggest the substitution of present temperate oaks by Mediterranean species (for example Q. cerris, Q. ilex) (Hanewinkel et al. 2012). The latter author showed that, depending on different realizations of three climate scenarios, between 21 and 60% (mean: 34%) of European forest lands will be suitable for a Mediterranean oak forest type only, by 2100. This option has not been considered in the present study, though future occurrence of species presently not occurring in the Carpathians should kept in mind in developing forest management strategies (in greater detail in deliverable SR2.T4.D2 of the CarpathCC project).

The concept of northward and upward expansion of oaks raises a question on change in competitive relations between oaks and beech, which is the main zonaly adjacent species to oaks. Contrasting physiological requirements and stress tolerance of the two zonaly adjacent species imply accelerated forest dynamics in their contact zone. Generally, the greater susceptibility of beech to xylem cavitation can may give oaks a competitive advantage in future forest communities as drought becomes more common and severe (Maherali et al. 2004). Oaks expansion can be expected especially on nutrient-poor and drier stands, where oak can successfully compete for resources with the resident species.

While drought tolerance of oak species implies their upward and northward expansion, drought-induced retraction of their lower range limit should not be pronounced in the Carpathians, though aforementioned increase of share of drought tolerant species can be expected. Therefore, in contrast to other tree species such as beech and spruce, only the expansion of oaks upper range limit, which is climatically controlled by air temperature, has been evaluated in this study. Case study from Hungary presented in Chapter 4.2.4 however suggests worsening of growth conditions for sessile oak across entire Hungary, though critical limits were not exceeded in the Carpathian part.

Limits of approach used in this study are variety of oak species which occur in the Carpathians, the ecology and drought tolerance of which is different (e.g. Epron and Dreyer 1993; Wamelink et al. 2009). Because of limited information of oak species distribution, we derived the climatic amplitude of Quercus robur and Quercus petraea for which the data were available in the results of statistical mapping of tree species in Europe, and projected the shift of such climatic space. Moreover, we have no data on distribution and ecological limits of Mediterranean oaks, and thus we could not investigate their potential to expand north to the Carpathians.

Our results suggests that under the reference climate 1961-1990, high elevations above the temperature limit approximately 4.5°C have been found as climatically not suitable for oaks. These areas were distributed mainly in Slovakia (in the High Tatras Mts., Low Tatras Mts. and Western Beskids Mts.), part of Western Beskids in Poland, main mountain crest of Ukraine and Romania, and minor areas in higher elevations in the southern Romania.

Projections imply that the area with climatically unsuitable condition will shrink substantially in the near future (2021-2050), and main spot of unsuitable conditions remains in highest elevations of northern Slovakia only. Sparse spots of unsuitable conditions will remain also in Ukraine and Romania. In the distant future (2071-2100), all Carpathians, except for highest elevations of the High Tatras Mts., are expected to provide climate suitable for oaks.

As only the air temperature is used in oak projections, there is relatively little uncertainty associated to the use of multiple climate models. In the distant future,
only the HIRHAM model indicates much large spot of unsuitable conditions in the High Tatras Mts. (Slovakia) as compared with other models.

The projected oak expansion can be limited by several factors, such as species specific dispersal rate (see chapter 2.1) and inherent persistence and competitiveness of resident species. In contrast, adaptive forest management may support oak’s expansion as increase of share of drought tolerant species is one of recommended forest adaptation measures (see Deliverable SR2.T4.D2 of the CarpathCC project).

Frequent windstorm damage in higher elevations may provide additional support to oaks` expansion by removing vulnerable coniferous and thus reducing their competitiveness, and releasing ecological space for species which can be favourite by future drier climate. Such process may initiate for example appearance of oak-spruce-fir communities, which, presently occur rarely in some inner valleys of the Western Carpathians.

**Projection of present bioclimatic space of European beech**

European beech is the most abundant native tree in Central Europe (Ellenberg 1996), and it generally plays a central role in current forest transition strategies (Tarp et al. 2000). Beech is a highly plastic and adaptable species, although it becomes climate sensitive close to its xeric distribution limit (Mátyás et al. 2010). Beech is considered a shallow-rooting species (Leuschner et al. 2001), a decrease in water availability is therefore likely to rapidly affect the level of evaporative cooling and hence carbon uptake during photosynthesis. The threat of drought induced decline of beech in Europe has been verified both by field observations (Jump et al. 2006, Mátyás et al. 2010) and modelling exercises (Hlášny et al. 2011). Since climate change may induce beech replacement by oaks in some localities, the trade-off between these two species can substantially shape the future of some European forests.

Sykes and Prentice (1996) projected that beech and other temperate hardwoods would spread to the north and that climate warming would induce an increased rate of beech establishment as a successional response after disturbances. In contrast to the projected increase in growth of beech at higher elevations, increased mortality and reduced production were projected to occur in its lower distribution range. Based on future projections of Ellenberg’s drought index, Mátyás et al. (2010) suggested that beech at lower elevations in south – Eastern Europe could survive increasing drought, assuming that extreme events with subsequent pest outbreaks do not occur. Other studies suggested a decline in beech regeneration (Czajkowski et al. 2005; Peñuelas et al. 2007; Lenoir et al. 2009) and an increase in mortality rates as a consequence of prolonged drought (Berki et al. 2009). Simulation under projected climatic change showed that beech could lose competitive ability if drought stress increases (Lindner 2000). Dry and hot weather during summer were also found to strongly reduce net primary production of beech forests (Ciais et al. 2005). Hlášny et al. (2011) implied that critical beech decline may occur in the distant future (2071-2100) at elevations approximately up to 500 m a.s.l. in the Western Carpathians.

Beech present bioclimatic space was defined using mean annual air temperature, which characterized species upper-range limit, and by Ellenberg climatic quotient, which characterized species lower range limit as has been found in several studies (see chapter 4.2.4 on species shift in Hungary). As can be seen in the map of beech`s bioclimatic optimum for the period 1961-1990 (Figure 33), beech suitable climatic conditions do not cover the highest elevations in the Carpathians (highest locations in Slovakia, Romania and marginally in Ukraine) and lowest elevations in Hungary and Romania. This reflects the inherent zonal distribution of vegetation; lower range limit is shaped by competition of oaks and lack of water, while the upper limit is characterized by transition to coniferous forests with fir and spruce, and low air temperature. Forest dynamics is the latter contact zone maybe accelerated by climate change, mainly in terms of increased beech competitiveness, and beech may take competitive advantage over spruce. Beech penetration into
spruce dominated zone may follow mainly southern slopes; high vulnerability of spruce to wind, snow and biotic agents may amplify beech expansion upwards. Such observations are frequent across the Carpathians.

In the near future (2021-2050), climate in large parts of lower elevations in Hungary, Slovakia, Romania and Serbia was projected to change and unsuitable conditions for beech persistence appeared (Ellenberg climatic quotient exceeded value 40) (Figure 33). Unsuitable conditions appeared mainly in the north of Hungary, Transylvanian Plateau, Outer Eastern Carpathians and Serbian Carpathians. In contrast to substantial retreat in lower elevations, beech suitable climatic conditions expanded to the highest elevations of the Carpathians, what may imply the aforementioned increased forest dynamics at contact zone of beech and coniferous.

In the distant future (2071-2100), conditions suitable for beech are projected to worsen substantially mainly in Romania and Serbia (Figure 34). This corresponds with increasing climatic exposure following the gradient of temperature increase passing from the Western Carpathians to the Eastern and Southern Carpathians (Chapter 4.1). Critical worsening of beech suitable climatic conditions was projected for entire Hungarian part of the Carpathians, and for the very south of Slovakia. Here, however, uncertainty related to the use of several climate models is high.
Figure 223 Bioclimatic space of oak in the Carpathians in periods 1961-1990, 2021-2050 and 2071-2100. The maps indicate the degree of match of four regional climate models used for the projections.
Figure 234 Bioclimatic space of beech in the Carpathians in periods 1961-1990, 2021-2050 and 2071-2100. The maps the degree of match of four regional climate models used for the projections.
**Projection of present bioclimatic space of hornbeam**

Hornbeam (*Carpinus betulus*) is a nemoral subcontinental species. Hornbeam thrives on most soil types, including variety of soil moisture regimes, but apparently avoids most acidic and poor soils. It is considered drought more tolerant species that beech and it can considered, in climate change adaptation, as admixture species in climatically exposed sites.

Hornbeam distribution was found, similarly to beech, well controlled by Ellenberg climatic quotient (Jensen et al. 2004). The author suggests that higher values of Ellenberg quotient, indicating drier and warmer climate, are associated with higher abundance of hornbeam as compare with areas with lower values of Ellenberg quotient, where beech dominates. This corresponds with Ellenberg (1996), who states that at sites with annual precipitation below 600 mm, and July air temperature above 18°C, the Ellenberg quotient exceed value 30 and Quercus-Carpinus forests predominate. This implies suitability of the same modelling approach as was applied in case of European beech in the previous chapter. Our investigations of climatic distributional limits of hornbeam and beech imply that hornbeam xeric limit is characterized by value of Ellenberg quotient ca. 35, while beech ca. 30. In case of upper distributional limit, value 4.5°C for hornbeam and 5°C for beech.

As can be seen in maps for the reference period (Figure 35), climatic distributional range of hornbeam covers larger area as compared with beech, though hornbeam upper distributional range does not reach as high elevations as beech do (see for example zone of unsuitable conditions in High Tatras Mts. in Slovakia). Maps for both near and distant futures (Figure 35) clearly indicate higher drought tolerance of hornbeam, what is represented by large areas of suitable conditions. Critical limits for hornbeam`s persistence were projected to be exceeded in Outer Eastern Carpathians in the distant future. Here, substitution of beech and hornbeam by drought highly tolerant oak species, including Mediterranean ones, will be needed.
Figure 245 Bioclimatic space of hornbeam in the Carpathians in periods 1961-1990, 2021-2050 and 2071-2100. The maps the degree of match of four regional climate models used for the projections.
**Projection of present bioclimatic space of Norway spruce**

Norway spruce is a highly vulnerable, water-demanding species that is currently distributed largely outside the range of its natural distribution in Central Europe (Ellenberg 1996), and thus not adapted to current disturbance regime which is different from mountainous areas of spruce natural distribution. Therefore, indirect effects of climate change, particularly those acting through changes in forest disturbances, are much more pronounced in spruce than in other species (Eriksson et al. 2005; Schütz et al. 2006). Hanewinkel et al. (2012) suggest that with an expected change of temperature and precipitation, cold-adapted and mesic species such as Norway spruce, one of the major commercial tree species in Europe, will over the long term lose larger fractions of their ranges at the cost of more drought-adapted species such as oaks.

Spruce vulnerability is further amplified by long-term planting unsuitable provenances, and present so-called "secondary" spruce forests show in many locations poor match to sites and weak resistance to damaging agents (Hlášný and Štiková 2010). These facts significantly limit the applicability of various approaches to environmental envelope modelling of spruce response to changing climate.

The following factors have been considered in the designation of model for projecting the shift of the present bioclimatic space of spruce:

- Spruce lower range limit is mainly shaped by biotic interactions (competition, pests) and forest management, therefore drought-related climate variables (e.g. Ellenberg quotient) were not considered to affect spruce distribution directly;
- European beech represents the main competitor of Norway spruce in the Carpathians, and beech expansion to the detriment of spruce forests has already been reported in several studies. Lower range limit was derived from the function of beech abundance response to mean annual air temperature; the limit was set at value where beech abundance starts declining and beech loses its competitive advantage;
- In higher elevations, where low air temperature poses the main limit to trees growth and survival, Norway spruce stands may benefit from increased temperature; in the same time, changes in precipitation are not expected to decrease critically to limit spruce persistence. Hence, we limited the upper spruce limit by air temperature.

Except for beech competition (and of other species respectively) in lower range of beech distribution, Norway spruce may suffer from drought effect through increase in trees susceptibility to bark beetle attacks. In the same time, bark beetles, mainly *Ips typographus*, may benefit from increased air temperature which accelerates beetles development, and allows them developing larger populations as compared with present-day conditions. In addition, newly emerging bark beetle species, such as northern spruce bark beetle *Ips duplicatus*, which has been observed in increased abundances in recent years (Holuša et al. 2010, Duduman et al. 2011), may cause additional damages, and thus affect spruce distribution. This further limits the applicability of spruce shift modelling.

As bark beetle population growth is substantially controlled by available resources of breeding material in form of mechanically damaged or physiologically stressed trees, increased incidence of windthrows and snow damages may power the unprecedented outbreaks which may devastate present spruce forests, and support establishment of beech and other broadleaved. Climate change effect of future development of spruce bark beetle has been analysed in the Deliverable SR2.T2.D1 of the CarpathCC project.

As can be seen in the maps of spruce bioclimatic space in the period 1961-1990 (Figure 36), all mountain areas with larger share of spruce are distributed within the limits described by lower and upper limiting values. Areas near the tree line, beyond the air temperature limit for spruce, can be seen as well. Spots of spruce forests distributed out of the displayed limits can be seen in the Czech part of the Carpathians. Here, however, spruce distribution has been substantially altered by
man and spruce cultivation range has largely expanded beyond the range of its natural distribution.

In the near future (2021-2050), upper climatic limit of spruce distribution was projected to shift upwards, and spruce suitable climatic conditions spread over all highest peaks of the Carpathians. In the Western Carpathians, the massifs of Low Tatras Mts., High Tatras Mts., and transboundary region of the Western Beskids remained within spruce suitable conditions. The same was projected for mountain range passing from Ukraine to Romania, and for some higher elevated regions in the southern Carpathians.

In some areas, of course, edaphic limit will not allow spruce reaching the highest elevations despite relaxed temperature limit. Competition of dwarf pine may also limit spruce expansion, though loss of dwarf pine zone induced by spruce expansion has already been observed, and it has been described in the previous chapters of this report.

In the distant future (2071-2100), spruce lower range limit (specified by upper limit of declining beech competitiveness), shifted upwards, and conditions suitable for spruce persistence disappeared almost across all Carpathians. This projection should not be interpreted in terms of spruce decline or even disappearance in the Carpathians because of increasing air temperature or drought. The projection implies expansion of climatic conditions suitable for beech, which may take competitive advantage over spruce and, in long run, beech may substitute spruce in many locations. Moreover, forest management focusing on the maintenance of homogenous spruce forests at large scale may face increasing risk, and increasing investments will be needed to preserve such management.

As air temperate was used as the only variable controlling spruce distributional range, uncertainty of projections based on the use of multiple RCMs is low.
Figure 256 Bioclimatic space of spruce in the Carpathians in periods 1961-1990, 2021-2050 and 2071-2100. The Figures indicate the degree of match of four regional climate models used for the projections.
5.3.4.4. Conclusions

Forests in the Carpathians contain climatic distribution boundaries of several forest tree species resulting from latitudinal and altitudinal gradients. The ranges of European beech (*Fagus sylvatica*) and several oaks (*Quercus* sp.) overlap to a certain extent and together they constitute some of the ecologically and economically most important species. Norway spruce is another zonal tree species which is typical of the Carpathians, and which constitutes large share of present forests. Undoubtedly, increased forest dynamics can be expected at present contact zone of these species, and such dynamics may result in change in species composition, substitution of current species by drought more tolerant ones having effects on overall biodiversity and provision of ecosystem services.

The competitiveness and stress tolerance of beech and various oak species has been recently increasingly recognized as central to future-proofing broadleaf temperate forests (Backes and Leuschner 2000; Epron and Dreyer 1993; Leuschner et al. 2001; Raftoyannis and Radoglou 2002). The profound understanding of the trade-off between stress tolerance of these species can be crucial for future forest management in temperate forests. The climatic optimum of oaks is expected to shift northwards and to higher elevations (Hlásny et al. 2011), while drought sensitive beech may lose its competitive ability (Gessler et al. 2007; Leuzinger et al. 2005). As a result, oaks will eventually replace beech in many forest communities (Czúc et al. 2011; Peñuelas and Boada 2003), either naturally or supported by forest management.

We laid stress in this report on these three tree species, as their response to climate change may substantially shape the future of Carpathian forests. In addition, economy and environmental importance of these species has initiated research of their responses to climate change in the recent decade, therefore there were grounds allowing us to evaluate the anticipated shift of the species.

Additionally to oaks, beech and spruce, we evaluated potential shift of hornbeam, the climatic response of which is similar to beech, and which can gain increasing importance in future species compositions. There is of course broad range of other species, which needs to be considered as part of present composition as well as in adaptation to anticipated climate change. Rule of these species is either difficult to evaluate because of lacking information on their ecology and responses to climate, or they can be evaluated on the basis of their physiological traits similar to other well documented species.

Projection of future species shift by Hanewinkel et al. (2012) suggests that Mediterranean oaks may by the end of the century (2070-2100) substitute present temperate species almost in entire Carpathians, except for higher elevations across main mountain crest (Figure 33). In the same time, beech was projected to substitute spruce forest except for highest elevations. We see thorough substitution of temperate oaks by Mediterranean oaks as very hypothetical though the magnitude of projected changes corresponds with projections for the Carpathians presented in this report; limits in dispersal, inherent humans’ tendency preserve the current species composition and avoid introduction of new species, and other factors may generate concern about factuality of such scenario. Anyway, the change in species composition of oak forests towards increased share of drought more tolerant oak species can be expected mainly in climatically exposed sites, and mainly in Eastern and Southern Carpathians. The author suggests that, depending on different realizations of three climate scenarios, by 2100, between 21 and 60% (mean: 34%) of European forest lands will be suitable for a Mediterranean oak forest type only.

The shrinking of future distribution of beech, as suggested by various bioclimatic models (e.g. Thuiller et al. 2005a; Czúc et al. 2011), represent probably pessimistic scenarios which may be alleviated not only by the mentioned features but also by prudent human support (e.g. artificial regeneration and other silvicultural measures, see Mátyás 2010). In the major part of the range, the predicted changes will not trigger any decline due to the plasticity of the species. It would be however misleading to expect the same level of persistence and plasticity at the threatened xeric limits as across the rest of
the range. Therefore the forecasts have to be taken serious close to the xeric limits, and especially at low elevations. Field observations near the retracting range confirm that the decline process is ongoing in many locations (Peñuelas et al. 2007; Berki et al. 2009). Considering the rapid shrinking of suitable bioclimatic space and the increasing selection pressure of abiotic and biotic stressors at the xeric limits, the results underline the importance of adaptive strategies both for management of forest resources and conservation planning.

We summarized in this report the observations of species shift, which could be induced by climate change, reported from countries in the Carpathians. Our survey implied that there is very limited information on observed species shift, evidences are scarce and unpersuasive in some cases. Species shift has generally not been addressed as topic of higher importance attracting attention of decision makers and scientists. Response from most of countries implies that species shift is relatively new and unexplored phenomenon. In addition, forest management and natural forest dynamics may largely interfere the climate change signal, what may question some of the reported observations.

In addition to overview of observation evidences, we explored the results of several modelling exercises which investigated the shift of species present bioclimatic space. Climate change effect on forest production has been reviewed as well, as it may be indicative of change in species competitiveness and thus potential changes in species composition. In contrast to sparse observational evidences, various projections, mostly based on environmental envelope modelling, were available in the Carpathian countries. The fact that such approach is methodologically stright and well documented in literature supports abundance of such studies.

As available modelling studies were based of various methods and data and they were hardly comparable among countries and regions, we presented in this reports also the results of unified modelling exercise focused on projection of present bioclimatic space of main zonal tree species in the Carpathians under ensemble of climate change scenarios. The most distinct form of climate change induced species shift is the upward expansion of tree line; i.e. which is in the Carpathians most often manifested by expansion of Mountain dwarf pine (Pinus mugo) to alpine grasslands above the current tree line. This process can be accompanied by spruce penetration to dwarf pine thicket and reducing its area, as has been reported for example from Romania. Tree line in the Carpathians has however been often reduced by human exploitation of alpine grasslands. Therefore only shifts occurring above the climatic tree line can be thought of as effects of climate change; large share of present tree line shift corresponds with change in management of alpine meadows, i.e. their abandonment and decline in grazing. Accurate identification of climatic tree line however poses methodological difficulties, such as low quality of climatic data to draw such limit accurately.

Because of coupled effect of change in landuse and changing climate, conclusions concerning climate change induced tree line shift from the Carpathians are ambiguous. Studies from High Tatras Mts. (Solár 2013, Solár and Janiga 2013) have not shown, up to us, clear evidence of recent effects of climate change on tree line, as has been reported for example from Alps (e.g. Gehrig-Fasel et al. 2007) or Ural Mts. in Russia (Grabherr et al. 2010, Koskhina et al. 2011). Observations from Ukrainian Carpathians imply remarkable forest dynamics in the tree line, containing both dwarf pine expansion to alpine grasslands as well as loss of dwarf pine habitats as a consequence of spruce expansion upward (Martazinova et al. 2011). Quality of climatic maps used for the identification of climatic tree line, and some other methodological difficulties, may however generate concern about relevance of these findings.

Similar observations come from Romania, and relatively complex shift of forest communities has been reported from Iezer Mts. (Southeastern Carpathians, Mihai et al. 2007). Colonization of barren land by dwarf pines, loss of dwarf pine zone due to spruce expansion, and gradual replacement of coniferous forests by mixed forests have been reported. The authors argue that effect of recent climate change is apparent in this case.
The other distinct process related to species shift is the retraction of lower limit of species distribution related to progressive aridification of the landscape; however, as for example Mátyás (2010) suggests, this process has hitherto received surprisingly low attention. Observations from Hungary presented in this report give some reliable evidences on several processes inducing the lower range limit retraction. Direct drought induced forest decline, effects of drought as predisposing factor to biotic damage, and continuous long-term change in species composition towards drought tolerant species have been reported. The fact that such events have been reported only rarely from southern parts of Slovakia and Romania, could be due to long-term systematic research in Hungary, which might have caused the prevalence of such studies over other regions. Therefore, the aforementioned observations from Hungary need to be thought of as alerts to other regions, and they should be considered in the assessment of future forest vulnerability. The most distinct features of presented pan-Carpathian projections are substantial worsening of growing conditions for beech, and exceedance of climatic limit which may cause decline of beech forest; and expansion of climatic conditions suitable for some oak species almost across all Carpathians. In the view of observational evidences and projections presented here, we summarize the changes in species composition, which are likely to occur in the Carpathians:

- In planar to colline zone, continuous change of present oak forests towards oak forests with higher share of drought tolerant species, such as Quercus cerris, may occur. Even the occurrence of species such as Q. frainetto or Q. illex can increase mainly on southern regions, or such species can be artificially introduced within the frame of forest adaptation. Share of other drought tolerant species of lesser importance may increase as well;
- Although European beech has been frequently considered as important component of temperate forests adaptation to climate change, its climatic sensitivity implies presence of beech mainly in higher elevation, and it should be treated very cautiously in drought exposed sites also considering the threat of newly emerging insect pests;
- Expansion of suitable conditions for oak species suggests increase of their share across almost entire Carpathians, except for the highest elevations. Increased dynamics in present contact zone of oaks and beech can be expected;
- Expansion of conditions suitable for oaks and worsening conditions suitable for beech implies appearance of communities composed of oaks and coniferous in higher elevations. Such communities rarely occur in some intra-Carpathians valleys, their sensitivity to climate change and future prospects however have not yet been investigated. We assume that increased diversity, improvement of stands static stability by admixture of broadleaved, and improvement of stand’s water management can make such communities promising to the future;
- Spruce needs to be thought of as highly vulnerable species, and climate change will induce additional pressure on decrease of spruce share except for highest elevations where spruce naturally occurs. In contrast, forest management can strive supporting spruce persistence also in unsuitable sites because of presently high commercial value of softwood. Hence, considering the trade-offs between environmental and economy interests, change in species composition towards decreased share of spruce can be thrilling part of future forest dynamics and adaptation.

The above described developments need to be viewed in the context of following factors:

- Species shift must be thought of as inherent adaptation mechanism, which allows species to track the shifting climatically optimal sites. As most of Carpathian forests are managed, rate of projected changes will depend in large extent on forest management, and human support to inherent adaptation mechanisms. For
this reason, adaptive forest management should support species shift and include such concept into regional forest management plans.

- We assume high diversity of interactions between natural forest adaptation and forest management among countries and regions in the Carpathians, reflecting varying level of awareness and available funding (for more information see Deliverable SR2.T4.D2 on adaptive forest management). Hence, both environment friendly and resource exploitative tendencies can be expected even in adjacent regions, bringing large uncertainty into projections of and expectations on species shift.

- Detrimental effects of species shift may occur in case of shifting tree line, as such shift may reduce the extent of valuable alpine habitats fostering vulnerable flora and fauna; such communities have minimal or none opportunities to migrate or adapt. In this case, forest management may act to preserve the vulnerable species and communities by eliminating the shifting vegetation from lower elevations. This may interfere, up to a certain extent, available projections of species shift.

- All the changes above are expected to be more pronounced in the Eastern, Southern and Serbian Carpathians as compared with Western Carpathians, because climatic exposure increases from north-west towards south-east; this tendency has been confirmed by all climate change scenarios presented in this report.
5.3.5. **Task 5: Climate change impact on forest protective functions in montane and alpine areas**

Montane and subalpine forests play an important multi-functional role in stabilizing landscapes, and represent a major component of landscape aesthetics that is of importance for tourism and associated human activities (Zach et al. 2008). The term “montane and subalpine forests” has a different meaning in every country. In Poland, montane forests are all forests above 600 m a.s.l, i.e. the definition of montane forests corresponds with the Carpivia classification (Carpivia 2013). In the Czech Republic montane forests are forests that belong to the last four national forest vegetation zones starting from 6th up to 9th zone. Forest vegetation zones follow the Czech national classification of forests based on site and soil fertility and main tree species (ÚHÚL 2003). These vegetation zones usually occur above 700 m a.s.l. In Slovakia, the term “montane forests” refers only to forests in 7th national forest vegetation zone defined according to (Zlatník 1976) on the base of elevation and climate. It usually occurs above 1,000 m a.s.l. This zone is also called spruce vegetation zone, because spruce is the only main species that can grow under such harsh conditions (Moravčík et al. 2005). (Note that forest vegetation zones in the Czech Republic and Slovakia are not the same). In Ukraine, montane forests are defined in the legislation document Rules of Final Felling in the Mountain Forest of the Carpathians (2008). This rule specifies regions where montane forests are located (Zakarpatska, Ivano-Frankivska and Lvivska and Chernivetska regions). In addition, there is a number of subcategories in Ukrainian legislation, which belong to montane and subalpine forests:

- Subalpine forest and bush complexes: include forests located within open montane and subalpine landscape (grasslands – "polonyny")
- High-montane forests: are located at an altitude of 1,100 m above sea level and higher;
- Prypolonynni forests: are forests adjacent to montane grasslands
- Forests in avalanche-prone basins: located at the upper timber line and their width depends on the length of the slope without forest cover.

Due to the differences in understanding the term montane forests between the countries, we used the definition of montane and subalpine forests of Carpivia (2013). Following this classification, montane and subalpine forests of the Carpathians occur at elevations above 600 m above sea level. These montane and subalpine forests make almost 60% of all forests in the Carpathians. They occur in all Carpathian countries except from Austria, where the Carpathians do not reach 600 m a.s.l. (Figure 37). More than a half of all montane and subalpine Carpathian forests (56%) is situated in Romania. High proportion of the Carpathian montane forests can also be found in Ukraine (21%) and Slovakia (14%). In Poland there are 6% of all Carpathian montane and subalpine forests. The proportion of the Carpathian montane forests in Hungary, the Czech Republic and Serbia is low (from 0.4% in Hungary up to 2% in Serbia).
Species composition is diverse reflecting site and climatic conditions, as well as the history of the particular region. In general, broadleaved forests prevail representing approximately 43% of all montane and sub-alpine Carpathian forests. Coniferous forests make 30% and mixed forests about 27% of the forests in the montane and subalpine region of the Carpathians. However, species composition significantly differs between the regions and countries. In Hungary and Serbia, broadleaved forests highly predominate; they cover almost the entire Carpathian montane region of the countries (>95% of all Carpathian montane forests in the country, Table 3) because in these countries the Carpathians have a peripheral position and do not reach high elevations (Figure 37). Also in Ukraine broadleaved montane forests are predominant (53%). In other countries, the proportion of broadleaved forests from the montane Carpathian forests is below 50%. However, the values vary a lot, with Romania having 43% of broadleaved montane forests, Slovakia 29%, Poland 25%, and in the Czech Republic only 11% of montane forests are composed of broadleaved species.

Coniferous montane forests are dominant in the Czech Republic. They represent 60% of all montane Carpathian forests of the country in spite of the fact that the Carpathians do not reach the highest sub-alpine zone (1,500 m a.s.l.) in the Czech Republic. The coniferous stands in the Czech Republic are predominantly secondary Norway spruce stands that were established in the last century due to the high demand for spruce wood and good productivity of this species at the sites (Slodičák et al. 2013). Coniferous forests are also frequent in Slovakia and Poland, although their share is below 50% (44% in Slovakia and 39% in Poland). High percentage in these countries is the result of the same trend in the past to grow pure spruce stands (Hlásny and Sitková 2010). Although spruce is a native species at most of the currently occupied sites, its actual proportion in species composition greatly exceeds its natural proportion. In the past, spruce was only admixed in the stands. According to Vladovič et al. (2008), in Slovakia the current

---

**Figure 267 Elevational zones across the Carpathian Mts. showing the distribution of montane and subalpine regions.**

![Elevational zones across the Carpathian Mts. showing the distribution of montane and subalpine regions.](image-url)
proportion of Picea abies is by about 12.3% higher than its potential natural proportion in the Carpathian sub-montane and montane beech forests and by 46.6% higher in Beech – Silver fir – Norway spruce forests.

The share of mixed montane forests exceeds 20% in all Carpathian countries except from Hungary and Serbia, where their proportion is around 1.5%. Mixed forests are predominant in Poland, where they make 35% of the Carpathian montane forests. In Slovakia, Romania, and the Czech Republic, the proportion of mixed forests from the Carpathian montane forests of the country is very similar (around 27%). In Ukraine, 20% of the Carpathian montane forests are mixed.

Table 3 Distribution and composition of the Carpathian montane and subalpine forests in the countries and geomorphological subprovinces.

<table>
<thead>
<tr>
<th>Country</th>
<th>Geomorphological subprovince</th>
<th>Montane and subalpine Carpathian forests</th>
<th>Broadleaved</th>
<th>Coniferous</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>km²</td>
<td>%</td>
<td>km²</td>
<td>%</td>
</tr>
<tr>
<td>Austria</td>
<td>Outer Western Carpathians</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Czech R.</td>
<td>Outer Western Carpathians</td>
<td>100.7</td>
<td>11.4</td>
<td>544.0</td>
<td>61.6</td>
</tr>
<tr>
<td>Slovakia</td>
<td>Inner Eastern Carpathians</td>
<td>130.2</td>
<td>93.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Outer Eastern Carpathians N.</td>
<td>2029.7</td>
<td>31.0</td>
<td>2556.8</td>
<td>39.1</td>
</tr>
<tr>
<td></td>
<td>Outer Western Carpathians</td>
<td>239.5</td>
<td>87.3</td>
<td>1.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Poland</td>
<td>Inner Western Carpathians</td>
<td>300.5</td>
<td>12.8</td>
<td>1552.8</td>
<td>66.2</td>
</tr>
<tr>
<td></td>
<td>Outer Eastern Carpathians N.</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Outer Western Carpathians</td>
<td>660.7</td>
<td>45.1</td>
<td>234.7</td>
<td>16.0</td>
</tr>
<tr>
<td>Hungary</td>
<td>Inner Western Carpathians</td>
<td>286.2</td>
<td>12.8</td>
<td>1179.0</td>
<td>52.6</td>
</tr>
<tr>
<td></td>
<td>Outer Eastern Carpathians N.</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Outer Western Carpathians</td>
<td>265.2</td>
<td>95.4</td>
<td>9.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Ukraine</td>
<td>Inner Eastern Carpathians</td>
<td>687.3</td>
<td>69.7</td>
<td>167.6</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>Outer Eastern Carpathians N.</td>
<td>6691.1</td>
<td>52.2</td>
<td>3511.9</td>
<td>27.4</td>
</tr>
<tr>
<td>Romania</td>
<td>Inner Eastern Carpathians</td>
<td>3077.6</td>
<td>29.1</td>
<td>5041.2</td>
<td>47.7</td>
</tr>
<tr>
<td></td>
<td>Outer Eastern Carpathians S.</td>
<td>2429.0</td>
<td>27.4</td>
<td>2483.3</td>
<td>28.0</td>
</tr>
<tr>
<td></td>
<td>Southern Carpathians</td>
<td>4107.5</td>
<td>44.2</td>
<td>1716.6</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>Transylvanian Plateau</td>
<td>1341.9</td>
<td>89.5</td>
<td>32.7</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Western Romanian Carp.</td>
<td>4838.9</td>
<td>75.7</td>
<td>1075.3</td>
<td>16.8</td>
</tr>
<tr>
<td>Serbia</td>
<td>Serbian Carpathians</td>
<td>1300.3</td>
<td>97.4</td>
<td>15.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

From the regional perspective, broadleaved forests dominate in the southern regions of the Carpathians (Serbian and Western Romanian Carpathians and Transylvanian Plateau). Also in the Outer Eastern Carpathians North, more than half of the montane forests (53%) are composed of broadleaved tree species only. The lowest frequency of broadleaved montane forests is in the Outer Western Carpathians (13%). The predominant part of the montane forests in this region is coniferous forests (60%). Mixed forests prevail in of the Outer Eastern Carpathian South, where they make 44% of all the montane and subalpine forests of the Carpathians. More detailed description of distribution and composition of the Carpathian montane and subalpine forests in the individual countries and geomorphological subprovinces can be found in Table 3.

Forest functions

Forests are an integral component of the Carpathian Mountains and fulfil many important functions (Bytnerowicz 2013). Forest function is a role that a man attributes to a forest (Brang et al. 2001). Usually three types of forest functions are distinguished (ForestEurope 2013):

- productive functions, which cover the production of wood as a main forest product as well as of other non-wood products;
- protective functions, which include the prevention and mitigation of erosion and loss of soil, avalanches, landslides and rock fall; the preservation of drinking water
resources; the stabilization of stream banks or sand dunes, and the reduction of noise pollution;

- socioeconomic functions, which account for the socioeconomic aspects of forests including recreation, cultural and spiritual values of forests.

At present, it is required that forests are managed sustainably in such a way that they can fulfil multiple functions at the same time. Nevertheless, the majority of countries classify their forests according to the prevailing forest function. The categorisation in individual Carpathian countries is presented in Table 4. Commercial forests include forests with the primary productive function, while they also need to fulfil other non-productive functions. The primary aim of forest management in these forests is to achieve high quality timber and other forest products.

**Table 4 Categorisation of forests in the Carpathian countries.**

<table>
<thead>
<tr>
<th>Forest categorisation</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>Czech Republic</td>
</tr>
<tr>
<td>Protective</td>
<td>Poland</td>
</tr>
<tr>
<td>Special purpose</td>
<td>Slovakia</td>
</tr>
<tr>
<td>Commercial</td>
<td>Ukraine</td>
</tr>
<tr>
<td>Protective</td>
<td>Romania</td>
</tr>
</tbody>
</table>

While the category of commercial forests is unambiguous, the remaining categories and their context are specific for each country. The categorisation in Slovakia and the Czech Republic follows the same principles due to the common past. The primary functions of the forests are specified in their Forest Acts (Slovak Act on Forests No.326/2005, Czech Act of Forests 289/1995). Protective forests are forests situated on extreme sites (screes, steep slopes, etc.), forests at timber line, and forests with prevailing protective function of soil to prevent and mitigate soil erosion, avalanches, landslides and rock fall. The primary function of so called “special purpose forests” is to ensure specific needs of society or individuals that require specific forest management regime. These forests comprise forests in buffer zones of water resources, recreation forests, gene pool forests, forests designated for forest research and forests that fulfil other socioeconomic functions. Protective and special purpose forests have to be declared by state administration. Currently, there are almost 75% of commercial forests, 2.7% of protective forests, and 22.6% of special purpose forests in the Czech Republic (http://issar.cenia.cz/issar/page.php?id=202). In Slovakia, 69% are commercial forests, 17% are protective forests, and 14% belong to the category of special purpose forests (Green report 2009). The proportion in the Carpathian region of Slovakia is similar (Table 4). As can be seen in Figure 38, protective forests are usually situated at higher elevations of the Low and the High Tatras.
In Ukraine, four main categories are defined (Table 4). Protective forests play mainly water-protective, soil-protective and other protective roles. Recreation forests primarily fulfil recreation, sanitation, hygiene and health-improving functions. Socioeconomic and protected forests include forests under nature protection, and forests for scientific, historical and cultural purposes with nature protective, aesthetic, scientific and other functions. Considering forests of the Ukrainian Carpathians in general, about 59% are commercial forests, while the remaining 41% belong to protective, recreation, socioeconomic and protected forests. In Romania two categories are defined: commercial and protective forests (Table 4). Protective forests include forests with special protective function for water, soil, climate and objects of national interest, forest for recreation, forests for biodiversity protection and forests declared as national monuments.

In Poland, three categories are defined (Table 4). From the forests situated in the montane and subalpine zone of the Carpathians, 32% are commercial forests, 11% are protected forests, and 56.6% of montane forests fulfil protective functions (Table 5).

Apart from this broad categorisation, protective functions are usually divided into specific functions. Each country follows its own system. Although the systems are not consistent, they distinguish similar functions. In Poland, specific protective functions are defined in forest management instructions (IUL 2012) as follows:

- soil protection
- water protection
- forests permanently damaged by industry
- areas of great natural interests
- permanent experimental plots
- seed stands
- animal sanctuary
- forests in a city and around a city
- health-resort
- military area

In Slovakia, each forest is assigned a so-called functional type specific for each forest category (Table 4). In the category of protective forests, 20 functional types are distinguished, which are grouped into 5 sub-categories depending on the main function: erosion control, preservation of water, avalanche control, streamside protection, deflation...
control (Green report 2008). Similarly, category of special purpose forests consists of 36 functional types that are grouped into 8 sub-groups according to their main functions: water purification, recreation, spa and wellness, nature conservation, mitigation of air pollution, game husbandry, education and research, and conservation of gene pools (Green report 2008).

Table 5 Country-wise classification of montane and subalpine forests of the Carpathians into forest categories defined by national legislation.

<table>
<thead>
<tr>
<th>Forest category</th>
<th>Poland</th>
<th>Slovakia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Montane</td>
<td>Subalpine</td>
</tr>
<tr>
<td>Commercial</td>
<td>164 623</td>
<td>0</td>
</tr>
<tr>
<td>Protected</td>
<td>45 756</td>
<td>8 800</td>
</tr>
<tr>
<td>Protective</td>
<td>281 500</td>
<td>0</td>
</tr>
<tr>
<td>Special purpose</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

In Ukraine, specific protective functions are defined within the category of protective forests as follows:

- soil and water protection - sub-categories “forests in ravines, cloughs and river valleys”, “forests on sandy soils subject to deflation”, “forests on lands subject to reclamation”, “forests on mountain slopes (30° or steeper at southern slope exposure, and 35° at northern slope exposure), “forest on shallow stony soils”
- ecosystem protection - sub-categories: “high-montane forests”, “Prypeplonynni forests (Forests adjacent to montane grasslands), “Subalpine forest and bush complexes”, the whole category “Protected forests”
- Protection from geological hazards: “forests in mudflow basins”, “forests in the avalanche-prone basins”, “forests around stone fields on slopes”
- Protection of railroads, motorways and canals;
- Protection of agricultural lands;
- Protection of settlements;
- Protection of water streams, lakes and reservoirs;

Additionally based on the subcategory of specially protected land areas the following protective functions are distinguished:

- Protection of lek grounds of capercaillies;
- Protection of banks and navigable water bodies;
- Protection of historical and cultural heritage;
- Protection of watershed divides;
- Protection of caves;
- Protection of pipelines;
- Protection of hydro–meteorological facilities;
- Protection from radiation impact.
Table 6 Overview of protective forest functions defined by legal documents in individual Carpathian countries (Y= yes, i.e. function is accounted for in legislation. Source: questionnaires from national experts).

<table>
<thead>
<tr>
<th>Protective functions</th>
<th>Poland</th>
<th>Slovakia</th>
<th>Czech Republic</th>
<th>Romania</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Air</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Natural ecosystems</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Gene pools</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wildlife</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Recreation</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education, Research</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Military area</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Man-made ecosystems</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other

- forests damaged by industry
- radiation impact

In general, a primary function of a protective forest is the protection of people or assets against the impacts of natural hazards or adverse climate (Brang et al. 2006). Two kinds of protective functions are distinguished: direct or indirect. Direct protective function is bound to the presence of a forest at a particular location, while indirect protective function depends only on the presence of a certain portion of forest at the landscape level, but not on its exact location (Brang et al. 2001, 2006). Many types of natural hazards are gravity driven, therefore, protective forests usually occur on steep slopes in mountain regions (Brang et al. 2001). The primary protective functions of montane and subalpine forests encompass soil protection (i.e. prevention and mitigation of erosion and loss of soil); prevention and mitigation of avalanches, landslides, and rock falls; and preservation of water resources (Moravčík et al., 2005). In addition, they often fulfill socioeconomic functions, such as aesthetic and recreation functions. The protective ability of a protective montane forest is provided by the presence of trees, which act as obstacles to mass movements (Brang et al. 2006). They act in many different ways that were summarised by Brang et al. (2006) as follows:

- tree stems halt falling stones;
- tree roots reduce the hazard of shallow landslides (Hamilton 1992) and increase the soil volume available for water storage;
- tree crowns prevent the build-up of a homogeneous snow layer that may cause avalanches;
- permanent input of litter reduces surface erosion and increases the water-holding capacity of the soil through the build-up of an organic layer (Hamilton 1992);
- lying dead wood acts as barriers to downslope mass transfers (Kupferschmid et al. 2003).

Hence, trees and forest cover are the main “products” of these forests (Brang, et al., 2006).

Table 7 presents the proportion of protective montane and subalpine forests of the Polish Carpathians fulfilling particular protective functions. As can be seen from this table, the main function of the majority of protective montane forests in Poland is water preservation followed by erosion control. In Slovakia, the most important issue is erosion, since almost 13% of all forests in Slovakia were assigned this protective function (Green
Preservation of water resources is the second most important protective function assigned to 3.8% of Slovak forests (Green report 2009).

Table 7 Proportion of montane and subalpine forests of the Carpathians in Poland fulfilling a particular protective function

<table>
<thead>
<tr>
<th>Protective functions</th>
<th>Montane and subalpine Carpathian protective forests in Poland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion</td>
<td>ha</td>
</tr>
<tr>
<td>Water quality</td>
<td>48 740</td>
</tr>
<tr>
<td>Air quality</td>
<td>201 426</td>
</tr>
<tr>
<td>Other (areas of great natural interest - 0.4%, damaged by industry - 2.5%, experimental plots - 0.8%, animal sanctuary - 0.7%)</td>
<td>9 450</td>
</tr>
<tr>
<td></td>
<td>21 883</td>
</tr>
</tbody>
</table>

Forest management in categories other than commercial is usually restricted. For example in Poland, special purpose management system is used in protected forests (IUL 2012). This system primarily answers the purposeful protection of non-productive forest functions. It is generally applied by single tree felling, mainly salvage felling or felling aimed at improving forest stability and structure. The form of felling allowable cutting depends on the form of protection applied, while in majority of areas tree harvesting is completely forbidden. On the other hand, dominant protective function of forests does not necessarily limit its productive functions. In such a case, forests are managed mainly by shelterwood and selection management systems.

Similarly, in Romania forest management needs to reflect their functions (article 25 of Law no. 46/2008 on Forest Code). According to article 69 of Emergency Ordinance of Government no. 195/2005 regarding environmental protection, forest owners in Romania have to provide specific conservation measures for forests with special protective functions located on lands with very steep slopes, with sliding and erosion processes, on debris, rocks, and at the upper timber line; and they have to respect the regime prescribed for conservation of woody vegetation on forestry grasslands which fulfil protection functions for soil and water resources.

In Ukraine, legal rules depend not only on the forest category but also on the location of forest land, sanitary conditions of forest, etc. The main limitations refer to the application of clear cut system. This system is prohibited in the forests, which protect spawning areas of especially important fish species, in the economic zones of national natural parks and regional landscape parks, forest of zones of anthropogenic landscapes of biosphere reserves and in especially protected forest areas (forest fringes on the border with un-forested lands and small forests surrounded by un-forested lands). These areas are the subject of selective and shelterwood system.

In Slovakia, forest management of protective forests has to be performed in such a way that their protective function is ensured. Usually, these forests are managed using so called “special purpose cut” based on the removal of individual trees to achieve desired forest stand structure (Act 326/2005). The main aim of this system is to create and maintain suitable conditions for the establishment, release and growth of natural regeneration of tree species suitable for the site in order to increase the ecological stability of forests and its non-productive forest functions (Regulation 453/2006). However, in reality most protective forests have been left to self-development.
5.3.5.1. Forest cover change

Due to protective and socioeconomic functions of montane and subalpine forests, any excessive disturbance of this forest belt forest evokes discussion about its known and unknown causes and consequences for nature, man and society (Zach et al. 2008). The process that transforms a part of the Earth surface with the effect on its functioning, diversity, site characteristics, etc. is called land cover change. It can either be performed via conversion or modification. Conversion means a replacement of one cover type by another (e.g. forests to pastures), while modification is the change of the character of land cover without changing its type (e.g. broadleaved forests to coniferous forests, Jaskowiec 2013).

The studies of land cover change are usually based on the comparison of maps or images from two or more time points. Long-term changes can be revealed by comparing historical maps and actual remote sensing images. Since in the past the large part of the Carpathians belonged to the Austrian-Hungarian Habsburg Monarchy, historical military maps are available covering the period since the late 18th century (e.g. http://geo.enviroportal.sk). These maps have already been used in a number of different studies (e.g. Boltižiar and Olah 2013; Marinescu et al. 2013; Shandra et al. 2013, Merganičová et al. 2013) that analysed the change of land cover across centuries. More recent changes can be detected by comparing remote sensing data from different years, as it was done by e.g. (Moravčík et al. 2005; Hlášny and Sitková 2010; Jaskowiec 2013).

However, most of the studies are local or regional that deal with a specific region in the Carpathians. One of the few studies encompassing the whole Carpathian region was presented by Jaskowiec (2013). She analysed recent land cover changes between 2001 and 2009 using MODIS NDVI data and revealed that in this period almost 92% of the total Carpathians remained unaltered. The most intensive changes were observed at low elevations (below 200 m a.s.l.), while areas at higher elevations experienced the smallest modifications.

In general, the land use of montane areas has been relatively stable in comparison to lowlands, where land use intensification was observed (Boltižiar and Olah 2013). At elevations above 1,000 m a.s.l. of the Carpathians, the proportion of forest cover has remained stable since 1880, as in 2000 only a non-significant decrease by -1.6% was detected relative to 1880 (Shandra et al. 2013). However, when accounting for spatial distribution of forest cover above 1,000 m a.s.l., Shandra et al. (2013) found that 9.6% of the investigated area was afforested, while 11.2% was deforested, which indicates the spatial shift of forest cover in the Carpathians. The authors also revealed significant differences between individual regions. In the Western and Outer Eastern Carpathians North, Shandra et al. (2013) found an overall increase of forest cover above 1,000 m a.s.l. by 8% and 1.4%, respectively. In contrast, in the Eastern and Southern Carpathians of Romania they revealed a decrease by 9.5% and 8.3%, respectively. The afforestation and deforestation values for each region were similar to overall values and fluctuated around 10%.

The real differences in land cover change occur at a local level. It has been documented that some areas have remained unchanged since the first Austrian military mapping, e.g. 95% of the forests in the Poľana Biosphere reserve in Slovakia has not changed since 1782 (Boltižiar and Olah 2013), while other areas show high temporal alternations.

The studies revealed the following main causes of land cover change in the Carpathians:
- conversion afforestation due to:
  - succession and forest expansion due to the abandonment of farmlands (Plesník 1987; Kozak 2003; Kuenmerle et al. 2008; Kuenmerle et al. 2009; Boltižiar and Olah 2013)
  - artificial reforestation of abandoned lands (Kulla and Sitková 2012; Jaskowiec 2013; Merganičová et al. 2013)
- rise of the timber line caused by climate change (Shandra et al. 2013; Marinescu et al. 2013)
- deforestation due to:
  - illegal logging (Bouriaud 2005; Kuemmerle et al. 2009; Jaskowiec 2013)
  - overexploitation (Kuemmerle et al. 2009; Marinescu et al. 2013)
  - clearance of forests due to grazing (Shandra et al. 2013)
  - deforestation due to increasing demands on forests (Marinescu et al. 2013)
  - deforestation due to hydrotechnical constructions (Marinescu et al. 2013)
  - abiotic disturbances, e.g. windthrow, fire (Boltižiar and Olah 2013; Falťan and Báňovský 2008)
  - pressure caused by tourism (Boltižiar and Olah 2013)
  - modification – change of tree species composition (Hlásny and Sitková 2010; Kulla and Sitková 2012).

In the Western Carpathians, the character of mountainous landscape was radically changed with the Wallachian colonisation at the end of 15th and the beginning of 16th century (Demek et al. 2012). This colonisation resulted in deforestation and grazing that accelerated erosion and landslides on steep montane slopes (Demek et al. 2012). In the 18th century, the largest portion of landscape was agricultural land (Demek et al. 2012). Intense plantations of spruce started in the second half of 18th century due to small forest cover, bad forest state and increasing demand for wood (Kulla and Sitková 2012). Some of these forests were established naturally on abandoned pastures, on which seeds from surrounding stands successfully regenerated (Plesník 1987). However, many of these forests were planted to increase wood production, particularly in the Beskids Mts. belonging to the Outer Western Carpathians (Hlásny and Sitková 2010; Kulla and Sitková 2012).

Due to this, the current proportion of coniferous forests in this region is almost 60%. Over the last 20 years the proportion of agricultural land in the Western Carpathians decreased (Raczkowska et al. 2012). Topography, the accessibility of farmland and land-use patterns strongly determined the spatial pattern of abandonment (Hostert et al. 2008). Forest expansion has affected mostly agricultural land above 800 m, especially pastures located in the subalpine belt of spruce forests (Kozak 2003). This change reflects major transformation in the traditional vertical economy of the montane area—a decline in grazing and the development of nature conservation, tourism, and forestry (Kozak 2003).

Merganičová et al. (2013) analysed forest cover changes at the bottom border of Slovak Carpathian montane forests. At the end of 18th century, they detected deforested areas around villages (Figure 39b-d). This documents the general recent trend of forest expansion due to the abandonment of farmlands that was also observed by other authors (e.g. Plesník 1987; Kozak 2003; Boltižiar and Olah 2013; Kuemmerle et al. 2008; Kuemmerle et al. 2009; Alix-Garcia et al. 2011; Jaskowiec 2013; Baumann et al. 2011 in Jaskowiec 2013).
While in the Western Carpathians, forest cover generally increases, in the Eastern and Southern Carpathians of Romania there is a trend of forest cover decrease (Shandra et al. 2013). The main causes are illegal loggings due to poverty and overexploitation caused by forest restitution (Bouriaud 2005; Kuemmerle et al. 2009; Marinescu et al. 2013; Jaskowiec 2013). In the border triangle of Poland, Slovakia, and Ukraine (Outer Eastern Carpathians North), Kuemmerle et al. (2007) analysed forest disturbances using Landsat MSS/TM/ETM+ images from 1978 to 2000. They found increased harvesting in all three countries (up to 1.8 times) in 1988–1994, right after the system change. Forest disturbance rates differed markedly among countries. The lowest disturbance was observed in Poland, while in Ukraine and Slovakia the rates were 4.5 times and 4.3 times higher than in Poland, respectively. In Ukraine, harvests tended to occur at higher elevations. Designation of protected significantly decreased harvesting rates in Poland and in Slovakia, but had no effect in Ukraine (Kuemmerle et al. 2007).

Marinescu et al. (2013) analysed forest cover change in one of the highest Romanian Carpathian ranges (Parang–Cindrel Mts.) and identified three main deforestation periods related to human disturbances:

- at the beginning of 20th century – deforestation caused by increasing the grazing area at high elevations
- in 1970s - deforestation due to the construction of hydrotechnical dams
- after 2006 – deforestation due to forest restitution that generated the overexploitation of the forests in the area.

Nevertheless, more than 60% of the forests have remained undisturbed since 1918 indicating that the majority of forests in the region are well preserved (Marinescu et al. 2013).

Recent significant deforestation is also observable in the eastern part of Romania, particularly in the Moldova region (Figure 40). The effect of deforestation was observed through the incidence of slow landslides (determined by freeze-thaw cycles) specific for subalpine belt in the forested areas (Andra 2007). In the Godeanu Mountains deforestation carried out in the proximity of water reservoirs has created conditions for
reactivating some geomorphological processes, resulting in gullies, ravines, torrential bodies. These processes occur on surrounding slopes which cause clogging of the reserves (Pietriș i 2010).

Figure 40 Coniferous deforestation and reforestation in the Moldova region, Eastern Romania (left) and in the watershed covering also the areas outside the region (right).

Apart from the tendencies of forest cover decrease in the Eastern Carpathians, reverse trends connected with abandonment of agricultural land have also been observed. Kuemmerle et al. (2008) analysed farmland abandonment in the border triangle of Poland, Slovakia, and Ukraine in the Outer Eastern Carpathians North using Landsat TM/ETM+ images from 1986, 1988, and 2000. The elevations in this region vary from 200 to 1,480 m above sea level. The authors found that an average farmland abandonment in post-socialist times was 16.1% of the farmland used before the change of the political system, while the highest proportion was revealed for the Slovak part of the region (20.7% versus 13.9% in Poland, and 13.3% in Ukraine). In Poland, substantial differences were found between cropland abandonment rates on farmland that remained private during socialism and the previously collectivised land, which was subject to twice as fast abandonment than the former groups. This was in some parts followed by afforestation (particularly at slopes steeper than 20%), while the other parts remained fallow land that can be subject to succession. In Poland and Ukraine, most of the abandoned land was left as fallow land. Reforestation was most pronounced in Slovakia, where at montane elevations above 600 m a.s.l. all abandoned land was reforested (Kuemmerle et al. 2008). At a global scale, this change might be considered environmentally beneficial in terms of afforestation resulting in increased carbon sequestration, while at a local level it might also be a threat to the “amenity” of the traditional village landscape (Alix-Garcia et al. 2011).

The national experts assessed a set of possible agents causing the ongoing forest cover change in montane and subalpine areas of the Carpathians (Table 8). As can be seen from the table, their level of importance varies between the countries. While in Poland, the main changes are related to farmland abandonment and its subsequent afforestation or succession, in Slovakia and Romania, wind and insects are main agents triggering changes at montane and subalpine zones of the Carpathians. Insects are extremely important also in the Ukrainian part of the Carpathians together with diseases and logging. Overexploitation and illegal logging represent the main threats in Romania, too. Below we will analyse the main agents in more detail.
Table 8 Importance (Imp.) of agents causing forest cover change in montane and subalpine areas of the Carpathians (1- extremely important, 2—moderately important, 3—slightly important, 4-unimportant, 5-not applicable).

<table>
<thead>
<tr>
<th>Agent</th>
<th>Poland</th>
<th>Slovakia</th>
<th>Ukraine</th>
<th>Romania</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>4</td>
<td>2004</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Year/Perio</td>
<td>Impo</td>
<td>Year/Perio</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2007</td>
<td>1989, 1990,</td>
</tr>
<tr>
<td>Snow</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>Associated with the wind</td>
</tr>
<tr>
<td>Landslides</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3*</td>
</tr>
<tr>
<td>Rime</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Diseases</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>Since 1980</td>
</tr>
<tr>
<td>Insects</td>
<td>3</td>
<td>2005 - 2008</td>
<td>1**</td>
<td>since 2004</td>
</tr>
<tr>
<td>Fires</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Air pollution</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Felling (including illegal logging)</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>XX century till 1970, since 1990</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Afforestation/reforestation</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>Since 1970</td>
</tr>
<tr>
<td>Succession on abandoned agricultural land</td>
<td>1</td>
<td>4</td>
<td>since 1990</td>
<td>3</td>
</tr>
<tr>
<td>Succession due to climate warming</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>Since 1980</td>
</tr>
</tbody>
</table>

*increase of 10 times in the period – 1986-2000
**in many cases as a cause of wind damages
5.3.5.2. Forest decline

Currently, most of the secondary stands suffer from forest decline (Hlásny and Sitková 2010). This process is characterised by reduced forest growth, shortened internodes, root necrosis, early yellowing of foliage, defoliation, mortality of branches at the upper part of the crown, or increasing occurrence of fungal pathogens (Manion 1981). It results in tree mortality, which can affect a large area causing deforestation (Grodzki 2010). Although a number of different hypotheses have been published about the causes of forest decline, nowadays it is generally accepted that it is caused by a combination of abiotic, biotic and physiological factors (Štefančík 2012). It is often coupled with Armillaria and Heterobasidion fungal pests, and bark beetle, which can act as a primary or a secondary mortality agent (Grodzki 2004; Jakuš et al., 2008).

In the Western Carpathians this process started already in the second half of the last century (Kulla and Sitková 2012). It mainly affects spruce forests at elevations from 400 to 1,000 m a.s.l. of all ages (Lomský, et al. 2006; Kulla and Hlásny 2010). In Slovakia, two forms of forest decline have been observed in recent decades: (1) destructive wind-driven decline typical for montane regions, such as the Tatras, and (2) decline driven mainly by biotic agents, typical for the Beskid Mts, particularly in the border triangle of Poland, Slovakia, and the Czech Republic (Figure 41, Hlásny and Sitková 2010).

![Map of the border triangle of Slovakia, Czech Republic and Poland affected by spruce forest decline.](image)

This region has been under long-term impact of air pollution from industrial plants in Ostrava and Katowice coal basin since the late 18th century, when mining activities in this region began. In the second half of the 20th century, the concentrations of sulphur dioxide (SO2), in particular, were critical, causing forest decline in the upper part of the Moravian-Silesian Beskids in the Czech Republic and in the Silesian Beskids in Poland (Hlásny and Sitková 2010). In Poland, the first symptoms of spruce decline were observed in the late 1950s, when stands were largely affected by Armillaria disease. In the Czech Republic, forests were heavily damaged by air pollution in the 1980s. Although heavy industry declined and signs of forest recovery became evident after 1990, in 2002 a new period of spruce forest decline began (Hlásny and Sitková 2010). The highest mortality was observed in 2007 and 2008 (Pavlenda et al. 2009). In the Polish part, montane forests were particularly affected between 2003 and 2008 mainly due to unfavourable climate conditions (physiological drought in 2003). Drought in 2003 accelerated forest decline also on the Slovak side, which was partly affected by windthrow 2004 (Orava region). The main cause of forest decline in the Czech part of the region is the allochthonous origin of spruce coming from south Tirol (Holuša 2004). The extent and spatial distribution of deforestation in the Beskid Mts. (Outer Western Carpathians) due to the forest decline was analysed using Ladsat TM and Landsat ETM+
remote sensing images in Hlásny and Sitková (2010, Figure 42). The changes in forest cover in the assessed region due to incidental felling are highlighted in red in Figure 43.

Figure 42 Regions used for the documentation of deforestation due to forest decline in the Outer Western Carpathians (Beskid Mts.) using remote sensing images. Source: Hlásny and Sitková (2010).

Figure 43 Forest cover changes in the selected part of the Outer Western Carpathians (Beskid Mts.) between 1994 and 2010 (sample area No.5 in Fig. 57). Red-coloured areas indicate changes in forest cover due to incidental felling. Source: Hlásny and Sitková (2010).
Windthrow

The main abiotic threat to the Carpathians is windthrow causing reductions of forest cover particularly at higher elevations. Several windthrows have been recorded in the Carpathian montane forests in the last decades. For example, in 2004 a catastrophic windstorm called “bora” affected a large part of the Tatra National Park in Slovakia (Střelcová et al. 2013) and destroyed more than 12,000 hectares of forests (Zach et al. 2008; Zielonka et al. 2009) at elevations from 800 to 1,300 m a.s.l. In Romania, the areas most affected by windstorms are in the north-eastern part and in the Carpathian Curvature area. Over the past three-four decades, as the climate has been warming up, the incidence of windthrows has been increasing. In these areas of the Eastern Carpathians, major windstorm events occurred in 1995, 2002, and 2009 (Bogdan and Cosconea 2011). Most of the affected areas were at high elevations (1,200 -1,800 m.a.s.l.). Iezer Mts. are also frequently affected by this disturbance factor, e.g. the windthrow in July 2005 destroyed 370 ha of forests in the area and left slopes with inclinations 25-30 degrees unprotected (Săvulescu and Bogdan 2012).

The areas affected by windthrow are generally overlapped with the areas covered by spruce (Săvulescu 2009). Although spruce is a species flexible to extreme climate and soil conditions, it is very susceptible to windthrow due to its shallow rooting (Střelcová, et al. 2013). In the Tatras (Western Carpathians), European larch (Larix decidua Mill.) was less affected by the windstorm in 2004 (Figure 44) because of its short crowns and because at the time of the windthrow larch trees were already needless (Zielonka et al. 2009). Therefore, it is assumed that larch can substantially increase forest resistance to windstorm, and mixed larch-spruce species should be promoted in high-elevation areas of the western Carpathians disturbed after heavy windstorms (Střelcová et al. 2013). Similarly to Slovakia, spruce was most affected also in Romanian Carpathians, while fir and beech showed to be more resistant to this disturbance (Bogdan and Cosconea 2011).

Figure 44 The High Tatras (Western Carpathians) after the windthrow in 2004 with larch trees that survived this extreme event.
Insects

As presented in SR2T2D3 Deliverable of this project, Ips typographus is the most destructive species of the genus Ips and the most serious pest on spruce in Europe. However, this species is usually a secondary pest attacking and killing trees which have already been stressed by other factors (e.g. drought) or have been damaged by windstorms. The pest is distributed in the entire Carpathians including montane and subalpine forests, and covers the whole distribution range of its primary host plant Norway spruce. Figure 45 shows the areas of the Carpathians Mts. affected by *Ips typographus*.

Several parts of the montane and subalpine forests in the Western Carpathians are influenced by the bark beetle outbreak (Figure 45). The Western Beskids Mts. represent one of the most important outbreak areas of *Ips typographus* (Hlášny and Sítková 2010; Hlášny and Turčáni 2013). As already presented above, this region is mostly covered by secondary Norway spruce forests that have been affected by air pollution since the late 18th century that reached its maximum in the second half of the 20th century. This affected forest health and soil conditions in the region. A large-scale bark beetle outbreak began in 1993 and persists to the present (2012). Turčáni and Hlášny (2007) revealed that the infestation was mainly caused by *Ips typographus*, although *Pityogenes chalcographus* (L., 1761), *Ips amitinus* (Eich. 1871), and *Ips duplicatus* (Sahl. 1836) were also observed.

![Figure 285 Areas of the Carpathian Mountains affected by Ips typographus. Left: Volume of incidental felling caused by Ips typographus in the Western Carpathians, Right: Percentage of forest cover infested by Ips typographus in the Eastern Carpathians of Romania (maps taken from SR2T2D3 Deliverable report).](image)

In the Tatra Mts., Slovakia, the windthrow in 2004 initiated bark beetle outbreak already 3 years after the windstorm (Zach et al. 2008). Although damaged timber had been removed from most wind-affected areas, strictly protected areas dominated by Norway spruce (*Picea abies*), have been left unsalvaged. The authors revealed that the availability of food resources, several additional windthrow events and two years of drought (2006, 2007) allowed *Ips typographus* population in protected areas to reach outbreak levels within three years (Zach et al. 2008).

Similar development is observed in Romania, Eastern Carpathians, where *Ips typographus* outbreaks usually appear as a consequence of damages produced by windthrows and/or snow. For the period 1990-2000 the most important outbreak occurred in 1995 (for more details see Deliverable: SR2.T3.D1.). In the period 2000 – 2010, high values of infestation by *Ips typographus* in districts under the Alba Forestry Department were related to forest damage caused by snow from April, 2001. One of the reasons for bark beetle propagation is the occurrence of windstorm inside national parks, which are under high conservation regime restricting interventions and wood removal only to exceptional cases (Simionescu et al. 2013).

The detailed analysis of other insect species and their impact on Carpathian forests is presented in SR2T2D3 Deliverable of this project.
Soil erosion

Although soil erosion is a natural process, its present extent is mainly the result of human activities (Schmidt 2000). It depends on a complex of factors including hydro-meteorological situations, soil qualities, land cover, and topography (Šír et al. 2013). In forest environment, it can occur after natural disturbances such as windthrow or after human-induced changes caused by e.g. clearcut management. Although soil covered by a forest is generally considered to be sufficiently protected from erosion, and a forest is considered the most effective anti-erosion measure, erosion occurs also in forests. As presented by Klč and Klč (1998), in the areas covered by forests, erosion occurs on and in the vicinity of paved or unpaved forest roads, as well as on unpaved touristic paths. The authors revealed that in the study area situated in the Low Tatras (Western Carpathians, Slovakia) almost one fourth of the forest road network area, and more than 90% of the area of touristic paths is eroded. Although the intensity of erosion does not reach values of agricultural land, it is faster than the creation of the material (Klč and Klč 1998).

Figure 29 Soil erosion on an unpaved forest road in the Western Carpathians of Slovakia.

Šír, et al. (2013) analysed the risk of soil erosion in the Moravian-Silesian Beskydy Mts. (the Outer Western Carpathians) using the USPED model, and found that maximum erosion risk was estimated for the area of the main precipitation centre. They also revealed a considerable influence of topography, when steeper northern slopes are more susceptible to erosion than gentle slopes with southern aspect. The analysis of vertical distribution of erosion processes in Pirot municipality in Serbia pointed out that the zone between 500 and 800 m a.s.l. suffers more from erosion than other elevation zones mainly due to land management (Perovic et al. 2012).

Undisturbed forests generally produce the least amount of runoff and soil erosion among all land use systems (Blanco-Canqui and Lal 2010). "Forests help keep soil intact and prevent it from eroding in a number of ways. By intercepting rain, a forest canopy reduces the impact of heavy rainfall on the forest floor, reducing soil disturbance. Leaves and natural debris on the forest floor slow the rate of water runoff and trap soil washing away from nearby fields. Tree roots can hold soil in place and stabilize stream banks" (http://www.seesouthernforests.org/case-studies/role-forests-erosion-regulation). Nijnik et al. (2012) proved that the share of forests in Ukrainian landscape significantly decreases the erosion rate. In the Carpathians of Ukraine, forest cover plays even a more important role in the prevention of erosion than in the country as a whole (Nijnik et al. 2012). According to the results of the authors, if there were no forests in rural landscapes, the eroded lands would comprise 79% of the Carpathians.

Over the last 20 years the proportion of agricultural land in the Western Carpathians decreased, and hence so called sheet erosion and deflation have also been reduced (Raczkowska et al. 2012). Increasingly frequent extreme weather events may have a negative effect on the currently stabilizing trend of landform evolution that has been observed over the last 20 years in the Western Carpathians (Raczkowska et al. 2012).
Particularly precipitation extremes may cause an increase of floods and landslides in the region (Stankoviansky et al. 2012).

**Landslides**

Landslides are a very common geomorphic hazard all over the Carpathians. They usually occur in hilly and montane regions, especially on flysch bedrock (Ondrášik 2002, Krejčí et al. 2002, Grozavu et al. 2013). Large landslides in the Carpathians are typically hydrologically complex given the alternating shale and sandstone stratigraphy and complex geologic structures of the flysch bedrock (Collins et al. 2011). Studies dealing with landslides attempt to determine actually and potentially unstable slopes based on the factors responsible for the process of landsliding. Their occurrence is primarily determined by slope inclination, altitude, soil class, geology, and distance to drainage network (Grozavu et al. 2013).

In Romania, several studies regarding landslide and erosion susceptibility have been conducted at a national (Bălteanu et al. 2010) or local levels (Cătănescu et al. 2012). Slow landslides determined by freeze-thaw cycles were observed after deforestation of subalpine forest belt (Andra 2007). In the Iezer Mountains (Figure 47), brown acidic soils were mostly affected by this disturbance, but the observed landslides were not in direct relation with most significant windthrow from July, 2005.

![Figure 307 Location of Iezer and Godeanu Mountains within the Carpathians.](image)

Grozavu, et al. (2013) conducted landslide susceptibility assessment in the upper Putna River basin in the Romanian Carpathians (210 km²). The region is situated at elevations from 459 m to 1588 m a.s.l. (mean = 899 m a.s.l.) with mean slope inclination 19 degrees (range 0-68 degrees). On the base of the landslide inventory they identified that 11% of the study area have been affected by landslides. However, the model of landslide susceptibility developed by authors suggests that potentially over 30% of the study area displays high and very high susceptibility to landsliding. Although they did not analyse the reasons between the actual and potential landslide area, we might assume that the presence of forest cover reduces the area affected by landslides, because scientific studies confirm the crucial role of trees and forests in preventing landslides by reinforcing and drying soils, and by directly obstructing smaller slides and rock falls (FAO 2011).
Avalanches

Avalanche disturbances primarily affect subalpine forests closest to the upper timber line (Bebi et al. 2009). They can damage or completely destroy trees at an area of over 10–100s of hectares located in vulnerable topographic conditions. According to Kovalchuk et al. (2012), in the Ukrainian Carpathians avalanches occur on slopes with inclinations of 20–45° at elevations of 300–2,000 m. Conversely, forests generally reduce the likelihood of avalanche occurrence. Bebi et al. (2009) summarised the conditions of forests that reduce the likelihood of avalanches: crown coverage of >30%, the absence of gaps >25 m in length, an increased terrain roughness associated with lying or standing trees that exceed snow-depth. Thus, forests can protect areas beneath including human settlements and infrastructure.

The positive influence of forests was documented by e.g. (Bartík et al. 2013) in a local study in the Slovak Carpathians. He used ELBA+ model to assess the vulnerability of montane environments below the main ridge of the Low Tatras in the in the valley Žúrová above the village Magurka (1,036 m a.s.l.), where on 14th March 1970 one of the largest avalanches ever recorded in Slovakia occurred (Figure 45). The avalanche started above the upper timber line at elevations from 1,620 to 1,680 m a.s.l. It was 2.2 km long, affected 39 hectares, and stopped at the beginning of the village. The authors tried to reconstruct the avalanche and to quantify the retarding effect of the forest on the avalanche path. Their results confirmed the positive influence of the forest on the release zone of the avalanche. However, if the release zone is situated above the timber line, forests situated below have a limited retarding effect on such large-scale avalanches.

Considering climate change and an upward shift of the upper timber line in the future, we might expect that the protective function of forests against avalanches will increase.

Figure 318 Avalanche in the valley Žúrová, Low Tatras, Slovakia, Western Carpathians on 14th March 1970
(Source: http://www.hoslavia.utc.sk/pages/12_lavina_nad_magurkou.htm).
Floods

Deforestation of small watersheds located in the mountainous areas may cause floodings in the lowlands. For example, in the counties of Vrancea, Bacau and Neamț, loss of forest cover in high elevations significantly contributed to the historical discharge recorded in July, 2005 on Siret River (4,650 m³/s at Lungoci) (Romanescu and Nistor 2011). Although the effects occurred outside the Carpathians, this event had a direct link with the Carpathians. The total surface affected by floods was 58,323.936 hectares. The main causes of forest cover decrease were the massive deforestation in the upper elevations of the Siret River watershed and the windthrow. The human-induced deforestation results from the restitution of forest lands and their intense and careless exploitation. Extending the analysis to the west from the assessed watershed we can see deforested areas also in Transilvania, which further increased the flooding risk in lower basins (Ursu et al. 2007).

The overall value of damages exceeded two million Euros: over 10,000 houses were completely destroyed, thousands of domestic animals were lost, and 24 human deaths were recorded after this event.

Valo (2013) presented that not only deforestation, but also soil compression on forest slopes due to forest logging with heavy machinery is one of the main reasons for floods. Both unpaved and paved forest roads act as trenches that drain water to the rivers much faster than natural soil surface. The author realised several measures in Slovakia, which consisted of disrupting unused forest roads by transverse agitation of the compressed soil with a suitable excavator and by building water systems in the forest vegetation, and found that such measures are much more efficient and also much cheaper than building anti-flooding dikes, dams and storm lakes at the foot of the mountains and plains (Valo 2013). Annually, forest offers over €90/ha of non-marketed gains in the prevention of floods and avalanches in the Carpathians (Gensiruk and Ivanytsky 1999) in (Nijnik et al. 2012).

Conclusions

Montane and subalpine forests are an important component of forest landscape. In the Carpathians, 60% of all the Carpathian forests are montane and subalpine forests situated at elevations above 600 m a.s.l. They fulfil multiple functions with the emphasis on protective and socioeconomic functions. On the other hand, they are very sensitive ecosystems that can be easily disturbed, while their restoration might be more difficult. In the past, many of the Carpathian montane forests were under the direct human influence, since their parts were often converted to agricultural land. Nowadays, this effect has been diminished, and a large part of farmland has been reforested. Currently, the protective function of montane and sub-alpine forests in the Carpathians is negatively affected by abiotic factors, such as wind and drought, which are usually followed by biotic factors, e.g. bark beetles and fungal pests. With the projected climate change it is expected that the intensity and the frequency of these disturbance factors will increase. In addition, some currently unimportant agents, such as fire, may become more important. Since the montane and subalpine forests are often situated on sites with extreme slopes, their sustainability is crucial to ensure their long-term protective functions. Therefore, continuous monitoring of these forests is needed. Although the effect of changes in forest cover on protective function of montane and subalpine forests is mentioned elsewhere, this issue has usually been addressed only at a local level and has only rarely been studied in a quantitative way. Such analysis could provide a comprehensive view of forest cover change in the Carpathians and quantify the influence of individual factors on the dynamics of montane and subalpine forests. Considering the future climate change, an upward shift of the upper timber line to higher elevations is expected. This shift will enhance protective function of forests against avalanches and rock falls. On the other hand, more frequent weather extremes are projected, which will have a negative influence on stability of montane forests, and at lower elevations it may even cause larger disruptions of ecosystems. To ensure that montane forests will be able to fulfil their protective functions under changing climate conditions, species shift has to be considered and adaptive management measures that will increase forest resistance to disturbance factors have to apply.
5.3.6. Task 6: Integrated assessment of forest vulnerability to climate change

Evaluation of integrated forest vulnerability to climate change in the Carpathians is the ultimate purpose of the Special Request 2: Impact on Ecosystems. We synthesized in this report the achievements and findings from other project deliverables, mainly those on forest adaptation to climate change (SR2.T4.D2), species shift (SR2.T5.D1) and present and anticipated effect of pests and pathogens (SR2.T2.D1 and SR2.T2.D3). Results of climate modelling, represented by an ensemble of carefully selected climate change scenarios and various climate maps, which were prepared within the frame of concurrent projects, provided key information on future climate development in the Carpathians.

We used broad range of information sources to elaborate the presented assessment, and we consulted particular inputs, mainly on current adaptive capacity of forestry sector in individual countries, with number of national experts. Despite our effort, some information remained inaccessible mainly because of regulations on access to national data. Hence, appearance of such information can be used to adjust the presented vulnerability assessment. Therefore, our assessment needs to be thought of as open, allowing users reconsidering input variables, and arriving at more precise and adequate conclusions.

We believe that presented vulnerability assessment can improve the efficiency of adaptation in the Carpathians by pointing out the weaknesses and strengths of individual regions, and thus optimising funds allocations to research of climate change vulnerability, and practical management of forest resources towards securing sustainable provision of forest goods and services under changing environment.

The main objectives addressed are:

- to propose framework for the assessment of Carpathian forests vulnerability to climate change using the exposure-sensitivity-adaptive capacity concept;
- to evaluate the climatic exposure of the Carpathians, i.e. the anticipated change in selected bioclimatic variables which can be expected to affect the future forest dynamics;
- to evaluate forest sensitivity in the Carpathians using several indicator, i.e. to evaluate the anticipated response of forests and services and functions to range of impact factors;
- to evaluate the current adaptive capacity based on indicators of countries’ development, awareness and legislation;
- to evaluate the integral forest vulnerability, and discuss the results.

We adopted in this study the vulnerability concept proposed by Lindner et al. (2008, 2010), who applied this approach in the assessment of climate change vulnerability of European forests using biogeographical zones of Europe as spatial frames for vulnerability assessment. The authors proposed the scheme in the Figure 49.
Scheme components are defined as follows:

- **Impact factors** are climatic, physical, and biological variables that are influenced by climate change and cause the impacts in the system.
- **Exposure** specifies the projected change of climate that is affecting the system.
- **Sensitivity** describes the degree to which a system is affected, either adversely or beneficially. The effects of climate change may be direct (e.g., changes in forest growth in response to a change in temperature or precipitation) or indirect (e.g., damages caused by an increase in the frequency of fires or a new biotic pest species).
- **Impacts** are the consequences of climate change that are likely to affect forest goods and services and forestry activities, as a function of exposure and sensitivity to changes.
- **Adaptive capacity** describes the ability of a system to adapt to changes in climate.
- **Inherent adaptive capacity** summarizes the evolutionary mechanisms and processes that permit tree species to adjust to new environmental conditions.
- **Socio-economic adaptive capacity** is the ability of human sectors, like forestry, to implement planned adaptation measures.
- **Vulnerability** can be defined as the degree to which a system is susceptible to be affected by adverse effects of climate change. The vulnerability of a given system is a function of the climate variation to which this system is exposed (exposure), its sensitivity (together resulting in impacts on goods and services), and its adaptive capacity.
5.3.6.1. Spatial frame for forest vulnerability assessment

Carpathian border used was designated as the union of borders specified by the Carpathian Ecoregion Initiative and Carpathians Environment Outlook (KEO 2007) (Figure 47) in order to provide the vulnerability assessment within a broader spatial frame suitable for various initiatives in the Carpathians. Size of the area is 229,966 km².

Specific division of the Carpathians was proposed as spatial frame for vulnerability assessment. Borders of countries were intersected with borders of geomorphologic subprovinces (Kondracki 1989) (Figure 50, Table 9). Outer Eastern Carpathians were divided into two parts by Ukraine-Romanian border, as several climate elements were intensively changing between these two sub-regions (see changes in air temperature and precipitation, Table 9); these two units were named Outer Eastern Carpathians North and Outer Eastern Carpathians South.

As only a minor part of Austria stretches into the study region (680 km², 0.29% of the study region), Austria has not been considered.

The 18 units were produced in the aforementioned intersection (CoGPs hereinafter) (Figure 50, Table 9). The component of subprovinces is used to evaluate the climatic exposure and forests sensitivity to climate change. These units represent the natural division with specific climate, biota and relief, hence we though them as suitable for evaluating physical (climatic exposure) and biological (forest sensitivity) components of the integrated vulnerability. As adaptive capacity (the social-economic component) largely depends on countries' economic development and legislation, adaptive capacity was evaluated in the frame of state boundaries, i.e. each country is assigned by semi-quantitative value indicating level of its adaptive capacity. Information on regional differences within countries was not considered, though differences between, for example forest enterprises, can largely increase the variability of adaptive capacity. Such information, however, was not available in the current study.
Table 9 Characteristics of geomorphologic units in the Carpathians used as spatial frame for the evaluation of species shift induced by climate change.

<table>
<thead>
<tr>
<th>Geomorphologic unit</th>
<th>Area (km²)</th>
<th>Forest cover (%)</th>
<th>T (°C)</th>
<th>P (mm)</th>
<th>Countries proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern Carpathians</td>
<td>19,019</td>
<td>60.8</td>
<td>6.7</td>
<td>703</td>
<td>RO 100</td>
</tr>
<tr>
<td>Western Romanian Carpathians</td>
<td>22,968</td>
<td>58.0</td>
<td>6.8</td>
<td>639</td>
<td>RO 100</td>
</tr>
<tr>
<td>Serbian Carpathians</td>
<td>9,607</td>
<td>45.3</td>
<td>9.7</td>
<td>642</td>
<td>Serb 100</td>
</tr>
<tr>
<td>Transylvanian Plateau</td>
<td>29,664</td>
<td>24.1</td>
<td>8.4</td>
<td>485</td>
<td>RO 100</td>
</tr>
<tr>
<td>Inner Eastern Carpathians</td>
<td>27,971</td>
<td>49.7</td>
<td>6.9</td>
<td>704</td>
<td>RO 77, UA 21, SK 2</td>
</tr>
<tr>
<td>Outer Eastern Carpathians</td>
<td>35,974</td>
<td>63.2</td>
<td>6.9</td>
<td>878</td>
<td>UA 60, PL 29, SK 11</td>
</tr>
<tr>
<td>Outer Eastern Carpathians</td>
<td>23,545</td>
<td>53.8</td>
<td>7.9</td>
<td>558</td>
<td>RO 100</td>
</tr>
<tr>
<td>Inner Western Carpathians</td>
<td>36,561</td>
<td>47.0</td>
<td>7.7</td>
<td>683</td>
<td>SK 68, HU 32</td>
</tr>
<tr>
<td>Outer Western Carpathians</td>
<td>24,659</td>
<td>40.1</td>
<td>7.1</td>
<td>773</td>
<td>PL 38, CZ 30, SK 30, AU 3</td>
</tr>
</tbody>
</table>

T (°C) – average annual air temperature during the period 1961-1990; P (mm) – average annual precipitation totals during the period 1961-1990; *proportion of the forested area. Climatic data were taken from the FORESEE database described in the next chapter.

Figure 50 Intersection of geomorphological subprovinces and state boundaries in the Carpathians. Such units of spatial division are used of frame for forest vulnerability assessment.
Table 10 Forests distribution in the Carpathians within spatial units defined as intersection of state boundaries and geomorphologic subprovinces. Such units are used as spatial frame for vulnerability assessment.

<table>
<thead>
<tr>
<th>Country</th>
<th>Geomorphologic subprovince</th>
<th>Vertical zone</th>
<th>Broadleaved</th>
<th>Coniferous</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt; 600 m a.s.l</td>
<td>km²</td>
<td>%</td>
<td>km²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>km²</td>
<td>%</td>
<td>km²</td>
</tr>
<tr>
<td>AT</td>
<td>Outer Western Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>134.5</td>
<td>93.5</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Outer Western Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>636.6</td>
<td>35.4</td>
<td>486.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>100.7</td>
<td>11.4</td>
<td>544.0</td>
</tr>
<tr>
<td>SK</td>
<td>Inner Eastern Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>274.1</td>
<td>97.1</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>130.2</td>
<td>93.5</td>
<td>0.0</td>
</tr>
<tr>
<td>PL</td>
<td>Inner Western Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>5074.2</td>
<td>82.7</td>
<td>326.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>2029.7</td>
<td>31.0</td>
<td>2556.8</td>
</tr>
<tr>
<td></td>
<td>Outer Eastern Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>1510.9</td>
<td>82.5</td>
<td>34.1</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>&gt; 600 m a.s.l</td>
<td>239.5</td>
<td>87.3</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>Outer Western Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>482.1</td>
<td>45.8</td>
<td>298.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>300.5</td>
<td>12.8</td>
<td>1552.8</td>
</tr>
<tr>
<td>HU</td>
<td>Inner Western Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>3819.7</td>
<td>92.4</td>
<td>103.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>265.2</td>
<td>95.4</td>
<td>9.0</td>
</tr>
<tr>
<td>UA</td>
<td>Inner Eastern Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>464.7</td>
<td>58.2</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>687.3</td>
<td>69.7</td>
<td>167.6</td>
</tr>
<tr>
<td></td>
<td>Outer Eastern Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>1517.4</td>
<td>47.4</td>
<td>60.7</td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>&gt; 600 m a.s.l</td>
<td>6691.1</td>
<td>52.2</td>
<td>3511.9</td>
</tr>
<tr>
<td>RO</td>
<td>Southern Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>2161.4</td>
<td>95.5</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>4107.5</td>
<td>44.2</td>
<td>1716.6</td>
</tr>
<tr>
<td></td>
<td>Transylvanian Plateau</td>
<td>&lt; 600 m a.s.l</td>
<td>5517.3</td>
<td>97.6</td>
<td>45.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>1341.9</td>
<td>89.5</td>
<td>32.7</td>
</tr>
<tr>
<td></td>
<td>Western Romanian Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>6843.4</td>
<td>98.8</td>
<td>24.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>4838.9</td>
<td>75.7</td>
<td>1075.3</td>
</tr>
<tr>
<td>RS</td>
<td>Serbian Carpathians</td>
<td>&lt; 600 m a.s.l</td>
<td>2980.0</td>
<td>98.6</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 600 m a.s.l</td>
<td>1300.3</td>
<td>97.4</td>
<td>15.2</td>
</tr>
</tbody>
</table>
5.3.6.2. Approach to vulnerability assessment

Climatic exposure was evaluated using climatic data taken from the FORESEE database (Dobor et al. 2012), which is described in greater detail in Deliverables SR2.T5.D1 (species shift) and SR2.T5.D3 (grasslands productivity) of the CarpathCC project. Mean annual air temperature, precipitation totals during growing season (IV-IX) and Ellenberg climatic quotient were used. Differences between future climates (2021-2050 and 2071-2100) according to four regional climate models and reference period (1961-1990) were used for exposure evaluation. Spatial and inter-model variability of future climates within used units of spatial division has not been considered.

As three climate variables used to describe the climatic exposure are correlated, and each of them implies slightly different ranking of CoGP units, we used the principal components analysis to reduce the number of variables, and to facilitate easier interpretation of information on climatic exposure. Therefore, first component extracted from three inputs climate variables was used to rank the CoGP units by their exposure. Semiquantitative scale taking on values “Low”, “Moderate”, “High” and “Very high” was used to further simplify the assessment and allow for integrated vulnerability assessment.

Evaluation of forests sensitivity is complex issue, as it includes sensitivity of several forest components to range of impact factors, with consequence on forest capacity to provide goods and services. Both wood and non-wood products, and services such as biodiversity maintenance, recreation, carbon storage, soil protection, water regulation and others can be considered, following the definitions from the previous chapter.

To cope with such complexity, we focused mainly on three main zonal tree species of the Carpathians – oaks (Quercus sp.), European beech (Fagus sylvatica) and Norway spruce (Picea abies). These species were addressed also in other reports of the SR2, and sufficient information on their sensitivity, in terms of anticipated shift of their distributional ranges or responses to array of pests and pathogens, is available. As impact factors and forest`s sensitivity are strongly coupled, we evaluated both of these factors within each CoGP to arrive at final sensitivity evaluation.

Sensitivity assessment was performed separately for each CoGP units designated in the previous chapter. The following indicators were considered:

- Species sensitivity in given CoGP to drought depending on species physiological settings, position on elevation gradient, observation of species response to elevated drought reported from other regions, and projections of drought induced species shift presented in Deliverable SR2.T5.D1.;
- Species sensitivity to abiotic damage and current position of evaluated forests in regions with certain disturbance regime;
- Species sensitivity to biotic damage, and current position of evaluated forest in regions with regular outbreaks; Mainly two pests – Lymantria dispar and Ips typographus – were considered, though other agents reported in national statistics as having serious impact in given regions are considered as well;
- Position of evaluated forests within regions exposed to non-climatic stressors, such as air pollution or regular game damages, which may amplify forest sensitivity to climatic stress;
- Share of mountain forests in CoGP. The following adverse and beneficial impacts and responses were considered:
  - Forest production and carbon accumulation in mountain areas is expected to benefit from climate change;
  - Species shift may pose threat to biodiversity to alpine communities (see deliverable SR2.T2.D1 on species shift for more details);
  - Effects of drought in high elevations should not be pronounced in the future;
  - Increase frequency of windstorms may increase damage to forests with subsequent bark beetle outbreaks;
  - Windthowns related deforestations may affect forest protective functions, mainly those related to water regulations and erosion prevention.
On these bases, the semiquantitative ranking of all CoGP was performed. Scale “Low”, “Moderate”, “High” and “Very high” was used.

Evaluation of forest adaptive capacity was based on the outputs of deliverable SR2.T4.D2 (adaptive forest management). Countries social-economic adaptive capacity was evaluated using several indicators. The same scale as in case of forest sensitivity assessment was used.

Though most of the aforementioned indicators of climatic exposure and forest sensitivity can be evaluated quantitatively, we decided not to perform the quantitative assessment of integrated forest vulnerability. This task would need to develop specific aggregation scheme, cope with weight assignment to input factors, and output values would be difficult to interpret and track back their origin. Therefore, expert panel based approach was used, and forest vulnerability in each CoGP unit was assessed using the results of evaluation of exposure, sensitivity and adaptive capacity using the aforementioned semiquantitative scale.
5.3.6.3. Forest vulnerability assessment

CLIMATIC EXPOSURE

Climatic exposure of CoGP units was evaluated on the basis of change in mean annual air temperature, precipitation total during vegetation season, and Ellenberg climatic quotient; differences between projected future and past climate were used as indicator of climatic exposure (Table 11). Spatial variability of increases in mean annual air temperature is relatively low, and it ranges among CoGP in the near future between 1.17 and 1.73°C, and between 3.11 and 3.72 in the distant future (Table 10). Considering this parameter, exposure of the Carpathians can be thought of as constant, though there is trend of increased warming from the Western Carpathians towards east and south (Annex 19). Following maps in this Annex, RegCM and RACMO show the most intensive warming, which is highest in the Romanian and Serbian part of the Carpathians; projected increase in air temperature reaches in some locations even 5.5°C; such variability is however smoothed at the scale of CoGPs. The Western Carpathians are expected to face the temperature increase between 2.5 – 3.5°C, in some southern locations even 4°C.

Much higher spatial variability can be seen in the changes in precipitation, and this variability is also high among used climate models (Annex 19). Despite high variability, spatial gradient in precipitation change decreases from the north-west to the south-east according to all models. The RACMO model implies substantial precipitation increase in the Czech and Polish part of the Western Carpathians while other models show precipitation in the Western Carpathians more-less equal to the reference period. Decrease in precipitation was projected by all models almost in all Romanian and Serbian Carpathians, the magnitude of change is however highly variable.

Ellenberg quotient takes on the range 10 – 85 across the Carpathians in the reference period, the spot of extreme values is however located in relatively small area in the Transylvannian Plateau. Most of the Western Carpathians is covered by values up to 30. Higher values indicating dry climate, are distributed mostly in the Hungarian part of the Carpathians and in the Outer Eastern Carpathians in Romania. Projected change in Ellenberg quotient shows similar large scale pattern in all RCMs used (Annex 19), regional differences are however more distinct as compared with air temperature. There is a remarkable trend in differences in Ellenberg quotient between the distant and reference climate, increasing from the Western Carpathians towards the Eastern and Serbian Carpathians.

To aggregate the information on projected change indicated by used climate variables, and to produce integrated exposure map, we used the scores of the first principal component (PC1) as such integrated indicator (see Figure 51 for values of PC1 and illustratively also for PC2). These scores were used to rank the CoGP by their climatic exposure (Table 12). Independent ranking was proposed for each future time period, though these rankings highly correlate.

As can be seen, climatic exposure apparently increases from the Western Carpathians towards the Romanian and Serbian Carpathians (Figure 52), following the general trend which was described using the maps in Annex 19. Polish part of the Carpathians shows only low exposure as compared with other units, as some climate models project even increase in precipitation in the future for this region. This may partly compensate the increased evaporative loss induced by increased air temperature. This fact is also reflected in minor increases in Ellenberg climatic quotient in the Western Carpathian CoGPs.

The important fact is that the proposed semiquantitative ranking describes relative exposure of CoGPs in the Carpathians. Therefore, for example category „Low“, indicates low exposure in the context of the Carpathians. On the other hand, Outer Western Carpathians are expected to face, according to some RCMs, even increase in precipitation during growing season, and Ellenberg quotient shows only minor increase comparing to the reference climate (Table 9). Therefore, low climatic exposure can be referred to the
projections for the Outer Western Carpathians, where no substantial affect on regional drought conditions is projected.

Figure 51 First two components (PCA1 and PCA2) extracted from differences in mean annual air temperature, precipitation totals during vegetation season and Ellenberg climatic quotient between period 2021-2050 and 1961-1990 (upper plot), and 2071-2100 and 1961-1990 (lower plot). Units of spatial division of the Carpathians used for vulnerability assessment are ordered by magnitude of PCA1. This order and these values indicate climate exposure of the Carpathians. Values and y-axis are unitless.
Table 11 Climatic exposure of countries intersected with geomorphologic subprovinces of the Carpathians. Mean changes of future climates (2021-2050 and 2071-2100) according to four regional climate models against reference period (1961-1990) are presented. AMT – annual mean temperature, PTGS – precipitation total during growing season IV-IX, EQ – Ellenberg climatic quotient.

<table>
<thead>
<tr>
<th>Country</th>
<th>Geomorphological subprovince</th>
<th>Code</th>
<th>AMT 2021-2050 (°C)</th>
<th>AMT 2071-2100 (°C)</th>
<th>PTGS 2021-2050 (%)</th>
<th>PTGS 2071-2100 (%)</th>
<th>EQ 2021-2050 (°C.mm⁻¹)</th>
<th>EQ 2071-2100 (°C.mm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>Outer Western Carpathians</td>
<td>AT-OWC</td>
<td>1.32</td>
<td>3.13</td>
<td>7.02</td>
<td>4.09</td>
<td>0.71</td>
<td>0.70</td>
</tr>
<tr>
<td>CZ</td>
<td>Outer Western Carpathians</td>
<td>CZ-OWC</td>
<td>1.33</td>
<td>3.21</td>
<td>1.28</td>
<td>-3.09</td>
<td>1.89</td>
<td>2.96</td>
</tr>
<tr>
<td>SK</td>
<td>Inner Eastern Carpathians</td>
<td>SK-IEC</td>
<td>1.26</td>
<td>3.33</td>
<td>-7.53</td>
<td>-15.86</td>
<td>3.10</td>
<td>5.66</td>
</tr>
<tr>
<td>SK</td>
<td>Inner Western Carpathians</td>
<td>SK-IWC</td>
<td>1.31</td>
<td>3.28</td>
<td>-3.17</td>
<td>-12.21</td>
<td>2.55</td>
<td>5.24</td>
</tr>
<tr>
<td>SK</td>
<td>Outer Eastern Carpathians</td>
<td>SK-OECN</td>
<td>1.25</td>
<td>3.26</td>
<td>-4.40</td>
<td>-12.85</td>
<td>2.67</td>
<td>5.15</td>
</tr>
<tr>
<td>SK</td>
<td>Outer Western Carpathians</td>
<td>SK-OWC</td>
<td>1.32</td>
<td>3.24</td>
<td>1.45</td>
<td>-5.40</td>
<td>1.68</td>
<td>3.36</td>
</tr>
<tr>
<td>PL</td>
<td>Inner Western Carpathians</td>
<td>PL-IWC</td>
<td>1.26</td>
<td>3.21</td>
<td>5.94</td>
<td>-3.06</td>
<td>0.37</td>
<td>1.78</td>
</tr>
<tr>
<td>PL</td>
<td>Outer Eastern Carpathians</td>
<td>PL-OECN</td>
<td>1.17</td>
<td>3.11</td>
<td>-1.56</td>
<td>-7.96</td>
<td>1.56</td>
<td>3.70</td>
</tr>
<tr>
<td>PL</td>
<td>Outer Western Carpathians</td>
<td>PL-OWC</td>
<td>1.27</td>
<td>3.16</td>
<td>2.15</td>
<td>-3.81</td>
<td>1.64</td>
<td>3.06</td>
</tr>
<tr>
<td>HU</td>
<td>Inner Western Carpathians</td>
<td>HU-IWC</td>
<td>1.31</td>
<td>3.27</td>
<td>-6.87</td>
<td>-15.87</td>
<td>3.24</td>
<td>6.94</td>
</tr>
<tr>
<td>UA</td>
<td>Inner Eastern Carpathians</td>
<td>UA-IEC</td>
<td>1.28</td>
<td>3.31</td>
<td>-14.05</td>
<td>-21.68</td>
<td>4.13</td>
<td>6.57</td>
</tr>
<tr>
<td>UA</td>
<td>Outer Eastern Carpathians</td>
<td>UA-OECN</td>
<td>1.29</td>
<td>3.20</td>
<td>-12.88</td>
<td>-19.21</td>
<td>3.69</td>
<td>5.80</td>
</tr>
<tr>
<td>RO</td>
<td>Inner Eastern Carpathians</td>
<td>RO-IEC</td>
<td>1.26</td>
<td>3.26</td>
<td>-10.11</td>
<td>-19.11</td>
<td>3.48</td>
<td>7.89</td>
</tr>
<tr>
<td>RO</td>
<td>Outer Eastern Carpathians</td>
<td>RO-OECS</td>
<td>1.43</td>
<td>3.36</td>
<td>-15.17</td>
<td>-25.08</td>
<td>9.16</td>
<td>16.70</td>
</tr>
<tr>
<td>RO</td>
<td>Southern Carpathians</td>
<td>RO-SC</td>
<td>1.52</td>
<td>3.62</td>
<td>-16.89</td>
<td>-29.00</td>
<td>5.91</td>
<td>13.04</td>
</tr>
<tr>
<td>RO</td>
<td>Transylvanian Plateau</td>
<td>RO-TP</td>
<td>1.45</td>
<td>3.46</td>
<td>-7.21</td>
<td>-18.06</td>
<td>2.49</td>
<td>7.62</td>
</tr>
<tr>
<td>RO</td>
<td>Western Romanian Carpathians</td>
<td>RO-WRC</td>
<td>1.73</td>
<td>3.86</td>
<td>-16.86</td>
<td>-27.65</td>
<td>7.17</td>
<td>13.44</td>
</tr>
<tr>
<td>RS</td>
<td>Serbian Carpathians</td>
<td>RS-SC</td>
<td>1.57</td>
<td>3.72</td>
<td>-23.62</td>
<td>-33.23</td>
<td>8.10</td>
<td>15.38</td>
</tr>
</tbody>
</table>

08/09/2013
Table 12 Exposure of CoGP units in the Carpathians evaluated on the basis of first principal component scores extracted from differences in mean annual air temperature, precipitation totals during vegetation season and Ellenberg climatic quotient between period 2021-2050 and 1961-1990), and 2071-2100 and 1961-1990.

<table>
<thead>
<tr>
<th>Country</th>
<th>Geomorphological subprovince</th>
<th>Code</th>
<th>PC1 score 2021-2050</th>
<th>PC1 score 2071-2100</th>
<th>Climatic exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>Outer Western Carpathians</td>
<td>AT-OWC</td>
<td>-1.10360</td>
<td>-1.47267</td>
<td>Low</td>
</tr>
<tr>
<td>CZ</td>
<td>Outer Western Carpathians</td>
<td>CZ-OWC</td>
<td>-0.65170</td>
<td>-0.91863</td>
<td>Low</td>
</tr>
<tr>
<td>SK</td>
<td>Inner Eastern Carpathians</td>
<td>SK-IEC</td>
<td>-0.25954</td>
<td>-0.07074</td>
<td>Medium</td>
</tr>
<tr>
<td>SK</td>
<td>Inner Western Carpathians</td>
<td>SK-IWC</td>
<td>-0.40848</td>
<td>-0.31231</td>
<td>Medium</td>
</tr>
<tr>
<td>SK</td>
<td>Outer Eastern Carpathians North</td>
<td>SK-OECN</td>
<td>-0.48435</td>
<td>-0.33011</td>
<td>Medium</td>
</tr>
<tr>
<td>SK</td>
<td>Outer Western Carpathians</td>
<td>SK-OWC</td>
<td>-0.71573</td>
<td>-0.75825</td>
<td>Low</td>
</tr>
<tr>
<td>PL</td>
<td>Inner Western Carpathians</td>
<td>PL-IWC</td>
<td>-1.25651</td>
<td>-1.00960</td>
<td>Low</td>
</tr>
<tr>
<td>PL</td>
<td>Outer Eastern Carpathians North</td>
<td>PL-OECN</td>
<td>-0.97265</td>
<td>-0.85896</td>
<td>Low</td>
</tr>
<tr>
<td>PL</td>
<td>Outer Western Carpathians</td>
<td>PL-OWC</td>
<td>-0.87445</td>
<td>-0.96890</td>
<td>Low</td>
</tr>
<tr>
<td>HU</td>
<td>Inner Western Carpathians</td>
<td>HU-IWC</td>
<td>-0.14382</td>
<td>-0.07231</td>
<td>Medium</td>
</tr>
<tr>
<td>UA</td>
<td>Inner Eastern Carpathians</td>
<td>UA-IEC</td>
<td>0.22732</td>
<td>0.16746</td>
<td>Medium</td>
</tr>
<tr>
<td>UA</td>
<td>Outer Eastern Carpathians North</td>
<td>UA-OECN</td>
<td>0.13409</td>
<td>-0.15928</td>
<td>Medium</td>
</tr>
<tr>
<td>RO</td>
<td>Inner Eastern Carpathians</td>
<td>RO-IEC</td>
<td>-0.09052</td>
<td>0.09597</td>
<td>Medium</td>
</tr>
<tr>
<td>RO</td>
<td>Outer Eastern Carpathians South</td>
<td>RO-OECS</td>
<td>1.41506</td>
<td>1.14030</td>
<td>Very high</td>
</tr>
<tr>
<td>RO</td>
<td>Southern Carpathians</td>
<td>RO-SoC</td>
<td>1.21061</td>
<td>1.42841</td>
<td>Very high</td>
</tr>
<tr>
<td>RO</td>
<td>Transylvanian Plateau</td>
<td>RO-TP</td>
<td>0.09878</td>
<td>0.37046</td>
<td>High</td>
</tr>
<tr>
<td>RO</td>
<td>Western Romanian Carpathians</td>
<td>RO-WRC</td>
<td>1.91742</td>
<td>1.80985</td>
<td>Very high</td>
</tr>
<tr>
<td>RS</td>
<td>Serbian Carpathians</td>
<td>RS-SeC</td>
<td>1.95806</td>
<td>1.91931</td>
<td>Very high</td>
</tr>
</tbody>
</table>
Figure 52 Climatic exposure of the Carpathians. The map is valid for both near and distant future (2021-2050 and 2071-2100). The categories were designated by classification of PCA scores. For more details see the text.

**IMPACT FACTORS AND FOREST SENSITIVITY**

**Czech part of the Outer Western Carpathians (CZ-OWC)**

The unit consists of two parts, western and eastern. The eastern unit contains mostly coniferous forests with prevalence of Norway spruce. Forests in the north-eastern part can be thought of as the most man-altered forest in the Carpathians. Intensive decline of spruce forests supposedly related to past industrial air pollution and commercial overuse is typical of the region (Hlásny and Sítková 2010, Hlásny and Turčáni 2013). Although there are presently only indirect indications of climate change effect on forests, compromised ecological stability and range on non-climatic stressors make these forests potentially highly sensitive to climate change. Bark beetle populations can benefit from warmer climate, and 1-generation increase was projected to occur in the entire region by the end of the century, posing additional pressure on forest sustainability. Recent appearance of northern bark beetle (*Ips duplicatus*) generate additional concern about future biotic damage to forest. The pest is expected to respond positively to climate change, following similar response pattern as *I. typographus* (Holuša et al. 2012).

Wood production and carbon accumulation can be adversely affected by progressive forest decline. Decline in spruce production up to 25% can be expected by the end of the century in elevations up to 600 m a.s.l. In the same time, soil protective and water regulative function may be affected. Because of highly altered species composition, and diverse natural conditions, impact on biodiversity cannot be estimated.

The western part of the unit has more natural species composition with higher share of broadleaved. This zone however regularly suffers from defoliations by Gypsy moth, and it
may also be affected in the future by progressive drought. This fact makes forest here moderately sensitive.

Taking into account structure and processes in both parts of the CZ-OWC unit, we consider sensitivity of these forests to climate change as “Very high”. The main factors backing up such classification are:

Factors increasing forest sensitivity:
- High share of secondary Norway spruce forests with compromised ecological stability;
- Highly elevated activity of biotic agents causing large-scale forest decline;
- Forest position in areas where increase in annual number of bark beetle generations was projected;
- Forest position in areas where regular defoliations by Gypsy moth occur, and which are expected to expand under climate change.

Slovak part of the Outer Western Carpathians (SK-OWC)

The unit consists of two parts, eastern and western. High share of secondary spruce forests suffering from the same problems as the previous unit (CZ-OWC), are typical of both subregions. The western part belongs to the cross-boundary (CZ-PL-SK) region of the Western Beskids, which is one of European hot-spots of spruce decline. The causes of spruce decline in the eastern parts are different, and it is supposed to be caused mainly by former air pollution from local sources combined with bark beetle outbreaks. Such non climatic stressor can substantially increase forest sensitivity to future climate change.

Both parts regularly suffer from wind damage, which is expected to be more frequent in the future. Bark beetle populations can benefit from warmer climate posing additional pressure on forest sustainability. Similar effects on production and bark beetle development as in the previous unit (CZ-OWC) can be expected.

High level of disintegration of present forests along with high share of secondary spruce forests implies high sensitivity of forests and provision of goods and services. Large scale decline affects adversely all considered services and functions, i.e. wood production, carbon sequestration, protective functions, biodiversity and complex of social functions.

We consider the sensitivity of these forests to climate change as “Very high”. The main factors backing up such classification are:

Factors increasing forest sensitivity:
- High share of secondary Norway spruce forests with compromised ecological stability;
- Highly elevated activity of biotic agents causing large-scale forest decline;
- Forest position in areas where increase in annual number of bark beetle generations is projected;
- Increased forest sensitivity by long term effect of non-climatic stressors such as air pollution and improper management.

Polish part of the Outer Western Carpathians (PL-OWC)

The unit represent the continuation of CZ-OWC and SK-OWC, and its western part contains part of the aforementioned region of the Western Beskids with intensively declining spruce forests. Therefore, the same indicators of forest sensitivity as in the previous unit need to be considered. In the western part, higher share of broadleaved occurs in species composition, and present health status of forest is much better as compared with the western part. More detailed description of sensitivity of this eastern part is given in the next section on the adjacent units.

We consider the sensitivity of these forests to climate change as “High”. The main factors backing up such classification are:
Factors increasing forest sensitivity:
- High share of secondary Norway spruce forests with compromised ecological stability;
- Highly elevated activity of biotic agents causing the large-scale forest decline;
- Forest position in areas where increase in annual number of bark beetle generations is projected;
- Increased forest sensitivity by long term effect of non-climatic stressors such as air pollution and improper management.

Factors reducing forest sensitivity:
- High share of broadleaved forests with suitable stand structure in the eastern part of the unit;
- Lower effect of non-climatic stressors in the eastern part of the unit.

Polish and Slovak part of the Outer Eastern Carpathians North, Slovak part of the Inner Eastern Carpathians (PL-OECN, SK-OECN and SK-IEC)

Large share of beech forests in elevations above 500 m a.s.l. with substantial admixture silver fir, oaks and other broadleaved trees as well as generally low share of Norway spruce suggest lower sensitivity to climate change as compared with the previous units. Uneven-aged mixed forests managed mainly with shelterwood and selection management system, occur over large areas. Primeval beech forests with high biodiversity value occur in the very east of Slovakia.

Except of Fraxinus dieback, no significant outbreaks of pest or problems with forest health have been observed. Low susceptibility of broadleaved to wind and snow damage as well as to biotic damage implies relatively stable forests. Expansion of outbreak areas of Gypsy moth in the distant future (2071-2100) to large part of the region was projected, intensive defoliation of beech stands can however be only hypothesized (based on observations from other regions). Projections of future species shift (Deliverable SR2.T5.D1) did not imply worsening of growing conditions for beech and silver fir. Improvement of conditions for oak species may imply gradual change of species composition in lower elevations. None of these processes should affect provision of forest services and goods substantially.

Another factor affecting forest sensitivity to climate change is origin and site matching of current forests. After the Second World War over 50% of abandoned farm lands in the eastern part of the Polish Carpathians were afforested. Depending on sites and available seeds, Scots pine, European larch and red alder were used for farmland afforestation. Only about 15 % of nurse crop stands had species composition compatible with the site conditions, and this implies potentially higher sensitivity of these forests to climate change. However the share of nurse crop stands in total forested area of the region is relatively low.

We consider the sensitivity of these forests to climate change as “Low”. The main factors backing up such classification are:

Factors increasing forest sensitivity:
- Sparse occurrence of Fraxinus dieback;
- Potential expansion of Gypsy moth outbreaks from lower elevations;
- Forest position in areas where appearance of newly emerging pest species attacking broadleaved can be expected.

Factors reducing forest sensitivity:
- Low share of vulnerable secondary spruce forests;
- High share of broadleaved in elevations in which critical drought should not occur;
- Low level of present biotic damage;
- High share of uneven-aged mixed forests which can be thought of as resilient to adverse effects of climate.
Slovak part of the Inner Western Carpathians (SK-IWC)

The unit is the largest in the Western Carpathians, and it contains quite diverse natural conditions. Several zonally arranged forest communities form the present forests. High share of the region lies in elevation range 600—1500 m a.s.l., and highest crests of the Carpathians with elevation above 1,500 m a.s.l. are present here.

The lowest elevations belong to the Pannonian Lowland, where negative effects of drought have already been observed in the recent years. Available projections imply overall decrease in beech production, and beech production optimum may shift from present 400-800 m a.s.l. to relatively narrow belt around 1,200 m a.s.l. (Hlášny et al. 2011). Remarkable decrease in beech productivity up to elevation of 500 m a.s.l., and occurrence of drought induced mortality in elevations up to 400 m a.s.l. were projected to occur by the end of the century.

Biotic damage to oak and beech forests may increase in the future. Outbreaks of Gypsy moth in both beech and oak stands are projected to expand in the future. In addition, novel phenomena such as beech damage by bark beetle Taphrorychus bicolour as a consequence of drought effect (Mátýás et al. 2010), or damage by European hardwood ambrosia beetle Trypodendron domesticum (Petercord 2008), which have been reported from other regions, can be expected as well.

Mountain forests with dominance of spruce can face increased frequency of windstorms, which is the main factor damaging these forests. Positive effect of climate change on bark beetle populations may induce additional damage, which may be critical for forest integrity in this region. Additional damages can be caused by array of pests and pathogens with positive response to climate change, which are described in greater detail in Deliverable SR2.T2.D1 of the CarpathCC project.

Mainly mountain areas where number of protected areas and national parks occur are rich in biodiversity; the effect of climate change of biodiversity in the Western Carpathians has not yet been explored in detail. Processes such as species shift and invasion can generate diverse responses of plant communities, the threats are however difficult to evaluate.

We consider the sensitivity of these forests to climate change as “High”. The main factors backing up such classification are:

Factors increasing forest sensitivity:
- Large share of climate sensitive beech forests in lower elevations;
- Regular occurrence of Gypsy moth outbreaks;
- Anticipated climate change induced increase in outbreak areas of Gypsy moth, and annual number of generations of spruce bark beetle;
- Potential risk of beech damage by newly emerging pests, mainly as a consequence of drought stress;
- Climate change induced decline in wood production and carbon accumulation of main tree species;
- Large share of spruce distributed outside the range of original distribution, with frequent severe damages by wind and subsequent bark beetle outbreaks;
- High frequency and intensity of windthrows affecting forest protective functions, mainly water regulation and soil erosion;

Factors reducing forest sensitivity:
- Large share of protected areas with better site matching species composition, and more natural stand structure;
- Projected improvement of growing conditions for beech and spruce growth in higher elevations;
- Absence of areas with extensive multifactorial forest decline;
- Absence of intensive effects of non-climatic stressor such as air pollution or nutrients exhaustion.
Hungarian part of the Inner Western Carpathians (HU-IWC)

The unit contains mostly broadleaved oak and beech forests, with admixtures of black locust, hornbeam and other species. Spruce occurs only marginally. Present health status of forests is on European average, and there are no areas with intensive forest decline, which could be further amplified by climate change. High game density is important factor damaging forests, though it mostly relates to improper management, and sensitivity to climate change cannot be expected.

Drought is the main factor adversely affecting forests in this region, and drought importance is expected to rise in the future. High share of climate sensitive beech forests in lower elevations imply risk to future wood production as well as to the provision of range of non production forest services. Recently documented biotic damage to beech (which can be thought of as novel phenomenon), apparently related to the incidence of drought events, generates additional concern about climate change impact on these forests. Regular defoliations by Gypsy moth and projected increase in annual number of spruce bark beetle generations (though in small areas), may further affect the forests adversely. Both these agents are expected to benefit from climate change. In addition, novel phenomena such as beech damage by bark beetle *Taphrorychus bicolour* as a consequence of drought effect (Mátyás et al. 2010), or beech damage by European hardwood ambrosia beetle *Trypodendron domesticum* (Petcord 2008), can be expected as well.

Documented species shift towards increased share of drought tolerant species may pose threat to regional biodiversity, though responses can be diverse.

We consider the sensitivity of these forests to climate change as “High”. The main factors backing up such classification are:

**Factors increasing forest sensitivity:**
- Presence of climate sensitive lower margins of beech distribution;
- Distribution of large share of forests in regions with recently observed adverse effects of drought, which can be amplified in the future;
- Effects of non-climatic stressor such as intensive forest damage by game, increasing forest`s climatic sensitivity;
- Regular outbreaks of Gypsy moth, which are expected to expand under climate change;

**Factors reducing forest sensitivity:**
- Low share of vulnerable spruce stands;
- Absence of intensive effects of non-climatic stressor such as air pollution or nutrients exhaustion.
- Absence of large scale forest decline.

Ukrainian part of the Outer Eastern Carpathians North and the Inner Eastern Carpathians (UA-OECN and UA-IEC)

The region contains part of the main Carpathian mountain crest (Gorgan, Chornogora, Marmarosh Mts.). Most of the Inner Eastern Carpathians in Ukraine is distributed in elevations up to 400 m a. s.l. and it is only sparsely forested. Main share of forests lies in the Outer Eastern Carpathians North. Beech and mountain spruce forests dominate. Most of forests lie in the elevations above 600 m a.s.l., where drought effects should not be pronounced enough to induce forest decline in the future. Abiotic disturbances such as wind and snow damage are frequent, and amount of sanitary felling is gradually increasing since 1980. High elevated site can be largely sensitive to increase in the frequency of windstorms with adverse effects on forest protective functions.

Recent observations of upward species shift, including tree line shift, may affect the regional biodiversity. There are also indications of invasion of new species, which may affect the biodiversity as well, though threats are difficult to evaluate.

Expansion of outbreak areas of Gypsy moth in the distant future (2071-2100) to large part of the region was projected, defoliation of beech stands can however be only
hypothesized. Projections of anticipated shift of beech bioclimatic optima (Deliverable SR2.T5.D1) did not imply worsening of growing conditions for beech. Improvement of conditions for oak species may imply gradual change of species composition in lower elevations. None of these processes should affect provision of forest services and goods substantially.

Considering simulation data from Slovakia, climate change induced decline in forest production can be expected, though higher share of mountain forests implies possible compensation of these losses by improved production of mountain forests above 800 m a.s.l.

Broad range of indicators of unsustainable forest management was reported by national expert included in the CarpathCC within the frame of deliverable SR2.T4.D3 (illegal logging), such as overharvesting, management inducing improper stand structure, etc. These factors are expected to amplify forest`s sensitivity to climate change.

We consider the sensitivity of these forests to climate change as “moderate”. The main factors backing up such classification are:

**Factors increasing forest sensitivity:**
- Increasing frequency of abiotic damage, and anticipated increase in the frequency of forest damaging windstorms;
- Regular occurrence of bark beetle outbreaks, which can be further fuelled by climate change;
- Effects of windthrows on forest protective functions, mainly water regulation and soil erosion;
- Effects of improper management increasing forest`s climatic sensitivity.

**Factors reducing forest sensitivity:**
- Projected improvement of growing conditions for spruce and beech;
- Low risk of drought in elevations where most of forests are distributed.

**Romanian part of the Inner Eastern Carpathians (RO-IEC)**

The unit contains the continuation of the main Carpathian mountain crest, and most of the unit has elevation above 600 m a.s.l. Therefore, sensitivity to climate change is typical for mountain forests.

Extensive mixed forests (spruce, fir and beech with admixture of maple and birch) occur between 600-900 m a.s.l. Pine occurs sparsely and it is mostly planted. Small area with natural Scots pine can be found in the Obcinele Bucovinei, and larger areas with naturally occurring pine are in the south part of this subprovince. The tree line is constituted mainly of spruce; cembra pine occurs in two massifs, Rodna and Calimani. Larch is present in Ceahlau only.

The highest intensity of wind damage out of the entire Romania is typical of this region; hence anticipated increase in the frequency of windstorms can generate substantial damage to regional mountain forests. An increase in frequency of catastrophic wind damages as well as of lower intensity (endemic) damages has been observed in the last decades.

In the same time, the most intensive forest infestation by bark beetles in Romania occurs here which can be further fuelled by climate change. Our projections imply that the region is expected to face two-generation increase in spruce bark beetle development by the end of the century as compared with period 1961-1990.

Recent appearance of northern bark beetle (Ips duplicatus) indicates that the pest needs to be thought of as potentially important climate change driven agent. In addition, the main migration path of this pest passes through the Inner Eastern Carpathians (Duduman et al. 2011). Therefore, current forests need to be thought of as highly sensitive to coupled effect of abiotic and biotic damage typical of mountain forests, and these effects can be further amplified by climate change.
Temperature increase in higher elevations of the region may improve forest production and carbon accumulation, these effects can however be negated by episodic releases of carbon due to disturbances. In addition, projections of species shift presented in Deliverable SR2.T5.D1 imply disappearance of beech suitable climate in the southern part of this unit, what may result in beech mortality.

Observed shift of tree line may enhance carbon accumulation though adverse effects on diversity of alpine communities can be encountered. Increased forest dynamics at contact zone of beech and spruce dominated forests, and spruce and dwarf pine zones, may also affect biodiversity, the responses can however be diverse. Improved regeneration and altitudinal shift of beech in higher elevations of this unit is distinct. Forest protective functions, mainly functions related to soil erosion preventions and water regulation can be adversely affected by windstorms related deforestation in high elevations.

We consider the sensitivity of these forests to climate change as “High”. The main factors backing up such classification are:

**Factors increasing forest sensitivity:**
- High windstorm damages to mountain forest, which are expected to increase in the future;
- High bark beetle damages, which may be substantially amplified by climate change by increasing annual number of bark beetle generations, and elevating drought stress to trees;
- Anticipated effects of newly emerging pests;
- Projected disappearance of beech suitable climate over large part of the unit.

**Factors reducing forest sensitivity:**
- Improved condition for beech growth in higher elevations;
- Lower share of forests exposed to drought in the northern part of the unit.

**Romanian part of the Outer Eastern Carpathians South (RO-OECS)**

The unit shape the eastern border of the Carpathians, and contain transition between low elevation oak-beech forests and mountain coniferous forests.

Though main outbreak areas of gypsy moth have not been occurring here during the recent decades, our projections for the distant future imply the expansion of moth`s outbreak ranges. Observations from other regions imply risk of severe defoliations of beech additional to primary host plant.

Large share of the unit is in the elevations where drought may substantially affect the forests. Intensive elevation gradient may induce accelerated forests dynamics, including species shift, with adverse effects on biodiversity.

Projections of species shift presented in Deliverable SR2.T5.D1 imply disappearance of beech suitable climate in the whole area of this unit by the end of the century. Worsening growing conditions for beech along with potential defoliations may induce critical increase in tree mortality. High damage to beech stands by *Nectria ditissima* (fungal pathogen causing beech canker) has been reported from some counties in the unit; these effects can be also amplified in the future.

We consider the sensitivity of the forests to climate change in the Outer Eastern Carpathians South as “High”. The main factors backing up such classification are:

**Factors increasing forest sensitivity:**
- Frequent windstorm damage followed by bark beetle outbreaks; both being climate change driven agents.
- Projected expansion of Gypsy moth outbreak ranges over the entire unit;
- Substantial worsening of climatic conditions for beech growth in the future;
- Present occurrence of *Nectria* disease;
- Potential increase in biotic damage to beech by other agents (as has been reported from Hungarian part of the Carpathians);
Factors reducing forest sensitivity:
- Low incidence of Gypsy moth defoliations;

Southern Carpathians (RO-SoC)
The unit shape the eastern border of the Carpathians, and contain transition between low elevation oak-beech forests and mountain coniferous forests.

Main outbreak areas of Gypsy moth in Romania are distributed in lower-elevation part of this unit. Projections for the distant future imply the expansion of moth’s outbreak ranges to higher elevation; observations from other regions imply risk of severe defoliations of beech additional to primary host plant.

Increasing incidence of forest fires has been observed during the recent decades, and fires frequency can be expected to rise further under increasing temperatures.

Large share of the unit is in the elevations where drought may substantially affect the forests. Intensive elevation gradient may induce accelerated forests dynamics, including species shift, with adverse effects on biodiversity.

Projections of species shift presented in Deliverable SR2.T5.D1 imply disappearance of beech suitable climate in the whole area of these units by the end of the century. Worsening growing conditions for beech along with increasing extent and intensity of defoliations may induce critical increase in tree mortality.

Frequent windstorms occur in higher elevations, though damages are lower as compared with the previous unit. Also damage by bark beetles does not reach the intensity of damage in the Inner Eastern Carpathians described above. Anyway, these forests need to be thought of highly sensitive to bark beetle infestation.

Such effects can substantially limit the provision of all ecosystem services, including wood production, carbon storage and range of social functions. Forest protective functions, mainly functions related to soil erosion preventions and water regulation, can be adversely affected by deforestation in higher elevations as well.

We consider the sensitivity of the forests to climate change in the Southern Carpathians as “Very high”. The main factors backing up such classification are:

Factors increasing forest sensitivity:
- Occurrence of intensive defoliations by Gypsy moth, and anticipated expansion of outbreak ranges to higher elevations;
- Recently increased incidence of forest fires, and prospects for further increase in their frequency under increasing temperatures.
- Substantial worsening of climatic conditions for beech growth in the future in almost entire area;
- Frequent windstorm damage followed by bark beetle outbreaks; both being climate change driven agents.

Western Romanian Carpathians (RO-WRC)
The unit shapes the western border of the Romanian part of the Carpathians. Broadleaved forests composed mostly of Pedunculate oak and sessile oak dominate up to elevation ca. 1,000 m a.s.l. Smaller region covered by coniferous spruce-fir forests occurs in higher elevations at the north of the unit.

High volumes of wind damaged coniferous are reported from the northern part of the unit; this subsequently induces higher damages by bark beetles (for maps of spatial distribution of forest damage see deliverables SR2.T2.D1 and SR2.T2.D3). Our projections imply that the entire area of coniferous forest in this unit is expected to experience two-generation increase in annual number of I. typographus generations by the end of the Century. In addition, the northern complex of coniferous is in the migration path of I. duplicatus (Duduman et al. 2012), which can start occurring here in increased abundances. For these reasons, northern part of the unit can be thought of as highly sensitive to windthrows, the frequency of which is expected to increase, as well as to subsequent bark beetle attacks fuelled by warmer climate.
Outbreaks of Gypsy moth have been occurring only marginally, and no significant defoliations have been reported. Future projections however imply improvement of climatic conditions for outbreaks incidence. In the northern counties of the unit, minor damage by Nectria disease was observed.

A projected species shift (Deliverable SR2.T5.D1) suggests worsening of climatic conditions for beech persistence, mainly in the southern part of the unit, and in its western edges. Despite this development, high share of present broadleaved forests will remain in beech suitable climate. Accelerated forest dynamics can be expected at mixed oak-beech forests, as oak suitable climatic conditions were projected to expand across the entire unit.

In addition, disappearance of spruce suitable climatic condition from the north of the unit was projected for end of the century. This may further amplify spruce sensitivity, and increase its susceptibility to biotic damage.

We consider the sensitivity of these forests to climate change as “Moderate”. The main factors backing up such classification are:

**Factors increasing forest sensitivity:**
- Marginal presence of vulnerable spruce forests suffering from regular wind damage followed by bark beetle outbreaks;
- Anticipated increase in the abundance of I. duplicatus;
- Projected increase in number of generations of most of bark beetle species;
- Occurrence of Nectria disease;

**Factors reducing forest sensitivity:**
- Lower level of present biotic risk in large part of the region covered by broadleaved forests;
- Persistence of climatic conditions suitable for present broadleaved also in the distant future;
- Highly sensitive coniferous cover only small portion of the unit in the north.

**Transylvanian Plateau (RO-TP)**

Transylvanian Plateau is the most arid unit of the Carpathians, and it contains part of beech’s lower range (xeric) limit and sparse oak forests. Our projections imply that critical climatic limits for beech persistence may be exceeded even in the near future (2021-2050). Marginally occurring beech is expected to be substituted by drought-tolerant oak species. Coupled effect of biotic agents and drought, which are projected to increase in the future, can induce disappearance of current forests.

During the recent outbreaks, defoliations by Gypsy moth were observed over substantial areas. As the pest is expected to benefit from climate change, coupled effect of progressive drought and defoliations may induce mass tree mortality. Damage to beech stands by Nectria ditissima was reported from some counties in the unit; these effects can be also amplified in the future.

We consider the sensitivity of these forests to climate change as “Very high”. The main factors backing up such classification are:

**Factors increasing forest sensitivity:**
- Occurrence of beech and some oak species near to their xeric margins;
- Projected disappearance of beech suitable climate in the near future;
- Presence of outbreak areas of Gypsy moth and occurrence of Nectria disease;
- Projected expansion of Gypsy moth outbreak areas in the future.
Serbian Carpathians (RO-SC)

The unit represents the very south of the Carpathians with an arid climate and it covers approximately 2% of the Carpathians. The unit contains the Homolje Mts. with the highest peak 1,344 m a.s.l. (Beljanica). Estimated forest cover is 406,000 ha. As the Serbian Carpathians has been addressed in the SR2 only marginally, we did not perform a specific assessment of forest sensitivity. Considering the minor extent of the unit, we classified forest sensitivity on the basis of the adjacent Romanian unit, the Southern Carpathians as “Very high”.
5.3.6.4. Summary of the sensitivity assessment and evaluation of main impact factors

Performed assessment indicated high level of forest sensitivity across the Carpathians. While high forest sensitivity in the Western Carpathians (CZ, SK, PL) mainly related to the presence of highly sensitive secondary spruce forests, and to direct or indirect effects of drought (SK, HU), the main factor affecting high forest sensitivity in the Romanian and Serbian Carpathians were coupled effects of drought and related biotic damage acting mostly upon broadleaved forests. High frequency of windstorms and subsequent bark beetle outbreaks were the main impact factors in mountain regions across the Carpathians, and mountain forests were thought of as highly sensitivity to these agents. Sensitivity classification of three units in the western Carpathians (PL-OECN, SK-OECN, SK-IEC) as “Low” may be questionable, we however did not identify factors related to the present forest structure and disturbance regimes, and to the future projections, which would give us grounds for other classification. Summary evaluation can be seen in Table 13, and in the map in Figure 54.

Figure 333 Forest sensitivity to climate change. Assessment is based on current status of forests, current disturbance regimes, and forests capacity to respond to anticipated changes in climate and dynamics of pests and pathogens.
Table 13 Results of the assessment of forest sensitivity to climate change in the Carpathians.

<table>
<thead>
<tr>
<th>Country</th>
<th>Geomorphological subprovince</th>
<th>Code</th>
<th>Integrated forest sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>Outer Western Carpathians</td>
<td>AT-OWC</td>
<td>not evaluated</td>
</tr>
<tr>
<td>CZ</td>
<td>Outer Western Carpathians</td>
<td>CZ-OWC</td>
<td>Very high</td>
</tr>
<tr>
<td>SK</td>
<td>Inner Eastern Carpathians</td>
<td>SK-IEC</td>
<td>Low</td>
</tr>
<tr>
<td>SK</td>
<td>Inner Western Carpathians</td>
<td>SK-IWC</td>
<td>High</td>
</tr>
<tr>
<td>SK</td>
<td>Outer Eastern Carpathians North</td>
<td>SK-OECN</td>
<td>Low</td>
</tr>
<tr>
<td>SK</td>
<td>Outer Western Carpathians</td>
<td>SK-OWC</td>
<td>Very high</td>
</tr>
<tr>
<td>PL</td>
<td>Inner Western Carpathians</td>
<td>PL-IWC</td>
<td>High</td>
</tr>
<tr>
<td>PL</td>
<td>Outer Eastern Carpathians North</td>
<td>PL-OECN</td>
<td>Low</td>
</tr>
<tr>
<td>PL</td>
<td>Outer Western Carpathians</td>
<td>PL-OWC</td>
<td>High</td>
</tr>
<tr>
<td>HU</td>
<td>Inner Western Carpathians</td>
<td>HU-IWC</td>
<td>High</td>
</tr>
<tr>
<td>UA</td>
<td>Inner Eastern Carpathians</td>
<td>UA-IEC</td>
<td>Moderate</td>
</tr>
<tr>
<td>UA</td>
<td>Outer Eastern Carpathians North</td>
<td>UA-OECN</td>
<td>Moderate</td>
</tr>
<tr>
<td>RO</td>
<td>Inner Eastern Carpathians</td>
<td>RO-IEC</td>
<td>High</td>
</tr>
<tr>
<td>RO</td>
<td>Outer Eastern Carpathians South</td>
<td>RO-OECS</td>
<td>High</td>
</tr>
<tr>
<td>RO</td>
<td>Southern Carpathians</td>
<td>RO-SoC</td>
<td>Very high</td>
</tr>
<tr>
<td>RO</td>
<td>Transylvanian Plateau</td>
<td>RO-TP</td>
<td>Very high</td>
</tr>
<tr>
<td>RO</td>
<td>Western Romanian Carpathians</td>
<td>RO-WRC</td>
<td>Moderate</td>
</tr>
<tr>
<td>RS</td>
<td>Serbian Carpathians</td>
<td>RS-SeC</td>
<td>Very high</td>
</tr>
</tbody>
</table>
**ADAPTIVE CAPACITY**

The evaluation of countries adaptive capacity has been fully based on the results presented above. The summary information is presented in Table 14 below.

*Table 14 Country-wise indicators of climate change adaptive capacities in forestry. The table is based on the evaluation provided by national experts.*

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Region / Country</th>
<th>Western Carpathians</th>
<th>East-Southern Carpathians</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hungary</td>
<td>Slovakia</td>
<td>Poland</td>
</tr>
<tr>
<td>Economy¹</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Awareness²</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Policy³</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Research⁴</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Transfer of knowledge⁵</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Cross-sectoral cooperation⁶</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Total adaptive capacity</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

¹Level of countries’ economic development, relative ranking within Carpathians by GDP
²Level of climate change related awareness of practitioners and decision makers
³Implementation of climate change adaptation into national legislation
⁴Attention paid to climate change adaptation in research institutions
⁵Transfer of knowledge on forest adaptation to climate change from research to practice
⁶Cooperation among sector towards integrated climate-friendly management of natural resources
5.3.6.5. Integral vulnerability assessment

Evaluating the integrated forest vulnerability to climate change on the basis of synthesis of partial vulnerability components possess some methodological difficulties, and there is presently no objective way for synthesizing the partial vulnerability indicators. Therefore, we proposed the simplified approach, which is based on the following considerations:

- Although there are remarkable differences in various indicators of adaptive capacity among countries, we argue that none of the Carpathians countries possess efficient mechanisms to adapt the forests and mitigate the climate change impacts.
- Both exposure and sensitivity components may critically influence forest vulnerability, their relative importance may however vary in time and space.
- For the reasons above, we have not considered the adaptive capacity as indicator which could substantially affect the forest vulnerability in the Carpathians. Therefore, forest vulnerability was assessed on the basis of exposure and sensitivity components so as the higher value of these two components determines the forest vulnerability.

*Table 15 Summary evaluation of climatic exposure, sensitivity and adaptive capacity of Carpathian forests. Integral vulnerability assessment is given as well.*

<table>
<thead>
<tr>
<th>Country</th>
<th>Code</th>
<th>Exposure</th>
<th>Sensitivity</th>
<th>Adaptive capacity</th>
<th>Vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>AT-OWC</td>
<td>Low</td>
<td>not evaluated</td>
<td>not evaluated</td>
<td>not evaluated</td>
</tr>
<tr>
<td>CZ</td>
<td>CZ-OWC</td>
<td>Low</td>
<td>Very high</td>
<td>Moderate</td>
<td>Very high</td>
</tr>
<tr>
<td>SK</td>
<td>SK-IEC</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>SK</td>
<td>SK-IWC</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>SK</td>
<td>SK-OECN</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>SK</td>
<td>SK-OWC</td>
<td>Low</td>
<td>Very high</td>
<td>Moderate</td>
<td>Very high</td>
</tr>
<tr>
<td>PL</td>
<td>PL-IWC</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>PL</td>
<td>PL-OECN</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>PL</td>
<td>PL-OWC</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>HU</td>
<td>HU-IWC</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>UA</td>
<td>UA-IEC</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>UA</td>
<td>UA-OECN</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>RO</td>
<td>RO-IEC</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>RO</td>
<td>RO-OECS</td>
<td>Very high</td>
<td>High</td>
<td>Moderate</td>
<td>Very high</td>
</tr>
<tr>
<td>RO</td>
<td>RO-SoC</td>
<td>Very high</td>
<td>Very high</td>
<td>Moderate</td>
<td>Very high</td>
</tr>
<tr>
<td>RO</td>
<td>RO-TP</td>
<td>High</td>
<td>Very high</td>
<td>Moderate</td>
<td>Very high</td>
</tr>
<tr>
<td>RO</td>
<td>RO-WRC</td>
<td>Very high</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Very high</td>
</tr>
<tr>
<td>RS</td>
<td>RS-SeC</td>
<td>Very high</td>
<td>Very high</td>
<td>Low</td>
<td>Very high</td>
</tr>
</tbody>
</table>
The results based on the assumptions above indicate that most of the Carpathians has received high and very high scores of forest vulnerability to climate change. Ukrainian Carpathians and Polish part of the Outer Eastern Carpathians received moderate and low ranking. In case of the Polish part, low climatic exposure along with good forest structure and low biotic risk backed-up such ranking. The classification of Ukraine as moderate can be questioned. The facts supporting such classification were moderate exposure, and presence of mostly mountain forests which are not expected to face substantial drought in the future. In addition, no indicators of critical forest decline and effects on non-climatic stressors were reported.

High vulnerability scores received by most of the Western and Eastern Carpathians mostly reflect the results of sensitivity evaluation. Generally, such classification needs to be interpreted cautiously, as each sensitivity value is based on number of diverse indicators, relevant for given CoGP. Therefore, the relatively uniform pattern of vulnerability covers diverse processes partly described in the section on the sensitivity evaluation above.

![Integrated forest vulnerability map of the Carpathians.](image)
5.3.7. Task 7: Grasslands and wetlands vulnerability

5.3.7.1 Grasslands species shift

The Slovak Phytosociological Database (Institute of Botany of the Slovak Academy of Science, Bratislava) was used to evaluate the species shift of grassland communities in the Western Carpathians. The database contains more than 50,000 phytosociological relevés of all vegetation types in the Slovak territory. The oldest relevés come from 1911, however, sufficient grassland data are available yet since 1950 onwards.

Temporal trend analyses were made separately for natural and semi-natural grasslands. Within the natural grasslands, grasslands on siliceous bedrock and grasslands on calcareous bedrock were distinguished. Within the semi-natural grasslands, dry grasslands, semi-dry grasslands, mesophilous grasslands and wet grasslands were distinguished. Phytosociological characteristics of habitat types analysed separately for temporal trends are as follows:

**Semi-natural grasslands:**
- Dry grasslands: narrow-leaved sub-continental steppes of *Festucetalia valesiaceae* and rocky grasslands of *Stipo pulcherrimae-Festucetalia pallentis*.
  - Included habitats of special importance: 6190 Rupicolous Pannonic grasslands (see Annex 20); 6240* Sub-Pannonic steppic grasslands; 6250* Pannonic loess steppic grasslands.
- Semi-dry grasslands: broad-leaved semi-dry grasslands of *Brometalia erecti* and *Koelerio-Phleeta phleoidis*.
  - Included habitats of special importance: 6210 Semi-natural dry grasslands and scrubland facies on calcareous substrates * important orchid sites.
- Mesic grasslands: mesic *Arrhenatherum* meadows, pastures and park grasslands and montane mesic meadows of *Arrhenatheretalia elatioris*, as well as submontane and montane Nardus grasslands of *Nardo-Agrostion tenuis* and *Violion caninae*.
  - Included habitats of special importance: 6520 Mountain hay meadows (see Annex 20).
- Wet grasslands: wet meadows, intermittently wet Molinia meadows and alluvial meadows of lowland rivers of Molinietaalia as well as vegetation of wet disturbed soils of *Potentillo-Polygoneta* and *Plantaginina-Prunellelata*.
  - Included habitats of special importance: 6410 Molinia meadows on calcareous, peaty or clayey-silt-laden soils (see Annex 20); 6510 Lowland hay meadows (*Alopecurus pratensis*, *Sanguisorba officinalis)*.

**Natural grasslands:**
- Natural grasslands on siliceous bedrock: grasslands of phytosociological classes *Caricetalia curvulatae, Carici rupestris-Kobresietea* and *Nardetalia strictae* (alliance *Nardion strictae*).
  - Included habitats of special importance: 6150 Siliceous alpine and boreal grasslands (see Annex 20); 6230* Species-rich *Nardus* grasslands on siliceous substrates in mountain areas and submountain areas in continental Europe.
- Natural grasslands on calcareous bedrock: phytosociological alliances *Caricion firmae, Seslerio-Asterion alpini, Seslerion tatrae* (class *Elyno-Seslerietea*) and alliance *Oxytropido-Elynion* (class *Carici rupestris-Kobresietea bellardii*).
  - Included habitats of special importance: 6170 Alpine and subalpine calcareous grasslands *Elyno-Seslerietea* Br.-Bl. 1948 (see Annex 20).
Changes in temporal frequency of plant species were tested in homogeneous data sub-sets including individual grassland types. For the mesic grassland sub-set with sufficient data available for numerous sub-sequent periods, data were aggregated to nine time intervals by the 5-years periods. For the other grassland types, with sufficient data available for such short intervals, the data were aggregated to three longer time periods. For each of data sub-sets, the methods of temporal trend analysis were adapted based on the sub-set size and spatial distribution of sample plots. The data sub-sets were prepared according to the following scheme:

- Identification of plots belonging to the respective syntaxon/syntaxa according either to the electronic expert system (Janišová et al. 2007, used for semi-natural grasslands) or to the original authors (used for natural grasslands). Only plots with recording date, precise geographical coordinates and standard plot size (16-25m²) were included to the sub-set of selected plots.
- Division of plots according to the recording date: three time intervals were distinguished for all grassland types except mesic grassland where nine time intervals could be distinguished.
- Visual inspection of spatial distribution of plots recorded in individual time intervals to insure representative coverage of data throughout the studied area and to avoid the local effects of the oversampled regions.
- For data sub-sets with three time intervals: Checking the vertical distribution of plot groups by analysis of variance (ANOVA) and comparison of environmental variables based on Ellenberg indicator values (Ellenberg et al. 1991) as well as percentage cover of the herb and moss layers. Calculation of alpha diversity (local species richness) of vascular plants for each plot. Differences among the time periods were tested by ANOVA and post-hoc comparison by unequal N HSD test. Bonferroni correction was used to control the familywise error rate. Frequencies of species with decreasing or increasing trend (only for species with mean frequency higher than 1% in at least one time period and significant differences between the periods) were visualized by box plots.
- For data sub-set with nine time intervals: Generalized linear models (GLM) were used to test changes in temporal frequency of plant species (R program script of Jandt et al. 2011 modified by P. Kráľ). Analysis of variance (ANOVA) of environmental variables was used to detect differences among time intervals. Species traits (Klotz et al. 2002) and Ellenberg indicator values (Ellenberg et al. 1991) between the groups of increased and decreased species were compared in order to identify changes in habitat conditions and functional structure of mesic grassland communities (Mann-Whitney test for comparison of plot ranks was used). Summary of observed trends and list of species with temporal decrease and increase in frequency was provided. The other methodological details are mentioned in the mesic grassland report.

The main conclusions related to grassland types addressed in our investigation are the following:

- **Mesic semi-natural grasslands:**
  The vegetation of mesic grasslands showed low temporal variability and did not reflect the effect of recent climate changes through the temporal changes in species frequency. The indicated changes in species traits were only slight and can be attributed rather to land-use changes and succession of abandoned grasslands. As mesic grasslands have a central position along the moisture and nutrient gradients, they can be assumed to be least sensitive to changes in climate characteristics in comparison to other grassland types.
• **Natural grasslands on calcareous bedrock:**
  We identified small changes that could be explained as a result of recent climate change, and some trends in species composition were observable. We summarize the changes that would be explained as a result of climate change as follows:
  - Increase in species with higher Ellenberg indicator values for temperature and continentality in the communities on calcareous bedrock indicate potential effects of climate change. High variation in temperatures between winters and summers, as well as between days and nights typical for regions with continental climate could occur in the Carpathian mountains in the future, and thus affect grassland communities towards higher shares of species reaching higher Ellenberg values for continentality.
  - Similarly, decreasing occurrence of species with higher requirements for light could be a consequence of warming, because light conditions are influenced by competition of taller plants, therefore, one of the first effects of temperature increase will be the modification of competitive relationships between plant functional types (Guisan et al. 1998, Theurillat et Guisan 2001).
  - Changes in climate that result in shortening of snow duration, and reducing snow depth and coverage may produce large changes in the C and N soil dynamics of alpine ecosystems (Williams et al. 1998). Organic matter content, can be affected by climate change (directly or indirectly, qualitatively and quantitatively), resulting in changes in the main soil processes (humification, podzolization) and the nitrogen cycle (Theurillat et al. 1998).
  - Non-significant differences in soil reaction could be a result of chemical buffering capacity of soils developed on calcareous bedrock, as suggested Theurillat et al. (1998).

• **Natural grasslands on siliceous bedrock:**
  It is supposed that climate change may have substantial effect on alpine habitats. Results from the Western Carpathians however have not highlighted these changes so distinctively. Comparison of three periods (1925-1970, 1971-1990, 1991-2010) shows just small differences in distribution, ecology as well as species diversity of compared plant communities. No statistically significant differences in altitudinal distribution of siliceous grasslands have been detected.
  - Decreasing trends in the occurrence of species with lower Ellenberg indicator values for nutrients, temperature, soil reaction and light indicate effects of widespread nitrogen and phosphorus changes as a consequence of land-use changes – for example decline of grazing in alpine areas. Decrease in soil reaction potentially indicates impact of air pollution in the Central Europe.
  - Decrease in species richness may be connected with land use changes rather than with climate changes since from the middle of the 20th century, important changes occurred in traditionally managed meadows. Many traditionally livestock-grazed montane grasslands were either abandoned, leading to their disappearance through invasion of shrubs, or higher selective pressure through sheep pasturing, which leads to a substantial decrease in the diversity of sensitive species and an increase in unpalatable clonal plants (Stampfli and Zeiter 1999).
We can conclude that our results show some small evidence of climate change effect on the addressed communities, though changes caused by direct human impact are much more evident.

- **Semi-dry grasslands:**
  There were no indications of changes in environmental conditions related to the climate in terms of species Ellenberg indicator value for temperature, continentality and moisture during the study period. Semi-dry grassland communities and the species typical of semi-dry grasslands did not show any signs of sensitivity to recent climate change.

- **Dry grasslands:**
  There are no indications of change in environmental conditions related to the climate change affecting the species composition. Neither dry grassland species nor dry grassland communities can be thought of as sensitive to climate change. The indirect effects (increasing cover of woody species and mesophilous highly competitive species) could result in decreasing number of specialist species well adapted to dry and warm conditions. Despite the slight increase in overall species richness in these communities, the mesophytisation process might result in reduction of typical dry grassland specialists due to shifts in floristic and functional composition (Kovács-Láng et al. 2000). As the dry grassland species are more resistant to climate-induced stress (summer drought, wind exposure, winter frosts, etc.), their gradual replacement by more mesophytic generalist species could induce further changes in the community composition.

- **Wet grasslands:**
  Changes in habitat conditions indicated by the measured (species richness and cover of the herb and moss layers) and calculated variables (Ellenberg indicator values) were significant in most cases, however, did not show obvious trend of decrease or increase. Increasing species richness at the plot scale is similar to other community types and may indicate certain shifts in species composition. The community may be enriched by new species e.g. from the neighbouring habitats. However, these accessoric species might involve not only species well adapted to the changed environmental conditions but also generalist species or unwanted ruderal species penetrating from the destructed habitats in the plot surrounding. According to our results, the changes in the vegetation have not visible trends, and can be interpreted rather as fluctuations in vegetation floristic composition. The impact of climate is either week or it will be detectable after considerable time lag.

The results have not supported the hypothesis about climate change induced changes in species composition on grasslands in the Western Carpathians. It seems that land use changes (mostly abandonment and decrease intensity of agricultural management) and increased nutrient input are better predictors of changes in grassland species composition than climate change. Those changes lead to higher abundance of tall competitive and ruderal species.

We expect that the trends detected in the Western Carpathians are relevant also for the eastern and southern part of the Carpathians, and we provide the reasoning of such assumption in Deliverable SR2.T5.D3.

Eastern and Southern Carpathian grasslands are different from the Western Carpathians in some aspects. Traditional management on grasslands is still present in many localities in the Eastern Carpathians, though trend of land abandonment is also present there, but not as pronounced as in the Western Carpathians. In
addition, due to a warmer climate there is a higher share of dry grassland types here, which have extremely high species richness. There is also some difference in species composition of grasslands reasoned by bio-geography (higher share of eastern Carpathian and pontic elements in the flora of Romania), but if we evaluate functional diversity, grasslands in eastern and western part of the mountains are very similar. In the Western and Eastern Carpathians, there are nearly the same habitat types, there are only some differences on sub-type mainly because of phytogeographic reasons. We may therefore expect, that the trends detected in the Western Carpathians will be relevant also for the eastern and southern part of the Carpathians. We also may expect, that trends of increased occurrence of tall plant competitors are not so evident here, because of higher intensity of management in Romania or Ukraine.
5.3.7.2. Wetland habitats vulnerability to climate change

Wetlands are azonal habitats related to special hydrological conditions (e.g. increased underground water level, flooding etc.). Therefore modelling their response to climate change poses several difficulties. Most of the changes will be induced by new hydrological conditions which will result from new climatic situation. Therefore, our analysis was mostly oriented on the analysis of wetland hydrology. Another important aspect is change in land-use and its impact on wetlands. Current land-use and related threats were defined for wetland habitats as factors which have important co-influence with climate changes.

Analysis was focused on wetland types protected by the network of protected areas NATURA 2000 (European Commission 2007). Wetlands were understood in broad sense as defined in Ramsar Convention on wetland protection including deep-water and flowing water habitats. Carpathian region was understood in wider sense including Intra-Carpathian Pannonian basin.

Hydrology of all wetland habitat (dependent on underground water, dependent on flood dynamics, dependent on running water, dependent on rain water, other) was analyzed as well as main threats linked mostly to land use. Special attention was paid to the habitat resilience (plasticity) which mostly determines habitat adaptability to climate change.

Local or regional studies focusing on wetland hydrology and dynamics were used as knowledge base for the analysis. Special attention was paid to studies, which were carried for several years and included the years with extreme hydrological events (hot wave in 2003, floods in 1997 or 2010 and many others).

According the results of the analysis, vulnerability of wetland habitats to climate change was evaluated and ranked into three categories (high, medium, low).

The distribution maps of the most vulnerable wetland habitats were prepared based on information from Carpathian Biodiversity Information System (www.carpates.org). The maps were prepared only for Carpathian Mts. sensu stricto, because no comprehensive information about habitat distribution is available for the Pannonian Basin (Annex 20).

Wetland types and their reaction to extreme weather events

Salt meadows, steppes and marshes

The group includes two habitats types: 1340 and 1530. The habitats are dependent on groundwater with high content of salts. Namely pH and salinity are important parameters determining species composition of the habitats (Tóth 2010). It is evident, that both parameters are dynamic and determine dynamics of species composition (Tóth 2010). Habitat types are suffering from the significant decline of groundwater table in the whole Pannonian Basin caused by large-scale drainages. Due to this fact, groundwater with high salt content is not able to reach the ground and to influence root zone of the plants. In advance many localities are threatened by abandonment of pastoral practices, which helped to suppress strong competitors (mostly grasses).

But on the other hand, halophytic communities are well-adapted to droughts, because droughts may be limiting for strong competitors and thus halophytes, which are usually weak competitors, has better chance to establish and grow.

Extreme rainfalls do not have positive impact on the habitat, because they can cause a leaching of upper soil horizon and flooding, which is tolerated by halophytic communities only for a short time (Tóth 2010).

We conclude that this group of habitat is mainly threatened by changes in the land use and it is not so vulnerable to climate change. Their vulnerability was considered as medium (see Annex 20).
Habitats related to surface water (standing or running)

The group includes variety of habitats which are linked to river or lake systems (3130, 3140, 3150, 3220, 3230, 3240, 3260 and 3270, partly also 6430). All these habitats are very dynamic and their distribution and area may change among years depending on weather and flow dynamics in the rivers (Ofáhelová and Banásová 2005). Consequently the ability to recover after extreme flood events is relatively good and they are able to react very fast (Ofáhelová and Banásová 2005, Loučková 2012).

Analysis of the ecological factors determining the species composition of the habitats showed, that naturalness of river ecosystems and water quality are the main factors influencing species composition of the habitats. Climate itself is strongly correlated to other factors and it is not a good predictor (Hrivnák et al. 2010). Similar situation is with water temperature, which might be influenced by increased air temperature.

Some of the habitats (e.g. 3130, 3270) may even profit from extreme droughts, because they usually occur on bare open land of river or lake bottom, which is a result of dry periods at the end of the summer. More frequent droughts may promote their more frequent occurrence.

Some of the habitats related to small mountain streams (e.g. 3230) may profit from more frequent floods induced by climate change, because they related to open gravel habitats created during flood events. On the other hand more frequent floods may accelerate efforts for river regulation which is highly threatening to such a habitat type. Several localities of the habitat 3230 (stands with Myricaria germanica) were destroyed or heavily damaged in northern Slovakia after extreme floods in 2010 during river regulations.

The habitats of this group has mostly low or medium vulnerability to climate change due to their good adaptability and ability to recover after extreme events (see Annex 20).

Habitats depending on regular floods

This group of habitats includes three habitats depending on regular floods (6440, 91E0, 91F0). Very high resilience (plasticity) is typical for these habitats, namely for types 6440, 91E0. They are usually flooded several times per year, period of floods may take several months in extreme case. Habitat 91F0 shows less dynamics, because it is flooded only occasionally during extremely high flood events.

Dynamic changes of species composition were observed especially on flooded meadows (type 6440) (Banásová et al. 1994; Šeffer et al. 1999; Jarolímek et al. 2000). Long periods of floods may cause a decline of species richness, decrease of terophytes and biennials and change of species composition towards marsh vegetation (Jarolímek et al. 2000). But Šeffer et al. (1999) reported paradoxically increase of species typical for drier stands after heavy floods in 1996. It is evident from these controversial results, that this habitat is highly dynamic and able to react to changes in flooding regime, but also to climate changes.

Similar situation is on floodplain forests, but they are under much stronger impact from human activities, especially from the forestry. Flood regime was significantly changed in some localities and due to absence of dynamic floods, ruderal and nitrophilous species can spread in the forests.

If we evaluate vulnerability of this group of habitats to climate change, we may assume it as low, because habitats have very high plasticity and they are able to adapt even to extreme weather situations (see Annex 20).
**High-mountain wetland types**

Specific group of wetlands are high-mountain wetlands which are represented by two habitat types (4080, 7240) and partly also by habitat 6430. These habitats may be dependent on groundwater from small springs or they are situated on places of snow accumulation, which influences higher soil moisture. There is a lack of studies focusing their long-term dynamics, most of studies are focused on their syntaxonomy and ecology (e.g. Veselá 1995; Kliment et al. 2010).

However, they are considered as habitats with relatively stable species composition and relatively low plasticity. Therefore, they could be theoretically threatened by fast and dramatic climate change, because of restricted area of alpine zone and they were evaluated as habitats with medium vulnerability (see Annex 20).

**Peatland habitats**

This group includes several habitat types (3140, 3160, 7110, 7120, 7140, 7220, 7230, 91D0, 9410) with different position on succession series or with different chemistry of groundwater sourcing the habitat. Some peatland localities are very old and relic with the age more than 10,000 years (Hájek et al. 2010). They are generally considered as relatively stable in natural conditions with direction of succession from fens to ombrotrophic mires (Hájková et al. 2011), but climate fluctuations may consider dramatic breakdowns in succession development (Hájková et al. 2012; Jakab et al. 2010; Magyari et al. 2001).

Peatland habitats belong to the most threatened habitat types in the Carpathian region. They are highly threatened by drainage, large-scale changes of land use and abandonment. If these negative effects are combined with effects of weather extremes, they can have a very negative impact on some peatland habitats. Hájek et al. (2008) reported decline of fen specialists and increase of meadow generalists on spring fens in Bílé Karpaty Mts. in the years 2003-2006. Decline of shallow pools on calcareous fens (hab. 3160) with several glacial relics e.g. Meesia triquetra, Calliergon trifarium was reported from the nature reserve Belianske lúky in Slovakia, probably due to droughts and changes in overall water regime of the locality (Madarás et al. 2012).

Therefore, it is evident, that peatlands habitats are vulnerable to climate change and the effect may be even enhanced by negative effect of land use changes. Their vulnerability was assumed as high or medium for some types (see Annex 20).

**Habitats with fluctuating soil moisture**

This habitat group is represented by four habitats (6410, 6430, 9190, 9110) which are related to the sites with fluctuating soil moisture. Due to variable moisture status, both habitats are relatively resistant to droughts and they are much more influenced by intensive agriculture or drainages (Halada 2008) or by intensive forestry (Jakubowska-Gabara 1996; Jamrichová et al. 2013).

There are no studies known studying natural dynamics of both habitats, but we may expect, they are relatively plastical towards fluctuations of climate and they are adapted to the high variability of moisture in the soil profile. However Doležal et al. (2010) reported decline of oaks after several dry years in Bílé Karpaty Mts. But they mostly grow on mesic or dry grasslands and they were not related directly to wetlands. So, we expect, their vulnerability towards climate change is low (see Annex 20).

**Subterranean wetlands**

This type of wetlands is represented only by caves (habitat 8310). However, it is a subterranean habitat, it may react very precisely on climate fluctuations (Siklosy et al. 2009; Rimbu et al. 2012). Climate may influence the speed of accumulation
of calcium carbonate. On the other hand, climate change is not able to induce changes which are harmful to the habitat. Therefore we may assume its vulnerability as low (see Annex 20).

Finally, maps of distribution of four highly vulnerable wetland types were prepared using the Carpathian Biodiversity Information System, and other data; these wetland types are Active raised bogs, Degraded raised bogs (still capable of natural regeneration), Alkaline fens and Bog woodland.

Figure 355 Orographic units with the occurrence of the habitat types 7110* Active raised bogs and 7120 Degraded raised bogs (still capable of natural regeneration). (prepared according Carpathian Biodiversity Information System, www.carpates.org and author`s knowledge), GIS-layer of orographic units - © Carpathian EcoRegion Initiative.
Figure 36 Orographic units with the occurrence of the habitat type 7230 Alkaline fens.

Figure 377 Orographic units with the occurrence of the habitat type 91D0* Bog woodland.
5.3.7.3. Climate change impact on grasslands productivity

Standard impact analysis protocol was used, i.e. the calibrated and validated biogeochemical model (Biome-BGC MuSo v1.2) was coupled with a number of climate projections to estimate the present day and future developments. During the past few years Biome-BGC v.4.1.1 (Trusilova et al. 2009) was developed by our group to enable accurate simulation of grassland biogeochemical cycles in Central Europe (Hidy et al. 2012; Hidy and Barcza 2012). The developed Biome-BGC (Biome-BGC MuSo v1.2) describes typical grassland management practices (grazing, mowing and fertilization), and the improved model is able to simulate drought effects on production and carbon balance.

Biome-BGC MuSo v1.2 was calibrated and validated against eddy-covariance based measurements in two Hungarian grassland sites (Hegyhátsál and Bugac; see Hidy et al. 2012) with contrasting climate (Bugac is located at the Hungarian Great Plains with low precipitation, while Hegyhátsál is located in Western Hungary where precipitation is higher (Barcza et al. 2003; Nagy et al. 2010).

In the present study uncertainty of the model simulations is addressed by using an ensemble of climate projections. Parameter uncertainty is not addressed separately because it was found that the variability in the trends of grassland productivity and carbon balance are mainly caused by the the uncertainty of future climate but not model parameterization.

We ran Biome-BGC MuSo v1.2 on a grid point base, using the 1/6° × 1/6° spatial resolution grid defined by the climate data (see below) using different site parameterization and management practices. In the simulations the Carpathians are covered by 985 grid cells.

Grassland productivity is primarily described using Net Primary Production (NPP; total biomass production per year expressed by carbon equivalent). NPP means total biomass production which both includes aboveground and belowground production. NPP (and other results) are typically expressed per unit surface (1 m²) per year. This practice is supported by the idea of easy comparability of model results and the simple upscaling of model results to larger areas (if grassland area is known).

Using NPP dry biomass production can be estimated based on the fact that carbon content of dry biomass is approximately 50% (IPCC 2003).

As for quantifying carbon cycle in a broader sense, other parameters are also simulated. Gross Primary Production (GPP; gross photosynthesis), Total Ecosystem Respiration (R\text{eco}; the total respiration of the ecosystem including soil heterotrophic respiration), Net Ecosystem Exchange (NEE; this is the net amount of carbon that is taken up from the atmosphere by the plant during one year; NEE=R\text{eco}-GPP) and Net Biome Production (NBP; the full carbon balance of the ecosystem including horizontal carbon transport e.g. due to harvest) of grasslands are also quantified (for carbon balance related definitions see Chapin et al. 2006).

The ultimate aim of such carbon balance related simulation is to estimate the interaction between climate and the carbon balance. If climate change causes decrease in NBP (or in other words in carbon sequestration) it means positive feedback to climate change as the grasslands eventually strengthen the greenhouse effect as they sequester less carbon, which means that more CO₂ remains in the atmosphere causing even stronger greenhouse effect and thus climate change.

In our approach past and future climate of the Carpathians are described using the FORESEE database (Dobor et al. 2012). FORESEE contains observation based, interpolated meteorology for the past (1951-2009) and an ensemble of bias corrected climate model results for the future (2010-2100) with 1/6° × 1/6° resolution. The climate models are all based on the A1B emission scenario (Nakicenovic and Swart 2000).

Because of limited information on distribution of grassland communities and management types, which substantially affect grasslands’ carbon cycle, we used the so-called end-member logic; i.e. we defined representative grassland types.
Grasslands productivity under present day climate

Simulated productivity of Carpathian grasslands is presented in Figure 58 for different end-members as mean NPP for the 1961-1990 time period. EM1, EM2, EM3 and EM4 are plotted, as grazing on good soil conditions (EM5) causes only minor change on overall productivity relative to the unmanaged case. Combined mowing and grazing (EM6) is also very similar to EM4, so it is now shown here.
Figure 38 Mean NPP for the different end-members in gC m\(^{-2}\) year\(^{-1}\) units for the 1961-1990 time period. 1st end-member (upper left), 2nd end-member (upper right), 3th end-member (lower left) and 4th end-member (lower right) are shown. Note the different color scales.

The figure shows that unmanaged (or abandoned) grasslands on good soil conditions have the highest productivity (though of course they are not necessarily present in all pixels shown in Figure 58).

Mean NPP for EM1 is 788 gC m\(^{-2}\) year\(^{-1}\) (standard deviation (SD) is 48 gC m\(^{-2}\) year\(^{-1}\), where SD is the measure of spatial variability of 30-year-means). Mean NPP for EM2 is 487 gC m\(^{-2}\) year\(^{-1}\) (SD is 70 gC m\(^{-2}\) year\(^{-1}\)). Mean NPP for EM3 is 238 gC m\(^{-2}\) year\(^{-1}\) (SD is 32 gC m\(^{-2}\) year\(^{-1}\)) which is remarkably lower than EM1. Mean NPP for EM4 is 761 gC m\(^{-2}\) year\(^{-1}\) (SD=58 gC m\(^{-2}\) year\(^{-1}\)), which is slightly lower than the unmanaged, optimal soil result.

Simulated NPP is the highest in Outer Western Carpathians and in parts of Inner Western Carpathians for simulations with optimal soil conditions (EM1 and EM4). EM2 and EM3 (simulation with intermediate and poor soils, respectively) show a relatively more productive region in Transylvanian Plateau, while EM2 also shows higher productivity in the border of Outer Eastern Carpathians North and South.

Productivity is low in the southern part of Inner Western Carpathians and in Inner Eastern Carpathians, also in Outer Eastern Carpathians South, and in the southern part of the Carpathians. Mowing seems to further decrease productivity where it is already low.
Considering individual pixels, standard deviation of annual NPP during the 30 years long period (1961-1990) varies between 83 and 185 gC m⁻² year⁻¹ for EM1 (with mean SD of 134 gC m⁻² year⁻¹), 48 and 176 gC m⁻² year⁻¹ for EM2 (mean SD=97 gC m⁻² year⁻¹), 17 and 67 gC m⁻² year⁻¹ for EM3 (mean SD=36 gC m⁻² year⁻¹), and 61 and 209 gC m⁻² year⁻¹ for EM4 (mean SD=124 gC m⁻² year⁻¹). The results suggest that NPP has large interannual variability, which is typically higher than the spatial variability of the long term means.

Climate change effect on grasslands productivity

Future evolution of grassland productivity in the Carpathians is estimated with an ensemble of 10 climate models (described above), using the different end-members separately. Simulations are performed from 1951 to 2100 in all cases. Ensemble technique is used to estimate uncertainty of the model simulations, and to address problems related to intra-model variability.

Note that application of many different climate models might be problematic from the point of view of interpretation of the results. For example, if the results strongly deviate because of the diverse climate projections then there can be no meaningful interpretation of the future changes. Thus, as the first step, consistency of the results based on the different climate projections has to be analyzed.

As the first step, projected NPP time series were analyzed for the different climate models for the regions in the Carpathians. Figure 59 shows the evolution of NPP for all pixels within Outer Eastern Carpathians North according to climate model results from the REMO-ECHAM5-r3 model. Note that Figure 59 is a typical result and is representative for the other regions and climate models and for the other end-members as well.

The figure reveals that the between-pixel variability of the results is much lower than the interannual variability caused by variability of meteorological conditions. The results suggest that clear conclusions can be drawn for the different Carpathian regions from one climate model as the pixel level results do not diverge, and the variability for the present day conditions remains essentially unchanged in the future predictions.

As the second (and probably more important) step, regions mean NPP projections have been calculated and compared according to the different climate model results. Figure 60 shows typical, region mean NPP time series for Western Romanian Carpathians (results for the other regions are very similar). In Figure 60 smoothed mean curves are plotted for clarity (c.f. Figure 59).

According to Figure 60 the different climate projections provide interpretable result which means that the results do not diverge much. Variability of model results is evident, which is caused by differences in the simulated daily meteorology provided by the different climate models.

As we demonstrated earlier the climate models predict diverse precipitation change for the Carpathians, but decreasing summer precipitation is common to all models. As grassland production is likely to be constrained by availability or lack of summer precipitation (as precipitation is ample in the other seasons) the similar behavior of the models might be the consequence of the similar summer precipitation trend.

Nevertheless, the results indicate that the multimodel approach is a feasible tool to estimate future trends in grassland productivity.
Figure 399 NPP time series for the 1951-2100 time period for all pixels from the Outer Eastern Carpathians North driven by the REMO-ECHAM5-r3 climate model. Results from EM1 are presented.

Figure 60 Region-mean smoothed NPP time series based on the ten climate models (Table 1) for the 1951-2100 time period for Western Romanian Carpathians. Smoothing is performed with 10 years moving averages to remove interannual variability of the results (see Figure 59). Results from EM1 are presented.
Productivity scenarios based on climate projections

Based on the end-member logic we can estimate the region mean NPP tendencies using projections provided by the different climate models. 30-year mean NPP climatologies are calculated representing present day conditions (1961-1990), near future (2021-2050), and distant future (2071-2100). Region mean NPP results are presented in Annexes 21-26 for the end-members. The tables provide simple and straightforward support for the identification of possible future productivity change of specific grassland types in the Carpathian regions. Stakeholders or farmers might select the representative end-member in their region and use the results quickly to estimate future pathways of grassland productivity. Ensemble of 10 models might provide a rough estimation about the uncertainty of the projections.

Overall, the results demonstrate that natural site conditions (fertility, hydrological properties, bedrock depth) and management practices (grazing, mowing and abandonment) strongly influence the estimated trends. In case of good soil conditions grazing has little effect on the overall trends. Mowing seems to decrease the overall positive trend of NPP in the future timeslices. The general trend (with some exceptions) is increase of NPP with variability between the different climate models except for EM6.

Uncertainty of the projections (expressed as standard deviation of the individual climate model based results) varies between the end-members. For good soil conditions without management (EM1) uncertainty varies between 31 gC m⁻² year⁻¹ (Outer Western Carpathians) and 67 gC m⁻² year⁻¹ (Outer Eastern Carpathians South) in the near future. In the distant future uncertainty varies between 57 and 97 gC m⁻² year⁻¹. For intermediate grazed grasslands (EM2) uncertainty varies between 20 and 61 gC m⁻² year⁻¹ in the near future, and it varies between 29 and 75 gC m⁻² year⁻¹ in the distant future. Poor grasslands show smaller variability – in the near future uncertainty varies between 18 and 31 gC m⁻² year⁻¹, while it varies between 20 and 36 gC m⁻² year⁻¹ in the distant future. Uncertainty of mowed grassland NPP on good soils (EM4) is 27-39 gC m⁻² year⁻¹ in the near future, and 23-42 gC m⁻² year⁻¹ in the distant future. Grazing on good soils (EM5) causes small change in uncertainty relative to the unmanaged case. For EM6 variability is 25-39 gC m⁻² year⁻¹ (near future), and 24-38 gC m⁻² year⁻¹ (distant future).

Best estimate for NPP changes: the multimodel mean

Consistency of climate model results provides us the opportunity to create a single best estimate for future productivity of grassland productivity within the different Carpathian regions.

Figures 61-66 show the ensemble time series of NPP (average of 10 climate models) for the 9 regions of the Carpathians. Smoothing with 10 years moving averages is used for clarity and easier interpretation. Uncertainty caused by the spatial variability of NPP within the regions (pixel level NPP versus region mean) is also plotted using simple error propagation rules utilizing the uncertainty of the individual results of the specific climate scenarios. Uncertainty intervals were also smoothed. NPP trends are also shown for the regions estimated by linear regression of NPP against time.
Figure 61 Simulated ensemble mean NPP time series for the different Carpathian regions. Grey lines show uncertainty intervals for the projections. The numbers indicate overall NPP trend (in gC m\(^2\) year\(^{-2}\)) estimated by linear regression. Data for EM1 are shown.

Figure 62 Same as Figure 61 but for EM2.
Figure 40 Same as Figure 61 but for EM3.

Figure 414 Same as Figure 61 but for EM4.
Estimated NPP trend can be as high as 2 gC m\(^{-2}\) year\(^{-2}\) in the Outer Western Carpathians for EM1. In this case the trend is higher than 1 gC m\(^{-2}\) year\(^{-2}\) in all regions except the Serbian Carpathians. The trends are statistically significant in all cases (p<0.0001).

EM2 shows smaller positive trends in the northern part of the Carpathians, with essentially no change in the southern part starting from the northern border of Romania. The trends are statistically significant (p<0.01) only for Inner Western Carpathians and Outer Western Carpathians.
Considering EM3 the trends are positive but smaller than for EM1 due to the lower productivity. The estimated trends are statistically significant for all regions ($p<0.001$ in all cases except for the Serbian Carpathians where $p<0.05$).

EM4 shows trends that are close to zero except in Outer Eastern Carpathians South and Inner Eastern Carpathians. The estimated changes are not statistically significant (only for Inner Eastern Carpathians at the $p=0.05$ level).

Grazing effect in EM5 is detectable although the difference between the unmanaged cases is much smaller than for the mowed cases. The change are statistically significant at the $p=0.001$ level in all cases.

The worst tendencies are estimated for the combined mowing and grazing scenario (EM6). Here the trend is negative in all regions. The trends are not significant for Outer Eastern Carpathians South, Inner Eastern Carpathians and Transylvanian Plateau. The changes are significant for Southern Carpathians (only at the $p=0.1$ level); for Inner Western Carpathians, Western Romanian Carpathians and Serbian Carpathians ($p<0.05$), for Outer Eastern Carpathians North ($p<0.005$) and for the Outer Western Carpathians ($p<0.001$).

These figures reveal that NPP trend generally decreases towards south probably because of spatial variability of precipitation trends. As we pointed out earlier, we also see strong dependency between NPP trends and site conditions. Uncertainty intervals show that spatial variability of NPP is not expected to change considerably until 2100.

**Spatial pattern of NPP change**

Besides region mean tendencies it might be interesting to see the spatial pattern of NPP change for the end-members. As grazing alone (EM5) makes small changes relative to the non-grazed scenario, only unmanaged and mowed grassland results are presented here (except for EM2 where there is no unmanaged scenario).

Figures 67-71 show that for EM1 the changes are almost exclusively positive. Up to 2100 the increasing NPP can be as high as 250 gC m$^{-2}$ year$^{-1}$ in the northern part of the Carpathians (mostly in the Outer Western Carpathians). EM2 shows negative trends in some parts of Romania, but the overall (region-mean) trend is close to zero (Figure 68). Increase in a narrow range of the Outer Western Carpathians is remarkable for EM2.

NPP for EM3 is increasing everywhere, with smaller differences as compared to EM1 (Figure 69). In case of EM4 and EM6 decrease is typical in the North (EM4) and everywhere (EM6). Decrease of NPP is less in the southern regions as compared to the north. In high elevation causes reversed tendencies in some pixels (Figures 70 and 71) in the High Tatras and in the Southern Carpathians. This is probably caused by temperature limitation of growth in the present day which is diminishes in the future due to warming.
Figure 44 Ensemble mean NPP differences between 2021-2050 and 2071-2100 relative to 1961-1990 mean. Results from EM1 are shown.

Figure 45 Ensemble mean NPP differences between 2021-2050 and 2071-2100 relative to 1961-1990 mean. Results from EM2 are shown.

Figure 469 Ensemble mean NPP differences between 2021-2050 and 2071-2100 relative to 1961-1990 mean. Results from EM3 are shown.
Figure 70 Ensemble mean NPP differences between 2021-2050 and 2071-2100 relative to 1961-1990 mean. Results from EM4 are shown.

Figure 71 Ensemble mean NPP differences between 2021-2050 and 2071-2100 relative to 1961-1990 mean. Results from EM6 are shown.

**Gross carbon balance components – GPP and R_{eco}**

Simulation results of GPP (and all other, carbon cycle related results) are presented for the entire Carpathians. Using information provided by the different climate scenarios mean GPP is calculated for the Carpathians, for present day (1961-1990), for the near future (2021-2050) and for the distant future (2071-2100). The results reflect the consequence of site conditions and management practices on the magnitude of grassland GPP within the Carpathians. Note that GPP is strongly coupled with NPP which means that GPP climatologies show very similar tendencies to those of NPP (presented earlier; this is also true for the Carpathian regions).

Using the 10 different climate projections multimodel mean GPP is calculated for the different end-members. Figure 72 shows the temporal evolution of Carpathians-mean estimated GPP for the different end-members for the time period of 1951-2100. For simplicity, uncertainty of the simulations is not shown.
Figure 72 Mean GPP time series for the entire Carpathians as estimated by the different end-members. 10-years moving averaging is used for clarity. The straight lines show the results of linear regression based on the smoothed GPP time series.

Figure 72 demonstrates that (according to the expectations) unmanaged grasslands on good soil conditions have the highest GPP in the future (EM1) (GPP is higher in the beginning of the simulations for grazed grasslands on good soils (EM5) but this is only a transient phenomenon). As expected, poor soil conditions are characterized with lower GPP. The results confirm that grazing has only a small negative effect on overall productivity as compared to the ungrazed scenario (EM1 and EM5 are similar, and also EM4 and EM6 are similar). Mowing causes more emphasized decrease than grazing. During the simulated 150 years GPP is increasing for EM1, EM2, EM3 and EM5, while GPP trend is negative for EM4 and EM6 (though trend for EM4 is close to zero). Overall GPP trend estimated by linear regression is 1.88 gC m\textsuperscript{-2} year\textsuperscript{-2} for EM1, 0.12 gC m\textsuperscript{-2} year\textsuperscript{-2} for EM2, 0.4 gC m\textsuperscript{-2} year\textsuperscript{-2} for EM3, and 1.45 gC m\textsuperscript{-2} year\textsuperscript{-2} for EM5. GPP trend of EM6 is -0.62 gC m\textsuperscript{-2} year\textsuperscript{-2}. The estimated trends are statistically significant for EM1, EM3, EM5 and EM6 (p<0.001 except for EM6 which is significant only at the p=0.005 level). The results suggest that site conditions and management might change the direction of future productivity of Carpathian grasslands.

GPP increase in undisturbed grasslands on good soil conditions is anticipated as ecosystem manipulation experiments (e.g. Free Air CO\textsubscript{2} Enrichment (FACE) experiments) predict increased GPP primarily due to CO\textsubscript{2} fertilization effect (Leakey et al. 2009). Limited nutrient availability (e.g. due to poor site hydrology or nitrogen limitation) is also expected to modulate the CO\textsubscript{2} fertilization effect. The presented results show that the overall trend of GPP can not be estimated from expert guess, but numerical experiments are needed that utilize realistic meteorological data and process based ecosystem model where the most important processes (including soil hydrology, plant phenology and mortality) are well represented.
Figure 73 shows the multimodel mean $R_{\text{eco}}$ averaged for the entire Carpathians according to the 6 end-members. The evolution of $R_{\text{eco}}$ is very similar to the temporal trajectory of GPP shown on Figure 72. This is not surprising since respiration is strongly coupled with GPP in ecosystems. This coupling is present partly due to increased maintenance and growth respiration caused by increased GPP (and NPP). Overall warming might also accelerate heterotrophic respiration (decomposition of SOM), which also increases plant respiration. However, this warming increased heterotrophic respiration might be constrained by the availability of soil moisture, so the response of the simulated grassland to the changing environmental conditions is not trivial. Once again, we would like to stress the importance of process based approach in simulating the productivity of ecosystems under changing environmental conditions.

Linear trend of $R_{\text{eco}}$ change is variable among the end-members. The trend is 2 gC m$^{-2}$ year$^{-1}$, 0.28 gC m$^{-2}$ year$^{-1}$, 0.49 gC m$^{-2}$ year$^{-1}$, 0.17 gC m$^{-2}$ year$^{-1}$, 1.67 gC m$^{-2}$ year$^{-1}$ and -0.30 gC m$^{-2}$ year$^{-1}$ for EM1, EM2, EM3, EM4, EM5 and EM6, respectively. Trends are significant for EM1, EM2, EM3, EM5 (p<0.001) and also for EM6 (p<0.05). The numbers show that respiration is increasing except for EM6 (combined mowing+grazing). Respiration trend is always higher than GPP tend, which means that total ecosystem respiration increases faster than GPP.

**Net carbon balance components – NEE and NBP**

NEE is a small residual determined by the two large fluxes of GPP and $R_{\text{eco}}$. Since NEE is generally an order of magnitude smaller than GPP and $R_{\text{eco}}$, any change in GPP or $R_{\text{eco}}$ might strongly affect the evolution of NEE (and NBP). It means that ecosystem carbon balance is very sensitive to the changing environmental conditions. Future evolution of NEE is analyzed separately according to the 10 climate scenarios, and the best estimate for overall change in NEE is analyzed by means of multimodel mean NEE.
Figure 484 Same as Figure 72 but for NEE. Negative NEE means CO$_2$ uptake from the atmosphere.

Figure 71 shows the temporal course of multimodel mean NEE from 1951-2100 (smoothing is used for clarity) for the different end-members. The figure demonstrates the high temporal variability of annual NEE.

NEE is the most negative (i.e. CO$_2$ uptake from the atmosphere is largest) for EM4 and EM6. This results might be surprising at the first glance, but this is the consequence of the lateral carbon flux (removal of yield) caused by human intervention. As part of the biomass is removed from the ecosystem due to frequent human intervention, it decomposes and returns to the atmosphere elsewhere. This phenomenon is also typical for croplands and managed forests.

Considering temporal tendencies Figure 74 shows unambiguous increase of NEE with time, which in our case means decreasing CO$_2$ uptake from the atmosphere (negative NEE indicates CO$_2$ uptake) for all end-members. Trend is the most emphasized in case of EM6 (0.32 gC m$^{-2}$ year$^{-2}$) and the lowest for EM3 (0.09 gC m$^{-2}$ year$^{-2}$). The trends are varying between 0.14 and 0.21 gC m$^{-2}$ year$^{-2}$ for the other end-members. In case of EM1 and EM3 the 30-year mean NEE in 2071-2100 is close to zero, which means carbon neutral ecosystem (form atmospheric perspective). The trends are statistically significant only for EM3 and EM6 (p<0.05).

Net Biome Production (which is the long term integral of Net Ecosystem Carbon Balance; see Chapin et al., 2006) is the result of combined vertical CO$_2$ fluxes (expressed as NEE; atmospheric flux) and horizontal fluxes (caused by human intervention or animal intake). NBP is the expression of the total carbon balance of ecosystems. NEP (= -NEE) is positive if the ecosystem takes up CO$_2$ from the atmosphere e.g. within a year. Horizontal carbon flux can be both positive (e.g. due to application of farmyard manure) and negative (e.g. due to yield harvest and grazing). If net lateral carbon flux is negative it means that NBP is smaller than NEP.
The same as Fig. 72 but for NBP. Positive NBP means carbon accumulation within the ecosystem.

Figure 495

Best estimate for overall NBP is analyzed by calculating multimodel mean for the entire Carpathians. Figure 75 shows the temporal variability of NBP associated with the different end-members. Note that NBP is generally small, and it basically reflects changes in SOM in case of herbaceous vegetation where there is no permanent standing biomass.

The values and trends of the resulting NBP are not trivial, and they are the consequences of many different environmental factors. In present day conditions only EM1, EM3 and EM5 are positive, which means carbon sequestration on the long term. This result is in accordance with the expectations which predict that undisturbed ecosystems sequester carbon on the long term. Small but still positive NBP for grazed grasslands on good soil conditions is somewhat surprising (EM5). Note that as NBP is very close to zero for EM1, EM2, EM3 and EM5, it might be more reasonable to assume that these grassland types are carbon neutral. In all cases the trends are probably more important than the absolute values given the uncertainties of the model projections and simplifications in the model.

Present day NBP is negative for EM2 and for the mowed ecosystems (EM4 and EM6). The results are in good agreement with the experiences about effect of management on plant productivity and carbon balance. Namely, as grazing and mowing causes carbon (and more importantly nutrient) loss for the ecosystem, the result is decreased productivity and decreased carbon sequestration. Grazing causes only small decrease in NBP as compared to the ungrazed scenario (EM1; Fig 89). It was demonstrated earlier in this study that NPP changes strongly due to mowing (or combined mowing+grazing). This effect is clearly detectable by the large negative NBP for EM4 and EM6 under present day conditions (-30 and -42 gC m\(^{-2}\) year\(^{-1}\), respectively. It is interesting to see that from atmospheric perspective, mowed grasslands are the strongest carbon sinks, while carbon loss is the highest from the soil in the long term as result of management.

Considering temporal trends only EM6 shows increasing NBP, while there is negative tendency for the other EMs in the future. NBP trend is -0.14 gC m\(^{-2}\) year\(^{-2}\) for EM1, -0.03 gC m\(^{-2}\) year\(^{-2}\) for EM2, -0.09 gC m\(^{-2}\) year\(^{-2}\) for EM3, -0.01 gC m\(^{-2}\) year\(^{-2}\) for EM4, -0.08 gC m\(^{-2}\) year\(^{-2}\) for EM5 and 0.09 gC m\(^{-2}\) year\(^{-2}\) for EM6. The trends are statistically not significant in one exception (EM3, p<0.05). According to Fig. 4.30 trend lines tend to converge until 2100, which is an unexpected result.
Model predictions show that unmanaged and grazed (grazing only, without mowing) ecosystems will be able to sequester less carbon in the future, while carbon loss will remain unchanged (EM4) or will be smaller (EM6) for mowed ecosystems.

Carbon balance of Carpathian grasslands seems to be vulnerable to climate change, but the overall response of the grasslands to changing environmental conditions strongly depend on human intervention (i.e. unlike climate change, it can be easily controlled via national legislation). Climate change seems to have positive effects on hay meadows (as their carbon loss might be mitigated to some extent), and negative effect on unmanaged (abandoned) or grazed ecosystems (relative to the present day conditions). In any circumstances, climate - carbon cycle feedback seems to be positive for unmanaged and grazed ecosystems, and it is zero (EM4) or positive (EM6) for mowed grasslands.

Though analysis of the end-members provide invaluable information on the effect of site conditions and management on the response of the ecosystems, it does not answer the question of overall carbon balance for the Carpathians taking into account the diverse nature of grasslands habitat types. Combination of habitat types and end-members gives answer to the overall picture regarding carbon balance and future evolution of carbon sequestration.

**Combined results – best estimate for grasslands carbon balance**

Figure 76 shows the results of combination of modelled NATURA 2000 habitat type distribution and carbon balance components of end-members. Multimodel mean EM values have been used for the construction of the best estimate for carbon balance of Carpathian grasslands.

Combined mean GPP is decreasing with time, but this trend is small (-0.21 gC m⁻² year⁻²; trend is not significant). GPP decrease is likely the consequence of dominance of NATURA 2000 habitat type 6510, where mowing and combined mowing+grazing is typical (EM4 and EM6; see above).

Linear trend of $R_{eco}$ is close to zero (0.003 gC m⁻² year⁻²; statistically not significant) which means that GPP decreases while $R_{eco}$ remains essentially unchanged. As NEE is the residual of two large fluxes of GPP and $R_{eco}$, it is not surprising that NEE increases (becomes less negative, which means decreasing CO₂ uptake from the atmosphere). NEE trend is 0.24 gC m⁻² year⁻² (statistically significant at the p=0.1 level).

Taking into account lateral carbon fluxes (caused by mowing and grazing) NBP trend becomes negligible (0.01 gC m⁻² year⁻²; trend is not significant). It means that according to our simulations area-averaged NBP remains unchanged in the future. In other words, soil carbon remains stable when averaged over the entire Carpathians.

As our results represent ideal conditions (without natural disturbances) it can be hypothesized that NBP will be eventually decrease due to e.g. lateral carbon flux caused by erosion, fires, drought induced grassland dieback, and other processes. Negative NBP might cause soil degradation, which might interact with productivity and carbon cycle. In any circumstances, changes in management practices will interact with the overall productivity and carbon balance of the Carpathians.
Figure 506 Overall trend of different carbon balance components in the entire Carpathians during the 1951-2100 time period based on the combination of end-members and habitat type distribution. Top left: GPP; top right: Reco; bottom left: NEE; bottom right: NBP. Thick line represents mean, while grey lines represent spatial variability. Time series are smoothed with 10 years moving average for clarity. The straight line shows linear trend.
5.3.7.4. Conclusions

The main results of this task are the following:

- Present-day simulation of NPP showed obvious dependence on soil texture. Estimation for combined mean NPP for the entire Carpathians was 665 gC m\(^{-2}\) year\(^{-1}\).
- Analysis of the simulation results for the end-members revealed that future changes strongly depend on the grassland types (NATURA 2000 categories). NPP of natural grasslands is expected to increase in the future, but poor soil conditions and regional differences in climate and elevation also modulate the expected tendencies. Grazing has small effect on NPP relative to the unmanaged case, while mowing (on hay meadows) basically negates the overall positive effects of increasing atmospheric CO\(_2\) concentration and climate change.
- Combination of end-members showed that overall NPP trend in the Carpathians is close to zero, which means that NPP remains unchanged. This is because of the dominant role of mowing within the Carpathians (at least according to our model for management and NATURA 2000 habitat types distribution).
- Carbon balance related simulation results indicated non-trivial response of grassland ecosystems to the changing multifactor environmental conditions. Considering overall carbon balance (expressed by Net Biome Production) results indicated zero change which means that in spite of the fertilization effect caused by the increasing amount of atmospheric CO\(_2\) the overall carbon balance might remain unchanged.
- The results highlighted that Carpathian grasslands are vulnerable habitats with considerable spatial and temporal variability in grassland production and carbon balance. While there is a potential for increasing grassland productivity in the future (positive effect of CO\(_2\) fertilization) management can ultimately negate this effect. The results emphasize that it is not only climate change but also human decisions that strongly affects productivity and carbon sequestration of Carpathian grasslands in the future. This means that national legislation has the potential to affect grassland production and vulnerability to climate change.
5.4. Outputs and Results

The SR2 focused primarily on various aspects of forest vulnerability to climate change in Carpathians using the information collected through the network of national experts as well as by downscaling and adopting general information on climate change impact on ecosystems at European or global scale. Minor portion of SR2 action focused on grasslands and wetlands vulnerability, including evaluation of climate change impact of grasslands production. We review here the main outputs and results of the SR2 following the structure of deliverables elaborated in the project.

5.4.1. Climate change impact on pests and pathogens in the Carpathians and anticipated threats to forests

Forest pest and pathogens can be thought of as climate change driven agents the effect of which may induce critical disruption of the provision of forest ecosystem services and functions. The main reason for this is the high sensitivity of mainly insect pests, which may respond to even minor changes in climate by substantial changes in their population dynamics and distribution. Therefore we focused on pan-Carpathian evaluation of the responses of key pests, and on the evaluation of their effect on forests. This information is a key part of the integral forest vulnerability assessment presented in respective deliverables of the SR2.

Results of pests and pathogens related research in the SR2 are summarized in three deliverables which focused on:

- Evaluation of recent forest pest dynamics in the Carpathians, and projections of anticipated development of key pests (Deliverable SR2.T2.D1)
- Creation of maps of present and anticipated pest dynamics in the Carpathians (Deliverable SR2.T2.D3)
- Analysis of forest protection strategies allowing forest managers for increasing forest stands resilience to adverse effects of pests and pathogens (Deliverable SR2.T2.D2)

The main results of these deliverables can be summarized as the following:

- Collection of information on recent pest dynamics in the Carpathians, using various national statistics, and evaluation of this dynamics from the view of climate change related threats to forests. In total, 21 pest and pathogens species were addressed, though information allowing for their evaluations from the view of climate change impacts could have been done for some species only. Compilation of heterogeneous national data on pest dynamics, and their evaluation at the pan-Carpathian scale, is an important asset of performed analyses.
- Creation of a number of pan-Carpathian maps depicting present and future pest dynamics; in total, 36 maps have been produced.
- For five species – spruce bark beetle (Ips typographus), double-spined bark beetle (Ips duplicatus), Gypsy moth (Lymantria dispar), pine weevil (Hylobius abietis) and nun moth (Lymantria monacha) – the projections of anticipated climate change impacts on their distribution and population dynamics were elaborated using modelling tools and GIS for the entire Carpathians. In some cases, new models have been used experimentally. Although the validity of some projections can be questioned, this material represents unique information vitally related to forest vulnerability assessment.
- Compilation of information on presently applied forest protection practices in the Carpathians using the questionnaires, and critical review of this information.
Our findings imply that activity of biotic agents has been elevated in recent decades in many regions of Carpathians, and that there are indications of the effect of climate change on population growth in some species. Our findings imply that activity of biotic agents has been elevated in recent decades in many regions of the Carpathians, and that there are indications of the effect of climate change on population growth of some species. Our results imply increasing impact of presently occurring pests on forests, as well as potential emergence of new pests. Bark beetles of the genera *Ips* can be thought of as the most important agents, the outbreak of which can be fuelled by increasing temperature accelerating their development, and elevating drought stress to trees, which is important factor increasing the susceptibility to infestations. While in higher elevations the outbreaks can be fuelled by increasing frequency of windstorms, in lower to medium elevations, where spruce has been extensively planted in many regions, drought can trigger unprecedented outbreaks. One to two generation increase in annual number of generations of spruce bark beetle (*Ips typographus*) was projected for the entire Carpathians, being more pronounced in the Romanian and Ukrainian part. Newly emerging northern bark beetle (*Ips duplicatus*) is expected to respond to changing climate similarly, and damage caused by this pest may further increase, mainly in the Romanian Carpathians. Satellite imagery displaying progress of deforestation due to bark beetle infestation from some regions is used to document some outbreaks.

Regions affected by non-climatic stressors, such as air pollution or improper management, can be especially prone to the effects of an array of pests and diseases; such non-climatic stressor may substantially increase forest sensitivity to climate change. For example, the region of the Western Beskids (Western Carpathians, CZ-SK-PL) represents extremely vulnerable region containing spruce forest with highly elevated activity of biotic agents, and declining over large area. The anticipated amplification of this decline as response to climate change may critically disrupt the provision of all services and functions provided by forests, including water regulation and erosion prevention.

Lower to medium elevations of the Carpathians are expected to face an increased pressure of defoliating insects, among which the Gypsy moth (*Lymantria dispar*) can be thought of as the most important. The pest is expected to benefit from climate change, and its regular outbreaks were projected to expand over larger areas. Upward shift and alternative severe defoliations of beech have been reported from several regions in the Carpathians. We elaborated the maps of pest’s recent dynamics in the Carpathians, and projection of anticipated expansion of outbreak ranges. An important finding is increasing biotic risk to beech, which can be thought of as novel climate change driven phenomenon. Except for already mentioned defoliations by Gypsy moth, which have not been occurring previously, beech damage by bark beetle *Taphrorychus bicolour* as a consequence of drought effect, or damage by European hardwood ambrosia beetle *Trypodendron domesticum* can be expected. In addition, beech damage by *Nectria ditissima* disease (fungal pathogen causing beech canker) is frequently reported, having increased incidence mainly in the Romanian Carpathians. These findings generate additional concern about beech sustainability mainly in drought-exposed sites.

Finally, we surveyed the management options which may allow for increasing forest stands resilience to biotic damage. We also surveyed the institutional set-up of forest protection in Carpathians countries, and their capacity to respond the anticipated changes in population dynamics and distributions of forest pests.

Integrated pest management is (IPM) promising strategy the importance of which may rise under climate change, therefore we summarized the IMP principles for forest pests and pathogens which were found to be important for forestry in the Carpathians.

The main conclusions of the assessment of forest protection set-up in the Carpathians are:

- Prognosis of short- to middle-term changes in pests’ population dynamics and distribution are important tools for hazard rating and taking effective
measures. The use of hazard rating models guiding forest management is however rare in the Carpathians; the reason for this is undoubtedly lack of awareness and insufficient transfer of knowledge from research to management;

- Conversion of present vulnerable species composition to more stable forests with lesser proportion of susceptible host plants is needed in some regions (for example part of the Western Beskids). Such radical changes however presume intensive cross-sectoral cooperation, which is insufficient and present legislation does not support the integrated landscape management. This issue should be promoted, mainly in trans-boundary vulnerable forested regions with elevated activity of forest pests;

- Monitoring of forest pests and changes in their distribution and population dynamics are generally not developed enough to face the anticipated changes. Therefore consolidation and trans-boundary harmonization of monitoring systems is needed;

- In the view of climate change, further education of foresters concerning newly emerging pests and anticipated climate change effects on forest ecosystems is needed. Forest management under climate change calls for consolidating personal and other resources of forest protection units;

- Financial and human resources in management and monitoring of forest pests are generally low in all countries in the Carpathians. Considered potential severity of pests` impact on forests under climate change, such resources are strongly advised to be consolidated.
5.4.2. Forest management in the Carpathians and its capacity to adapt the forest to climate change

Dominant share of Carpathian forests is managed, and forest management practices differ in various aspects among countries. Forest management represent powerful tool of forest adaptation to climate change for example through changes in species composition, it may however also act detrimentally in terms of over harvesting or promoting interventions opening the canopy or disrupting stand`s water regime. Adaptive capacity of forest management is important part of forest vulnerability assessment, the assessment of which is described in the next sections.

We elaborated detailed overview of presently applied forest management practices, and we collected the information on adaptive capacity of forest management in Carpathian countries. National legislation, including National Forest Programmes, has been reviewed, and information on climate change adaptation has been evaluated. Except for “standard” practices such as alterations of tree species composition, applied thinning and harvesting techniques, etc., also broader issues such as awareness of forest managers and policy makers, and level of cross-sectoral cooperation have been addressed. Gross domestic product per capita was used as indicator of countries’ economic development indicating countries’ capacity to implement the adaptation measures effectively. The detailed information on adaptive capacity of forest management is presented in Deliverable SR2.T4.D2. The main conclusions are as follows:

- We revealed that none of the Carpathian countries have directly addressed the climate change in forestry legislation yet. Although this issue is usually included in the national forestry strategy plans, programmes and actions as one of the objectives, these document do not specify any adaptive forest management strategies and ways of their implementation in forest management.

- Research activities on climate change impact assessment are well developed throughout the whole Carpathian region. However, adaptation measures suggested by scientific community are not commonly implemented in forestry practice per se because of insufficient knowledge transfer and also due to the rigid policy regulations related to forest management. Hence, introduction of forest adaptation to forest management strongly depends on professional skills and awareness of individuals.

- The awareness of the climate change in Carpathian forestry community can be thought of as moderate, though with high regional differences. Practitioners do not usually address climate change per se, but mainly with reference to actual threats; such measures can however be often thought of as part of adaptive forest management.

- The regional differences are high, varying among individual indicators. For example in Hungary, the private forestry sector starts considering climate change impact seriously due to organised communication. In contrast, there are indications that in the Czech Republic, in spite of great problems with Norway spruce plantations, Norway spruce is still highly promoted species in forestry practice. In addition, the “climate-scepticism” among policy makers is sound. In Poland many private forests do not have actual forest management plans, what makes the efforts on climate change adaptation unorganized and difficult to evaluate. Restitution seems to be a problem affecting forest management in Poland and Romania. In some regions in Romania and Ukraine, illegal logging is one of the serious threats for sustainable forest management; direct link to poverty of local communities is however not a rule. In Hungary, large game population seriously threat the general implementation of continuous-cover forestry.
The main conclusion on adaptive capacity of countries can be summarized as follows:

- **Hungary**: Assessment of Hungarian adaptive capacity indicates the above average status as compared with other Carpathian countries. Good awareness of private sector, which seems to exceed the other Carpathians countries, implies good adaptive capacity, especially concerning beech forests which are generally recognized as vulnerable. There are also efforts to connect adaptation in forestry with measures in climate-dependent agricultural sectors. Recent decline of economy (World Bank) and national policy-related threats to using European funds, however, generate concerns on enforceability of adaptive measures.

- **Slovakia**: Research of climate change is well supported, and the level of awareness is adequate. Modern technologies are used in forest management, knowledge base and infrastructure allowing for climate change related hazard rating is available. Lacking cross-sectoral cooperation and insufficient transfer of knowledge from research to practise significantly hampers integrated forest and landscape management, and climate change adaptation.

- **Poland**: Research of climate change impact on forest ecosystems and adaptation is well developed. Although forest managers do not consider climate change as an important issue, sustainable forest management is widely accepted and supported. Lacking forest management plans in most of private forests make organized adaptation difficult, mainly in regions with diverse ownership.

- **Romania**: The level of awareness of climate change is moderate, but slowly increasing. A number of other issues such as restitution and illegal logging are more important for sustainable forestry at current stage of development of the country. Although the overall adaptive capacity of Romania can be though of as below average of the Carpathian countries, the reforestation goals and the activities to increase the awareness of the society are promising steps towards the adaptive behaviour of the forestry sector.

- **Ukraine**: Only the academic society is adequately aware of the climate change. The adaptation plans and forest management measures have not been developed. The overall adaptive capacity of Ukraine does not reach the average of the Carpathian countries. Nevertheless, due to the disturbance problems there are tendencies towards more natural species composition and close-to-nature forest management, which can be considered as steps of forestry adaptation to climate change. More political and financial support is required to promote adaptive actions. However, such resources are currently lacking, as the country faces more urgent economic issues.
5.4.3. Climate change induced forest tree species shift in the Carpathians – observational evidences and modelling

Climate change induced species shift is an important ecological concept which has been recently increasingly recognized. Such interest has been also fuelled by need for knowledge based management of natural resources under changing environment, and adaptation to climate change.

Species shift is inherent adaptation mechanism of species to cope with changing environment, which allows species to track the shifting climatically optimal sites.

Inability of species to follow the shifting climate may cause population decline and, in some cases, extinction. Species shift may represent threat to biodiversity, which is especially pronounced in mountain areas, where species have limited options to migrate or adapt.

Though observations of species shift from the Carpathians are rather scarce, and available modelling studies are quite heterogeneous in outputs and methods, we strived to compile the available knowledge, run new simulations, and draw conclusions specific to the Carpathians. We focused on two most distinct features of species shift, i.e. species expansion upward in elevation and northward in altitude, including tree line shift, and on the retraction of lower range limit, which may be induced by water scarcity.

Our survey implied that there is very limited information on observed species shift, evidences are scarce and unpersuasive in some cases. Species shift has generally not been addressed as topic of higher importance attracting attention of decision makers and scientists. Response from most of countries implies that species shift is relatively new and unexplored phenomenon. In addition, forest management and natural forest dynamics may largely interfere the climate change signal, what may question some of the reported observations.

As results of modelling studies reported from the Carpathian countries were based of various methods and data, and they were hardly comparable among countries and regions, we elaborated unified modelling exercise focused on projection of present bioclimatic space of main zonal tree species in the Carpathians under ensemble of climate change scenarios.

In the view of collected and evaluated observational evidences and projections, we summarize the changes in species composition, which are likely to occur in the Carpathians:

- In planar to colline zone, continuous change of present oak forests towards oak forests with higher share of drought tolerant species, such as *Quercus cerris*, may occur. Even the occurrence of species such as *Q. frainetto* or *Q. illex* can increase mainly on southern regions, or such species can be artificially introduced within the frame of forest adaptation. Share of other drought tolerant species of lesser importance may increase as well;
- Though European beech has been frequently considered as important component of temperate forests adaptation to climate change, its climatic sensitivity implies presence of beech mainly in higher elevation, and it should be treated very cautiously in drought exposed sites also considering the threat of newly emerging insect pests;
- Expansion of suitable conditions for oak species suggests increase of their share across almost entire Carpathians, except for the highest elevations. Increased forest dynamics in present contact zone of oaks and beech can be expected;
- Expansion of conditions suitable for oaks and worsening conditions suitable for beech implies appearance of communities composed of oaks and coniferous in higher elevations. Such communities rarely occur in some intra-Carpathians valleys, their sensitivity to climate change and future prospects however have not yet been investigated. We assume that increased diversity, improvement of stands static stability by admixture of broadleaved, and
improvement of stand’s water management can make such communities promising to the future;

- Spruce needs to be thought of as highly vulnerable species, and climate change will induce additional pressure on decrease of spruce share except for highest elevations where spruce naturally occurs. In contrast, forest management can strive supporting spruce persistence also in unsuitable sites because of presently high commercial value of softwood. Hence, considering the trade-offs between environmental and economy interests, change in species composition towards decreased share of spruce can be thrilling part of future forest dynamics and adaptation.

The above described developments need to be viewed in the context of following factors:

- As most of Carpathian forests are managed, rate of projected changes will depend in large extent on forest management, and human support to inherent adaptation mechanisms. For this reason, adaptive forest management should support species shift and include such concept into regional forest management plans.
- We assume high diversity of interactions between natural forest adaptation and forest management among countries and regions in the Carpathians, reflecting varying level of awareness and available funding (for more information see Deliverable SR2.T4.D2 on adaptive forest management). Hence, both environment friendly and resource exploitative tendencies can be expected even in adjacent regions, bringing large uncertainty into projections of and expectations on species shift.
- Detrimental effects of species shift may occur in case of shifting tree line, as such shift may reduce the extent of valuable alpine habitats fostering vulnerable flora and fauna; such communities have minimal or none opportunities to migrate or adapt. In this case, forest management may act to preserve the vulnerable species and communities by eliminating the shifting vegetation from lower elevations. This may interfere, up to a certain extent, available projections of species shift.
- All the changes above are expected to be more pronounced in the Eastern, Southern and Serbian Carpathians as compared with Western Carpathians, because climatic exposure increases from north-west towards south-east; this tendency has been confirmed by all climate change scenarios presented in this report.
5.4.4. Integrated forest vulnerability assessment

Evaluation of integrated forest vulnerability to climate change in the Carpathians is the ultimate purpose of the SR2. We adopted the vulnerability concept proposed by Lindner et al. (2008, 2010) (vulnerability = exposure × sensitivity × adaptive capacity), who applied this approach in the assessment of climate change vulnerability of European forests. Specific division of the Carpathians was proposed as spatial frame for vulnerability assessment, and borders of countries were intersected with borders of geomorphologic subprovinces. The component of subprovinces is used to evaluate the climatic exposure and forests sensitivity to climate change. As adaptive capacity (the social-economic component) largely depends on countries` economic development and legislation, adaptive capacity was evaluated in the frame of state boundaries.

We proposed an approach based on Principal Component Analysis for the evaluation of integrated climatic exposure using projected changes of several climate elements. The results indicated that climatic exposure apparently increases from the Western Carpathians towards the Romanian and Serbian Carpathians. Polish part of the Carpathians shows only the low exposure as compared with other units, as some climate models project even increase in precipitation in the future for this region. This may partly compensate the increased evaporative loss induced by increased air temperature. In particular, we found out the following:

- RegCM and RACMO show the most intensive warming, which is highest in the Romanian and Serbian part of the Carpathians; projected increase in air temperate reaches in some locations even 5.5°C. The Western Carpathians are expected to face the temperature increase between 2.5 – 3.5°C, in some southern locations even 4°C.
- Much higher spatial variability can be seen in the changes in precipitation (differences of future minus reference climate), and this variability is also high among used climate models (Annex 19). Despite high variability of such differences, spatial gradient in precipitation change decreases from the north-west to the south-east according to all models. The RACMO model implies substantial precipitation increase in the Czech and Polish part of the Western Carpathians while other models show precipitation in the Western Carpathians more-less equal to the reference period. Decrease in precipitation was projected by all models almost in all Romanian and Serbian Carpathians, the magnitude of change is however highly variable.
- Ellenberg quotient, which is used in the SR2 as indicator of drought, takes on the range 10 – 85 across the Carpathians in the reference period; the spot of extreme values is however located in relatively small area in the Transylvannian Plateau. Most of the Western Carpathians is covered by values up to 30. Higher values indicating dry climate, are distributed mostly in the Hungarian part of the Carpathians and in the Outer Eastern Carpathians in Romania. There is a remarkable trend in differences in Ellenberg quotient between the distant and reference climate, increasing from the Western Carpathians towards the Eastern and Serbian Carpathians.

Evaluation of forests sensitivity is complex issue, as it includes sensitivity of several forest components to range of impact factors, with consequence on forest capacity to provide goods and services. Range of indicators was considered to evaluate the forest sensitivity to climate change in the Carpathians, and results of several tasks of the SR2 where integrated. The proposed classification of Carpathian forests by their sensitivity to climate change including the main impact factors, is the following:
Czech part of the Outer Western Carpathians – Very high sensitivity.

- Factors increasing forest sensitivity are:
  - High share of secondary Norway spruce forests with compromised ecological stability;
  - Highly elevated activity of biotic agents causing large-scale forest decline;
  - Forest position in areas where increase in annual number of bark beetle generations was projected;
  - Forest position in areas where regular defoliations by Gypsy moth occur, and which are expected to expand under climate change.

Slovak part of the Outer Western Carpathians - Very high sensitivity.

- Factors increasing forest sensitivity are:
  - High share of secondary Norway spruce forests with compromised ecological stability;
  - Highly elevated activity of biotic agents causing large-scale forest decline;
  - Forest position in areas where increase in annual number of bark beetle generations is projected;
  - Increased forest sensitivity by long term effect of non-climatic stressors such as air pollution and improper management.

Polish part of the Outer Western Carpathians - High sensitivity.

- Factors increasing forest sensitivity are:
  - High share of secondary Norway spruce forests with compromised ecological stability;
  - Highly elevated activity of biotic agents causing large-scale forest decline;
  - Forest position in areas where increase in annual number of bark beetle generations is projected.

- Factors reducing forest sensitivity are:
  - High share of broadleaved forests with suitable stand structure in the eastern part of the unit;
  - Lower effect of non-climatic stressors.

Polish and Slovak part of the Outer Eastern Carpathians North, Slovak part of the Inner Eastern Carpathians – Low sensitivity

- Factors increasing forest sensitivity:
  - Sparse occurrence of Fraxinus dieback;
  - Potential expansion of Gypsy moth outbreak from lower elevations;
  - Forest position in areas where appearance of newly emerging pest species attacking broadleaved can be expected.

- Factors reducing forest sensitivity:
  - Low share of vulnerable secondary spruce forests;
  - High share of broadleaved in elevations in which critical drough should not occur;
  - Low level of present biotic damage;
  - High share of uneven-aged mixed forests which can be thought of as resilient to adverse effects of climate.
Slovak part of the Inner Western Carpathians – High sensitivity

- Factors increasing forest sensitivity:
  - Large share of climate sensitive beech forests in lower elevations;
  - Regular occurrence of Gypsy moth outbreaks;
  - Anticipated climate change induced increase in outbreak areas of Gypsy moth, and annual number of generations of spruce bark beetle;
  - Potential risk of beech damage by newly emerging pests, mainly as a consequence of drought stress;
  - Climate change induced decline in wood production and carbon accumulation of main tree species;
  - Large share of spruce distributed outside the range of original distribution, with frequent severe damages by wind and subsequent bark beetle outbreaks;
  - High frequency and intensity of windthrows affecting forest protective functions, mainly water regulation and soil erosion.

- Factors reducing forest sensitivity:
  - Large share of protected areas with better site matching species composition, and more natural stand structure;
  - Projected improvement of growing conditions for beech and spruce growth in higher elevations;
  - Absence of areas with extensive multifactorial forest decline;
  - Absence of intensive effects of non-climatic stressor such as air pollution or nutrients exhaustion.

Hungarian part of the Inner Western Carpathians – High sensitivity

- Factors increasing forest sensitivity are:
  - Presence of climate sensitive lower margins of beech distribution;
  - Distribution of large share of forests in regions with recently observed adverse effects of drought, which can be amplified in the future;
  - Effects of non-climatic stressor such as intensive forest damage by game, increasing forest`s climatic sensitivity;
  - Regular outbreaks of Gypsy moth, which are expected to expand under climate change;

- Factors reducing forest sensitivity:
  - Low share of vulnerable spruce stands;
  - Absence of intensive effects of non-climatic stressor such as air pollution or nutrients exhaustion;
  - Absence of large scale forest decline.

Ukrainian part of the Outer Eastern Carpathians North and the Inner Eastern Carpathians – Moderate sensitivity

- Factors increasing forest sensitivity are:
  - Increasing frequency of abiotic damage, and anticipated increase in the frequency of forest damaging windstorms;
  - Regular occurrence of bark beetle outbreaks, which can be further fuelled by climate change;
  - Effects of windthrows on forest protective functions, mainly water regulation and soil erosion;
  - Effects of improper management, increasing forest`s climatic sensitivity;
Factors reducing forest sensitivity:
- Improvement of growing conditions for spruce and beech;
- Low risk of drought in elevations where most of forests are distributed.

Romanian part of the Inner Eastern Carpathians – High sensitivity

Factors increasing forest sensitivity are:
- High windstorm damages to mountain forest, which are expected to increase in the future;
- High bark beetle damages, which may be substantially amplified by climate change by increasing annual number of bark beetle generations, and elevating drought stress to trees;
- Anticipated effect of newly emerging pests;
- Projected disappearance of beech suitable climate over large part of the unit.

Factors reducing forest sensitivity:
- Improved condition for beech growth in higher elevations;
- Lower share of forests exposed to drought in the northern part of the unit.

Romanian part of the Outer Eastern Carpathians South – High sensitivity

Factors increasing forest sensitivity are:
- Frequent windstorm damage followed by bark beetle outbreaks; both being climate change driven agents.
- Projected expansion of Gypsy moth outbreak ranges over the entire unit;
- Substantial worsening of climatic conditions for beech growth in the future;
- Present occurrence of Nectria disease;
- Potential increase in biotic damage to beech by other agents (as has been reported from Hungarian part of the Carpathians).

Factors reducing forest sensitivity:
- Low incidence of Gypsy moth defoliations.

Southern Carpathians – Very high sensitivity

Factors increasing forest sensitivity:
- Occurrence of intensive defoliations by Gypsy moth, and anticipated expansion of outbreak ranges to higher elevations;
- Recently increased incidence of forest fires, and prospects for further increase in their frequency under increasing temperatures.
- Substantial worsening of climatic conditions for beech growth in the future in almost entire area;
- Frequent windstorm damage followed by bark beetle outbreaks; both being climate change driven agents.

Western Romanian Carpathians – Moderate sensitivity

Factors increasing forest sensitivity:
- Marginal presence of vulnerable spruce forests suffering from regular wind damage followed by bark beetle outbreaks;
- Anticipated increase in the abundance of *I. duplicatus*;
Projected increase in number of generations of most of bark beetle species;
- Occurrence of *Nectria* disease;

- Factors reducing forest sensitivity:
  - Lower level of present biotic risk in large part of the region covered
    by broadleaved forests;
  - Persistence of climatic conditions suitable for present broadleaved
    also in the distant future;
  - Highly sensitive coniferous cover only small portion of the unit in the
    north.

**Transylvanian Plateau – Very high sensitivity**

- Factors increasing forest sensitivity:
  - Occurrence of beech and some oak species near to their xeric
    margins;
  - Projected disappearance of beech suitable climate in the near future;
  - Presence of outbreak areas of Gypsy moth and occurrence of Nectria
    disease;
  - Projected expansion of Gypsy moth outbreak areas in the future.

**Serbian Carpathians – Very high sensitivity**

- As the Serbian Carpathians has been addressed in the SR2 only marginally,
  we did not performed specific assessment of forest sensitivity. Considering the
  minor extent of the unit, we classified forest sensitivity on the basis of the
  adjacent Romanian unit the Southern Carpathians as “Very high”.

  Performed assessment indicated high level of forest sensitivity across the
  Carpathians. While high forest sensitivity in the Western Carpathians (CZ, SK, PL)
  mainly related to the presence of highly sensitive secondary spruce forests, and to
  direct or indirect effects of drought (SK, HU), the main factor affecting high forest
  sensitivity in the Romanian and Serbian Carpathians were coupled effects of
  drought and related biotic damage acting mostly upon broadleaved forests. High
  frequency of windstorms and subsequent bark beetle outbreaks were the main
  impact factors in mountain regions across the Carpathians, and mountain forests
  were thought of as highly sensitivity to these agents.

  Forest *adaptive capacity* was evaluated using the outputs of the above mentioned
  task on adaptive capacity of forest management in the Carpathians, which is
  presented in details in Deliverable SR2.T4.D2. Semiquantitative ranking of
  Carpathian countries by their adaptive capacity was used as the final component of
  integrated vulnerability assessment.

  Our assessment of integrated forest vulnerability indicates that most of the
  Carpathians has received high and very high scores of forest vulnerability to climate
  change. Ukrainian Carpathians and Polish part of the Outer Eastern Carpathians
  received moderate and low ranking. In case of the Polish part, low climatic exposure
  along with good forest structure and low biotic risk backed-up such ranking. The
  classification of Ukraine as moderate can be questioned. The facts supporting such
  classification were moderate exposure, and presence of mostly mountain forests
  which are not expected to face substantial drought in the future. In addition, no
  indicators of critical forest decline and effects on non-climatic stressors were
  reported.

  High vulnerability scores received by most of the Western and Eastern
  Carpathians mostly reflect the results of sensitivity evaluation. Generally, such
  classification needs to be interpreted cautiously, as each sensitivity value is based
  on number of diverse indicators, relevant for given CoGP. Therefore, the relatively
  uniform pattern of vulnerability covers diverse processes partly described in the
  section on the sensitivity evaluation above.
5.4.5. **Effect of changes in forest cover on protective function of montane and subalpine forest**

Montane and subalpine forests play an important multi-functional role in stabilizing landscapes, and represent a major component of landscape aesthetics that is of importance for tourism and associated human activities. Montane and subalpine forests make almost 60% of all forests in the Carpathians, and provide a complex of forest services and functions, including protective. A primary function of a protective forest is the protection of people or assets against the impacts of natural hazards or adverse climate (Brang et al. 2006). The main protective functions of montane and subalpine forests encompass soil protection (i.e. prevention and mitigation of erosion and loss of soil); prevention and mitigation of avalanches, landslides, and rock falls; and preservation of water resources (Moravčík et al. 2005).

We addressed several issues related to disturbances in montane and alpine forests in the Carpathians, and potential impacts on their protective functions. As a starting point, we calculated using various data the extent of montane and alpine forests in Carpathians countries, and share broadleaved, coniferous and mixed in individual categories. An important issue addressed was the definition of montane forests according to national legislations of Carpathian countries, and categories of these forests (such as commercial, protective, protected, special purpose, etc.). In addition, there are variable perceptions of forest protective functions among countries, therefore we made a survey to clarify this issue. For some countries, we provided information on the share of protective forests fulfilling certain protective functions (erosion, water quality, air quality, etc.). For Poland, Slovakia, Ukraine and Romania, we evaluated the importance of main agents reducing the extent of montane and alpine forests. We found out that while in Poland, the main changes are related to farmland abandonment and its subsequent afforestation or succession, in Slovakia and Romania, wind and insects are main agents triggering changes at montane and subalpine zones of the Carpathians. Insects are extremely important also in the Ukrainian part of the Carpathians together with diseases and logging. Overexploitation and illegal logging represent the main threats in Romania, too.

Finally, effect of main disturbances was demonstrated, specifically for so-called non-specific forest decline that extensively occurs in the Western Carpathians, windthrows and insects. Effect on soil erosion, landslides, avalanches, and floods was addressed.
5.4.6. Observed species shift in grasslands communities, wetlands vulnerability and climate change impact on grasslands productivity

Although the major part of the SR2 focused on forest ecosystems, the final task addressed grasslands and marginally also wetlands in the Carpathians.

The Slovak Phytosociological Database (Institute of Botany of the Slovak Academy of Science, Bratislava) was used to evaluate the species shift of grassland communities in the Western Carpathians. The database contains more than 50,000 phytosociological relevés of all vegetation types in the Slovak territory. The oldest relevés come from 1911, however, sufficient grassland data are available yet since 1950 onwards. The results have not supported the hypothesis about climate change induced changes in species composition on grasslands in the Western Carpathians.

It seems that land use changes (mostly abandonment and decrease intensity of agricultural management) and increased nutrient input are better predictors of changes in grassland species composition than climate change. Those changes lead to higher abundance of tall competitive and ruderal species.

We expect that the trends detected in the Western Carpathians are relevant also for the eastern and southern part of the Carpathians, and we provide the reasoning of such assumption in Deliverable SR2.T5.D3.

The main conclusions related to grassland types addressed in our investigation are the following:

- **Mesic semi-natural grasslands:**
  - The vegetation of mesic grasslands showed low temporal variability and did not reflect the effect of recent climate changes through the temporal changes in species frequency. The indicated changes in species traits were only slight and can be attributed rather to land-use changes and succession of abandoned grasslands. As mesic grasslands have a central position along the moisture and nutrient gradients, they can be assumed to be least sensitive to changes in climate characteristics in comparison to other grassland types.

- **Natural grasslands on calcareous bedrock:**
  - We identified small changes that could be explained as a result of recent climate change, and some trends in species composition were observable. We summarize the changes that would be explained as a result of climate change as follows:
    - Increase in species with higher Ellenberg indicator values for temperature and continentality in the communities on calcareous bedrock indicate potential effects of climate change. High variation in temperatures between winters and summers, as well as between days and nights typical for regions with continental climate could occur in the Carpathian mountains in the future, and thus affect grassland communities towards higher shares of species reaching higher Ellenberg values for continentality.
    - Similarly, decreasing occurrence of species with higher requirements for light could be a consequence of warming, because light conditions are influenced by competition of taller plants, therefore, one of the first effects of temperature increase will be the modification of competitive relationships between plant functional types (Guisan et al. 1998; Theurillat and Guisan 2001).
    - Changes in climate that result in shortening of snow duration, and reducing snow depth and coverage may produce large changes in the C and N soil dynamics of alpine ecosystems (Williams et al. 1998). Organic matter content, can be affected by climate change (directly or indirectly, qualitatively and quantitatively), resulting in changes in
the main soil processes (humification, podzolization) and the nitrogen cycle (Theurillat et al. 1998).
- Non-significant differences in soil reaction could be a result of chemical buffering capacity of soils developed on calcareous bedrock, as suggested Theurillat et al. (1998).

- **Natural grasslands on siliceous bedrock:**
  - It is supposed that climate change may have substantial effect on alpine habitats. Results from the Western Carpathians however have not highlighted these changes so distinctively. Comparison of three periods (1925-1970, 1971-1990, 1991-2010) shows just small differences in distribution, ecology as well as species diversity of compared plant communities. No statistically significant differences in altitudinal distribution of siliceous grasslands have been detected.
  - Decreasing trends in the occurrence of species with lower Ellenberg indicator values for nutrients, temperature, soil reaction and light indicate effects of widespread nitrogen and phosphorus changes as a consequence of land-use changes – for example decline of grazing in alpine areas. Decrease in soil reaction potentially indicate impact of air pollution in the Central Europe.
  - Decrease in species richness may be connected with land use-changes rather than with climate changes since from the middle of the 20th century, important changes occurred in traditionally managed meadows. Many traditionally livestock-grazed montane grasslands were either abandoned, leading to their disappearance through invasion of shrubs, or higher selective pressure through sheep pasturing, which leads to a substantial decrease in the diversity of sensitive species and an increase in unpalatable clonal plants (Stampfli and Zeiter 1999).
  - We can conclude that our results show some small evidence of climate change effect on the addressed communities, though changes caused by direct human impact are much more evident.

- **Semi-dry grasslands:**
  - There were no indications of changes in environmental conditions related to the climate in terms of species Ellenberg indicator value for temperature, continentality and moisture during the study period. Semi-dry grassland communities and the species typical of semi-dry grasslands did not show any signs of sensitivity to recent climate change.

- **Dry grasslands:**
  - There are no indications of change in environmental conditions related to the climate change affecting the species composition. Neither dry grassland species nor dry grassland communities can be thought of as sensitive to climate change. The indirect effects (increasing cover of woody species and mesophilous highly competitive species) could result in decreasing number of specialist species well adapted to dry and warm conditions. Despite the slight increase in overall species richness in these communities, the mesophytisation process might result in reduction of typical dry grassland specialists due to shifts in floristic and functional composition (Kovács-Láng et al. 2000). As the dry grassland species are more resistant to climate-induced stress (summer drought, wind exposure, winter frosts, etc.), their gradual replacement by more mesophytic generalist species could induce further changes in the community composition.
**Wet grasslands**:  
- Changes in habitat conditions indicated by the measured (species richness and cover of the herb and moss layers) and calculated variables (Ellenberg indicator values) were significant in most cases, however, did not show obvious trend of decrease or increase.  
- Increasing species richness at the plot scale is similar to other community types and may indicate certain shifts in species composition. The community may be enriched by new species e.g. from the neighbouring habitats. However, these accessory species might involve not only species well adapted to the changed environmental conditions but also generalist species or unwanted ruderal species penetrating from the destructed habitats in the plot surrounding.  
- According to our results, the changes in the vegetation have not visible trends, and can be interpreted rather as fluctuations in vegetation floristic composition. The impact of climate is either week or it will be detectable after considerable time lag.

The analysis of wetland habitats vulnerability in the Carpathians focused on wetland types protected by the network of protected areas NATURA 2000 (European Commission 2007). Wetlands were understood in broad sense as defined in Ramsar Convention on wetland protection including deep-water and flowing water habitats. Vulnerability of wetland habitats to climate change was evaluated and classified into three categories (high, medium, low). The main conclusions are the following:

- The most vulnerable wetland habitats are peatlands, because of their limited plasticity towards climate fluctuations and their high sensitivity to human activities and land use changes.  
- Halophytic habitats and some types of water and river banks habitats we found less vulnerable. These habitats posses some plasticity towards climate fluctuations, but they are highly sensitive to human activities and changes in land use.  
- The lowest vulnerability was detected for the habitats depending on floods, habitats on the stands with fluctuating soil moisture, for subterannean wetlands and for some river bank and water habitats. These habitats can be thought of as very plastic and they are able to adapt even to drastic fluctuations in the weather conditions. However, many of them are threatened by human activities and they may decrease regardless of climate change.  

Detailed overview of wetlands vulnerability to climate change is given in Annex 20, and in the Deliverable SR2.T5.D3 of the SR2. In addition, maps of the distribution of four highly vulnerable wetland types were prepared using the Carpathian Biodiversity Information System, and other data; these wetland types are Active raised bogs, Degraded raised bogs (still capable of natural regeneration), Alkaline fens and Bog woodland.

The main part of the grassland related task of the SR2 focused on the modelling on future grasslands productivity across the entire Carpathians. We estimated the future changes in grassland productivity and carbon balance in the Carpathians, taking into account range of environmental and anthropogenic factors. Standard impact analysis protocol was used which means that calibrated and validated biogeochemical model (Biome-BGC MuSo v1.2) was coupled with a number of climate projections to estimate present day and future processes. 10 climate projections were utilized that were retrieved from the so-called FORESEE database (http://nimbus.elte.hu/FORESEE/). Because of limited information on distribution of grassland communities and management types, which substantially affect
grasslands’ carbon cycle, we used the so-called end-member logic; i.e. we defined representative grassland types (according to NATURA 2000 habitat type classification) combined with obvious management of each grassland type. Net Primary Production (NPP) and different carbon cycle components have been simulated for the entire Carpathians. The main results of this task are the following:

- Present-day simulation of NPP showed obvious dependence on soil texture. Estimation for combined mean NPP for the entire Carpathians was 665 gC m⁻² year⁻¹.

- Analysis of the simulation results for the end-members revealed that future changes strongly depend on the grassland types (NATURA 2000 categories). NPP of natural grasslands is expected to increase in the future, but poor soil conditions and regional differences in climate and elevation also modulate the expected tendencies. Grazing has small effect on NPP relative to the unmanaged case, while mowing (on hay meadows) basically negates the overall positive effects of joint increasing atmospheric CO₂ concentration and climate change.

- Combination of end-members showed that overall NPP trend in the Carpathians is close to zero, which means that NPP remains unchanged. This is because of the dominant role of mowing within the Carpathians (at least according to our model for management and NATURA 2000 habitat types distribution).

- Carbon balance related simulation results indicated non-trivial response of grassland ecosystems to the changing multifactor environmental conditions. Considering overall carbon balance (expressed by Net Biome Production) results indicated zero change which means that in spite of the fertilization effect caused by the increasing amount of atmospheric CO₂ the overall carbon balance might remain unchanged.

- The results highlighted that Carpathian grasslands are vulnerable habitats with considerable spatial and temporal variability in grassland production and carbon balance. While there is a potential for increasing grassland productivity in the future (positive effect of CO₂ fertilization) management can ultimately negate this effect. The results emphasize that it is not only climate change but also human decisions that strongly affects productivity and carbon sequestration of Carpathian grasslands in the future. This means that national legislation has the potential to affect grassland production and vulnerability to climate change.
6. **Evaluation**

Compare the results achieved against the objectives: briefly assess whether the objectives were met and describe the successes and lessons learned. This could be presented in a Table 16, which compares through quantitative and qualitative information the actions implemented in the frame of the project with the objectives in the revised proposal.

**Table 16 The actions implemented in the frame of the project with the objectives in the revised proposal.**

<table>
<thead>
<tr>
<th>Task</th>
<th>Foreseen in the approved project</th>
<th>Achieved</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kick-off meeting (Task 1 of the Inception Report)</td>
<td>Structure of the Inception Report, including working plan and specification of responsibilities of the experts involved</td>
<td>Inception Report was compiled and approved. Responsibilities of key experts (i.e. those responsible for deliverables, or delivery of information for individual countries) were specified.</td>
<td>Objectives met successfully.</td>
</tr>
<tr>
<td>Subtask 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kick-off meeting (Task 1 of the Inception Report)</td>
<td>Overview of national data and national impact studies</td>
<td>Brief overview of freely available data for the Carpathians was done, and some studies on CC impacts on ecosystems were reviewed. This provided very preliminary information on SR2 geodatabase development, and this task continued in the next period.</td>
<td>Objectives met successfully. Overview of available data presented in kick-off meeting was very tentative, and much of additional work was needed to survey available sources, acquire the data and develop SR2 database</td>
</tr>
<tr>
<td>Subtask 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pest and pathogens (Task 2 of the Inception Report)</td>
<td>Evaluate the importance of presently occurring pests and pathogens in the Carpathians, make a list of species addressed in the project.</td>
<td>Collection of species which are generally recognized as causing damage to forest in the Carpathians we prepared, and ecology and bionomy of each species was compiled. This material was then distributed among national experts, and several new species were added on the basis of their feedback.</td>
<td>Objectives met successfully. No problems were encountered in this task.</td>
</tr>
<tr>
<td>Subtask 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task</td>
<td>Foreseen in the approved project</td>
<td>Achieved</td>
<td>Evaluation</td>
</tr>
<tr>
<td>------</td>
<td>---------------------------------</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Pest and pathogens (Task 2 of the Inception Report)</strong></td>
<td>Evaluate recent observations of climate change-induced alteration of pests outbreak ranges, population dynamics, predator-prey and host-parasitoids relations, distribution and virulence of pathogens</td>
<td>National data on sanitary felling were acquired from individual countries, and maps for selected pest species were produced. Some of main outbreak areas were described in greater detail, also using remote sensing data. Point occurrences of Ips duplicatus, which is an important invasive pest, we collected from several countries and evaluated. Most of data is available for several year period, hence pests dynamics could be evaluated.</td>
<td>Objectives met successfully. Serious problems were encountered in relation to acquisition of national data on pest induced damages (this however concerns data in all tasks). National legislation either hampered such acquisition, or experts hired in the project were not able to reach the data for other reasons. The lesson learned is to consider carefully structure of consortium so as institutions supervising key national data sources were included. In the current project, this factor caused substantial delays.</td>
</tr>
<tr>
<td>Task</td>
<td>Foreseen in the approved project</td>
<td>Achieved</td>
<td>Evaluation</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>----------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Pest and pathogens (Task 2 of the Inception Report) Subtask 3</td>
<td>Modelling the effect of climate change on key pests in the Carpathians</td>
<td>Projections of future population dynamics and distribution were developed for the most important species. Ips typographus, Ips duplicatus, Hyllobius abietis, Lymantria monacha and Lymantria dispar were addressed. For each species, maps of their future distribution, shift of outbreak areas or change in number of annually produced generations, was evaluated.</td>
<td>Objectives met successfully. Obstacles were related mainly to limited knowledge on pests’ response to climate change. Development of new algorithms went beyond the scope of the project.</td>
</tr>
<tr>
<td>Pest and pathogens (Task 2 of the Inception Report) Subtask 4</td>
<td>Remote sensing based evaluation of changes in forest cover due to the effects of main pests and pathogens</td>
<td>Models regions, in which characteristic changes in forest cover occurred, were identified, and these changes were documented using time series of remote sensing imagery.</td>
<td>Objectives were met, though we expected to process more areas and infer more informative results. Such investigation apparently needs much more interactive collaboration between regional experts and remote sensing team. Such specific assessments seem to suit better for different type of project.</td>
</tr>
<tr>
<td>Task</td>
<td>Foreseen in the approved project</td>
<td>Achieved</td>
<td>Evaluation</td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Pest and pathogens (Task 2 of the Inception Report)</strong> Subtask 5</td>
<td>Producing the maps of present and future distribution of main pest, identification of vulnerable areas.</td>
<td>Maps of present and projected distribution of selected pests were produced, and submitted as Deliverable SR2.T2.D3. The 26 maps for 5 key species were produced.</td>
<td>Objectives met successfully. Problems related to above-mentioned acquisition of data on pests distribution.</td>
</tr>
<tr>
<td><strong>Pest and pathogens (Task 2 of the Inception Report)</strong> Subtask 6</td>
<td>Elaborating inventory of options to increase forest-stand natural resilience against pests and pathogens.</td>
<td>Report on forest management options which may allow combating increased impact of pests and pathogens were proposed. Attention has been paid to the principles of Integrated Pest Management. Questionnaire on some aspects of forest protection in Carpathians countries were elaborated, and returned information is presented in the Deliverable SR2.T2.D2.</td>
<td>Objectives met successfully though some difficulties were encountered. This topic expected specific professional background of experts providing the information needed. Expert pool of the current project did not fully disposed with such experts. The lesson learned is to consider more carefully suitability of expert pool in relation to specific tasks addressed in the project.</td>
</tr>
<tr>
<td>Task</td>
<td>Foreseen in the approved project</td>
<td>Achieved</td>
<td>Evaluation</td>
</tr>
<tr>
<td>------</td>
<td>---------------------------------</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Protective functions (Task 3 of the Inception Report)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Subtask 1</strong></td>
<td>Analysis of montane and subalpine forests in the Carpathians</td>
<td>Report on the spatial distribution of montane and subalpine forests in the Carpathians and their species composition</td>
<td>Objectives met successfully though some problems occurred in relation to acquisition of national data on montane and subalpine forests. The definition of montane forest differs among countries, thus options for uniform pan-Carpathian assessment are limited.</td>
</tr>
<tr>
<td><strong>Protective functions (Task 3 of the Inception Report)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Subtask 2</strong></td>
<td>Country-wise survey of national legislation dealing with forest functions.</td>
<td>Report on national policy and legislation that specify forest functions with the emphasis on protective functions of forests in individual countries. Questionnaires on forest functions in the Carpathian countries were elaborated, and returned information is presented in the Deliverable SR2.T3.D1.</td>
<td>Objectives met successfully. Problems occurred in relation to acquisition of national data on forests fulfilling particular protective functions.</td>
</tr>
<tr>
<td>Task</td>
<td>Foreseen in the approved project</td>
<td>Achieved</td>
<td>Evaluation</td>
</tr>
<tr>
<td>------</td>
<td>--------------------------------</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Protective functions (Task 3 of the Inception Report)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtask 3</td>
<td>Analysis of factors affecting protective functions of forests</td>
<td>Review of factors affecting protective functions of montane and subalpine forests and their importance in the Carpathians. Questionnaires on factors affecting protective forest functions in the Carpathian countries were elaborated, and returned information is presented in the Deliverable SR2.T3.D1.</td>
<td>Objectives met successfully.</td>
</tr>
<tr>
<td><strong>Management (Task 4 of the Inception Report)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtask 1</td>
<td>Country-wise survey of relevant policies, national reports on the state of forests, and national legislations on forest management.</td>
<td>Report on national and international forest policy and legislation that regulate the applied forest management in individual countries. Questionnaires on some aspects of forest management in the Carpathian countries were elaborated, and returned information is presented in the Deliverable SR2.T4.D2.</td>
<td>Objectives met successfully. Problems occurred in relation to acquisition of national data on forest management practices. The lesson learned is to consider carefully structure of consortium so as institutions supervising key national data sources were included. In the current project, this factor caused substantial delays.</td>
</tr>
<tr>
<td>Task</td>
<td>Foreseen in the approved project</td>
<td>Achieved</td>
<td>Evaluation</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Management (Task 4 of the Inception Report)</strong></td>
<td><strong>Subtask 2</strong></td>
<td>Analysis of low cost satellite images to assess loggings and forest cover time evolution within selected model regions in the Carpathians</td>
<td>Remote sensing-based evaluation of changes in forest cover was not included into deliverable related to this task because we found very limited options to link identified changes in forest cover to applied forest management practices. Therefore, remote sensing based assessments are part of deliverables SR2.T3.D1 (Forest protective functions), SR2.T2.D1 (Pests and pathogens) and SR2.T2.D3 (Pest maps).</td>
</tr>
<tr>
<td>Task</td>
<td>Foreseen in the approved project</td>
<td>Achieved</td>
<td>Evaluation</td>
</tr>
<tr>
<td>------</td>
<td>---------------------------------</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>Management (Task 4 of the Inception Report)\nSubtask 3</strong></td>
<td>Review of basic forest management systems and international reports on adaptive forest management</td>
<td>Review of generally accepted forest management systems and their effect on forest ecosystems, and report on the available international knowledge about possible adaptive forest measures to climate change. This material was distributed among national experts, and on the basis of their feedback additional information was included in the report.</td>
<td>Objectives met successfully. No problems were encountered in this task.</td>
</tr>
<tr>
<td><strong>Management (Task 4 of the Inception Report)\nSubtask 4</strong></td>
<td>Establishing links between applied management and its potential to adapt the forests to climate change</td>
<td>Integration of knowledge on actual forest management with knowledge on potential of forest management to mitigate negative effects of climate change. Questionnaires on this issue in the Carpathian countries were elaborated, and returned information is presented in the Deliverable SR2.T4.D2. For each vegetation zone and forest type the overview of the current state and current management was elaborated and adaptation measures were suggested.</td>
<td>Objectives met successfully though some difficulties were encountered. This topic expected specific professional background of experts providing the information needed. Expert pool of the current project did not fully dispose with such experts. The lesson learned is to consider more carefully suitability of expert pool in relation to specific tasks addressed in the project.</td>
</tr>
<tr>
<td>Task</td>
<td>Foreseen in the approved project</td>
<td>Achieved</td>
<td>Evaluation</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------</td>
<td>----------</td>
<td>------------</td>
</tr>
</tbody>
</table>
| **Management**  
( Task 4 of the Inception Report)  
Subtask 5 | Collecting questionnaires on illegal logging, felling of losses and their expected impacts on the environment. | All questionnaires returned filled, and they contained sufficient information for completing the report. | Objectives met successfully. Problems were related to quality and availability of data on accidental data in individual countries, which is common problem also for some other task. |
| **Species composition**  
(Task 5 of the Inception Report)  
Subtask 1 | Evaluation of climate change-induced shift of main forest tree species. Description of recent observational evidences and compilation of the outputs of various modelling exercises of species shifts. | Information on species shift was collected from all countries, and critically evaluated. Unified modelling exercise was run, and result of projected species shift for the entire Carpathians are presented in respective deliverable. | Primary intention to collect the data using questionnaires distributed among national experts was not successful as only general and rough information returned. Therefore, iterative discussions with experts were needed to collect the required information. |
| **Species composition**  
(Task 5 of the Inception Report)  
Subtask 2 | Evaluation of recent evidences of change in species composition, structure and distribution of grassland communities | Comprehensive statistical evaluation of the Slovak Phytosociological Database was performed, and trends in species diversity and ecology were evaluates. | Data suitable for such analysis were available for Slovak part of the Carpathians only. Extrapolation of such information to eastern and southern Carpathians may have limited value. |
<table>
<thead>
<tr>
<th>Task</th>
<th>Foreseen in the approved project</th>
<th>Achieved</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species composition (Task 5 of the Inception Report)</td>
<td>Analysis of climate change effect on grasslands productivity</td>
<td>Comprehensive modelling exercise was ran using Biome-BGC model, and simulations of future grasslands productivity were produced under ensemble of 10 climate change scenarios for the entire Carpathians. Objectives were met successfully, and no problems were encountered. Minor methodological issue concerned availability of information on grassland types for the entire Carpathians. As such information is not available, a simplified surrogate had to be used. Therefore, some simulations may have limited value.</td>
<td></td>
</tr>
<tr>
<td>Subtask 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Species composition (Task 5 of the Inception Report)</td>
<td>Analysis of present status of wetlands in the Carpathians; identification of main climate change and landscape management-related threats</td>
<td>Report was compiled using available information from Carpathian countries. Analysis was mainly based on published studies concerning wetland ecology and dynamics. Analysis of available sources showed uneven coverage of different wetland types by relevant ecological studies. Several relevant studies were available for instance for peatland habitats, but riverine habitats were only poorly covered. In general, there is a lack of studies in the Carpathians, focusing on wetland dynamics and changes of species composition.</td>
<td></td>
</tr>
<tr>
<td>Subtask 4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Species composition (Task 5 of the Inception Report)

<table>
<thead>
<tr>
<th>Task</th>
<th>Foreseen in the approved project</th>
<th>Achieved</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subtask 5</td>
<td>Map wetlands distribution in the Carpathians</td>
<td>Distribution maps of the most vulnerable wetland habitats in Carpathian orographic units were prepared.</td>
<td>In general wetland habitats are not mapped in most of Carpathian countries, so our knowledge about their distribution is very fragmented and insufficient. Therefore occurrence in orographic units was the only possibility, how to show their distribution, based on information on web <a href="http://www.carpates.org">www.carpates.org</a>. More attention should be paid to wetland inventories in the Carpathian countries and to the harmonization of the data.</td>
</tr>
</tbody>
</table>
7. **Conclusions**

Broad range of collected data and performed analysis brought number of results, and we strived to compile conclusion on the end of each task or report. The conclusions which we have found worth emphasizing are the following:

- As the climatic exposure was found to remarkably increase from the Western towards the Eastern and Southern Carpathians, the latter ecosystems can be expected to face more intensive changes in terms of their physiological processes, migration and related species shift, potentially followed by decline and extinction.

- Two wide-spread Carpathian forest ecosystems, which should receive increased attention in research and adaptation, are beech and spruce forests. While the unsustainability of large areas of spruce forests in Europe has been recognized for long, there are new sound indications of increasing drought-related and biotic risk to beech, potentially leading to decline of some beech forests.

- Expansion of climate suitable for oaks across large parts of Europe, including substantial increase of areas suitable for Mediterranean oak types, has been suggested be several modelling studies, including our simulations presented in this report; such measure seems important for future climate-proofing of the Carpathian forests. Inclusion of the substantial increase of oaks share in Carpathian countries into forest management plans, however, is not generally accepted concept in forest management planning. Therefore, further research is needed to recognize the assets of such measure, and its applicability.

- Compressed vegetation zones in montane areas may face increased forest dynamics under climate change, including shift of tree line. As montane forests foster diverse valuable species and communities, such dynamics may threat the biodiversity. Coupled effect of climate change accelerated forest dynamics and forest management, however, make such changes hardly predictable, and conservation strategies may be difficult to propose.

- Biotic risk in terms of change in population dynamics and distribution of resident pests as well as in terms of emergence of new pest species needs to be though of as the most important climate change related threat to forest ecosystems; this fact calls for the urgent consolidation of adequate monitoring systems, including their transboundary harmonisation, and supporting the capacity of national forest protection services.

- Effect of non climatic stressors such as improper management, air pollution, nutrient exhaustion, etc. can critically amplify the effects of climate change; such regions in the Carpathians should receive increased attentions from the view of monitoring and adaptation.

- None of the Carpathians countries posses efficient mechanisms to adapt the forests and mitigate the climate change impacts efficiently; considering the present status of a number of socio-economic indicators, and the fact the current economic crisis lays in all Carpathian countries stress on issues other than climate change adaptation, we do not see short to middle term prospects on the improvement.

- Lacking cross-sectoral cooperation is common problem in Carpathian countries, often hampering the effective adaptation. This factor limits the options for adaptation through integrated landscape or watershed management.

- Grasslands communities were found relatively resistant to recent effects of climate change, and no changes in species composition indicating the effect of climate change were identified. In addition, our simulations indicated relative stability of future grasslands productivity and carbon cycle. These findings corroborate the fact that direct human effects related mainly to change in landuse and grasslands management remains dominant drivers determining the structure and distribution of Carpathian grasslands.
8. **Implications**

Our work pointed out several topics related to the assessment of climate change impacts and adaptation in the Carpathians, which would be worth receiving further attention.

- We consider the report on integrated vulnerability assessment to be the most important, as it strives to synthesize key findings of partial evaluations of climate change impacts to arrive at final assessment of forest vulnerability. During the interpretation of results, we encountered several difficulties related to spatial scale at which the assessment was performed. The used intersection of geomorphologic subprovinces and state boundaries was not suitable in some regions, where substantial changes in forest structure occurred within the subprovinces. Hence, the finer division would allow for more correct classification of forest sensitivity as compared with our proposal, and such classification would be closer to forest management planning scale. Therefore, we suggest further developing the delivered vulnerability assessment and shifting the evaluation to finer spatial scales.

- Integrated vulnerability assessment based on the concept of exposure-sensitivity-adaptive capacity would require further methodological development. While assessment of climatic exposure is relatively straightforward, quantitative assessment of sensitivity and adaptive capacity seems difficult, mainly because of number of indicators the importance of which varies among countries and regions. The approach used in the SR2 allowed for arriving at final classifications relying on expert-panel approach, anyway methodological development towards more quantitative assessment would be beneficial for the ongoing vulnerability studies.

- Evaluation of future grasslands productivity using the Biome-BGC model was markedly limited by unavailability of data on grasslands distribution in the entire Carpathians, and by unavailability of information on grasslands management. The used approach based on the so-called end-members can be thought of as methodologically correct, it however represent substantial simplification of real data on grassland types and management. For these reasons, further developments would focus on recalculating our simulations using finer data, which are available in institutional databases in some of the Carpathian countries.

- The fact that our evaluations were based mostly on freely available data limits the value of presented outputs. Institutional databases such as national forest management plan or databases on grasslands distribution were not available. For this reasons, for example, data on tree species distribution from forest management plans had to be substituted by results of statistical mapping and Corine LandCover data, and data on grasslands types had to substituted by our highly simplified model. The same problem concerns climate data, remote sensing based classifications of changes in forest cover, national forest inventories, etc. We strongly advise supporting the further research of forest vulnerability in the Carpathians by data and knowledge available in existing institutional structure of the Carpathian countries.

- As we pointed out in the Conclusions (Chapter 4), adaptive capacity of Carpathian countries is insufficient, and substantial improvements cannot be expected. Anyway, there are examples of good practice, which would be worth using in awareness increase programs. We suggest surveying such examples and supporting them in the future projects.
9. References


Giurgiu, V. (2010). Forest and Climate Change. Forests magazine 125, 3. (in Romanian)


Hlášny, T. et al. (2009).: *Recommendations and development of management options for an improved land use systems in agriculture crop production and forest management under the regional climate change scenarios*. Deliverable D 6.8. Project No. 037005 CECILIA (Central and Eastern Europe Climate Change Impact and Vulnerability Assessment) Specific targeted research project. National Forest Centre – Forest Research Institute Zvolen, Slovakia.

Hlášny, T. et al. (2010). *Central and Eastern Europe Climate Change Impacts and Vulnerability Assessment*. Project of the 6FP EU.


Geographical variability of spruce bark beetle development under climate change in the Czech Republic. *Journal of Forest Science* 57, 6, 242-248.


McCarthy R. (2010). Met Office Hadley Centre - "Impacts of Climate Change in Ukraine". Ukraine


80/09/2013 Page 240 of 280


List of Deliverables of the SR2


Annex 1 *Ips typographus* in the Western Carpathians: Pest distribution indicated by damage to forest in the period 2008-2010.

Bark beetle (*Ips typographus*) in the Eastern Carpathians: Pest distribution indicated by damage to forest in the period 1990-2010

The spruce bark beetle (*Ips typographus*) is widely distributed in the Southern Carpathians and is the most important insect pest in Norway spruce (*Picea abies*). Healthy trees and deadwood of Norway spruce are highly valuable to various stakeholders and are a highly appreciated amenity and landscape feature. Natural spruce and firs are declining. Spruce bark beetle outbreaks are taking place in the southern Carpathian range.

For the period 1990-2008 the most important outbreaks occurred in 1995 for which models were available. The year 2008 is considered to be the beginning of a new outbreak. The number of infested hectares have reached 350,000 ha (Bainosanu et al., 2009). Data for Ukraine and Northern parts were not available. Data for Romania after 2009 are not available.

Spruce bark beetle (Ips typographus) in the Carpathians: Estimated number of generations completed per year under the reference climate 1961-1990
Annex 4 Ips typographus in the Carpathians: Estimated number of generations completed per year under the future climate 2021-2050.

Spruce bark beetle (Ips typographus) in the Carpathians: Estimated number of generations completed per year under the future climate 2021-2050

European spruce bark beetle

Ips typographus is the most destructive species of the genus Ips and the most notable one in spruce In Europe. Though, 26 species of spruce and fir in Europe can host Ips typographus, the species is specifically reported to be a primary pest in Norway spruce stands which are already stressed for other reasons (Schröder 1990). Ips typographus is a vector of several important fungi which can cause dieback in spruce and other coniferous species. (Harmon et al. 1996).

Today spruce beetles are considered as one of the most important threats to the conservation of Central European forest landscapes. Their importance is even higher in the context of climate change, which is expected to have significant impacts on the distribution of Ips typographus in Europe.

Ips typographus is a polyphagous species that can attack a wide range of coniferous and deciduous trees. In the Carpathian region, it is mainly found in Norway spruce forests.

Data and methods

The model was based on the model ECOFOREST – A Complex Hierarchical Model of I. typographus (Ritter et al. 2017). The model was specific for European forests and used species distribution models (SDMs) to predict the potential distribution of the species under different climate scenarios.

The model was run at a resolution of 5 km and used climate data from the WorldClim database (Hijmans et al. 2005) and the CORINE Land Cover dataset (Lauryn et al. 2010). The model was validated against field data from the Carpathian region.

Estimated number of generations completed per year under the reference climate

Number of generations

0 1 2 3 4

Norway spruce distribution

Change in mean annual temperature (2021-2050) - (1981-1990)

(average of 3 RCMs)

Proportion of Norway spruce forests in Carpathian countries in categories allowing for development of certain number of bark beetle generations

08/09/2013
Annex 5 Change in number of generations per year of Ips typographus in the Carpathians between periods 1961-1990 and 2021-2050.

Change in number of generations per year of European spruce bark beetle (*Ips typographus*) in the Carpathians between periods 1961-1990 and 2021-2050

Data and methods

The multiple-tree model of the model (CIMBER - A Complex International Model of European Forests) was used in the study. The model was developed in the 1990s by the European Forest Institute.

The climate data for the model were sourced from the WorldClim database (Hijmans et al., 2005), which contains the modified results of regional climate simulations performed within the framework of the ENSEMBLES project (Van der Linden et al., 2009). Two regional climate models (BCC and INM) were used for the development of future climate - RCM - BEHMANN, KUANG. Norway spruce distribution data were taken from the adapted mapping of two species over the Carpathians (Hietala et al., 2013). Original data were sourced from the Center for Landscape Data.

Change in the proportion of Norway spruce forests in Carpathian countries allowing for the development of certain number of bark beetle generations per year.

08/09/2013
Annex 6 Ips typographus in the Carpathians: Estimated number of generations completed per year under the future climate 2071-2100.

Spruce bark beetle (Ips typographus) in the Carpathians: Estimated number of generations completed per year under the future climate 2071-2100

Data and methods

The analyses were based on the model BOREAS - A coupled Physiological Model of Z. typographus (Blaustein et al. 2007). The main assumptions are:

- Developmental thresholds for growth are 4.5°C.
- Used climate data were taken from the FORBES database (Biber et al. 2012), which contains the modified results of regional climate simulations performed within the scope of the EURO-CORDEX project (Van der Linden et al. 2009). Average of three Regional Climate Models (RCMs) were used for the depiction of future climate - HadCM, HIRHAM, KNMI. Norway spruce distribution data were taken from national mapping of tree species over Europe (Stein et al. 2012). Original data were corrected using the Centre for Environment.

Change in mean annual temperature (2071-2100) - (1981-1999) (average of 3 RCMs)

Estimated number of generations completed per year under the future climate

Number of generations

Norway spruce distribution

Proportion of Norway spruce forests in Carpathian countries in categories allowing for development of certain number of bark beetle generations
Annex 7 Change in number of generations per year of Ips typographus in the Carpathians between periods 1961-1990 and 2071-2100.

Change in number of generations per year of European spruce bark beetle (Ips typographus) in the Carpathians between periods 1961-1990 and 2071-2100.

European spruce bark beetle

Ips typographus is the most destructive species of the genus Ips found in the spruce forest ecosystems of Europe. Although it is not distributed throughout the whole of Europe, it is present in spruce forest ecosystems in western, central and eastern Europe. The beetle has an effective reproductive potential and also represents a real threat to the sustainable use of forest ecosystems. The beetle population dynamics are conditioned by several factors such as climate conditions, host quality, and disturbance events.

Data and methods

The analysis was performed using the model PHENSYM - A Complex Phenological Model of 5 species (Biber et al., 1997). The most important developmental thresholds were added by Weise and Rudel (1995).

In this study, a model was taken from the FORING database (Biber et al., 2015), which contains the model results of a regional-scale simulation performed as a part of the INCOSE (INCO-136805) project (Knappe et al., 2008). Average of these regional climate data were used for the development of future climates. For future climate scenarios, RCM-MME (Rosa et al., 2008). Norway spruce distribution data were taken from the Global Woodland Mapping of Norway spruce over Europe (Biber et al., 2013). Original data were converted using the Carpathian Forest map.

Change in the proportion of Norway spruce forests in Carpathian countries allowing for the development of certain number of bark beetle generations per year.
Annex 8 Remote sensing-based assessment of changes in forest cover due bark beetles infestation in the Western Beskids (part 1).

Remote sensing-based assessment of changes in forest cover due to bark beetle infestation and subsequent sanitary felling in the Western Beskids

Sample area 1
Sample area 1 represents the Javoriski (investa 460 m a.s.l.) in Slovakia with size 0.57 km² and forest in 2004. Landsat TM imagery acquired in July 1994 describes the forest before the main period of decline, with clearly visible regular-shaped areas of planned felling. The September 2005 image describes the first irregularly shaped areas of accidental felling, the onset of which was dramatically up to June 2010. The fourth image with the composite of 2004 and 2010 temporal bands describes trends and the changes in forest cover between 1994 and 2010.

Sample area 2
Sample area 2 describes part of the Roszaprzedz mountain range from the “Czech Republic” (2,350 m a.s.l.) to the “Rajec” (1,430 m a.s.l.). Size of this area is 0.61 km² with 73% cover of both pine and spruce forests in 1994. Two thirds of the total forest cover were originally made up of spruce. The LANDSAT imagery from 1994 describes the first appearing spots of declining stands, probably due to disease in some of compact spruce forest (dark brown) close northly from the village of Suchy Rajec. The 2003 image describes widespread belt of declining spruce stands as well as east defoliated area. Regular tamarisk stripes in the northern edge of the image portray ski slopes. The 2010 image describes almost total disappearance of spruce stands in the central part of the sample area, and spread of the beetle in the west. The fourth image describes increased defoliated changes.
Annex 9 Remote sensing-based assessment of changes in forest cover due to bark beetle infestation in the Western Beskids (part 2).

Remote sensing-based assessment of changes in forest cover due to bark beetle infestation and subsequent sanitary felling in the Western Beskids.

Sample area 3
Sample area 3 describes the highest parts of the Silian Beskids with Barynia Ginya Mt. (1,220 m a.s.l.) and with source of the Waba river. Plot size is 366 km². The 1994 image describes the initial status with continuous spruce forest cover in the central and southern part of the mountain crest. The 2005 and 2007 images describe the progress of decline. Coniferous spruce stands in the south-west of the Barynia Ginya Mt. were strucken as the last. The fourth image describes in red the aforementioned changes.

Sample area 4
Sample area 4 with size of 97 km² describes compact spruce forest in the Glownowski Mts. (1,022 m a.s.l.) on Slovak-Polish border (Slovakia). Landsat TM imagery acquired in September 1994 describes the initial stage of decline of private spruce forest, occurring mainly in the southern part of the forested area. This is the initial spot from where the decline spreads to the central part (May 2001 image) and further to all the remaining parts (June 2010 image). This area represents one of the main initial spots of spruce decline in the Orava region. Armillaria disease was extremely important agent in the initial stages of decline. As can be seen in the fourth image, the decline occurred both in Slovak and Polish parts of the forested area.
Annex 20 Remote sensing-based assessment of changes in forest cover due bark beetles infestation in the Western Beskids (part 3).

Remote sensing-based assessment of changes in forest cover due to bark beetle infestation and subsequent sanitary felling in the Western Beskids

Sample area 1

Sample area 1 describes the total area of the Kravov, Horní Išovice and adjacent regions in the Czech Republic and Poland. The area of this area is 4.956 km². Bark beetle parasites have affected mainly the southern and eastern parts of the main mountain range. Similar damage can be seen in the adjacent parts of theSegoe basin in the Slovenský and Nízke Beskydy. Further spots of decline occurred in the eastern part of theformerly Muš. The northern part of the Kravov rozhledu Muš is largely stornen.

The most affected areas in the Ostrava region can be seen in the surrounding of the Kravov (northern edge of the Ostravské Beskydy) and Příleská (western part of the Šumava) forests. Some areas have been affected by bark beetle infestation, but the overall damage is less severe compared to the Kravov region. Important areas of decline are located in the outermost parts of the image.
Annex 31 Outbreak areas of Lymatia dispar in the Western Carpathians in the period 2003-2005.

Outbreak areas of Gypsy moth (Lymatia dispar) in the Western Carpathians in the period 2003-2005

Gypsy moth is known as a polyphagous herbivore, Quercus spp. are the primary hosts, although moth may feed on beech and other broadleaved as alternative hosts, mainly in the vicinity of oak outbreak area (Hilmer and Turcani 2000).

Information about infested surface (ha) for the period 2003-2005 presented in the map were obtained from reports published by national Forest Protection Service. Data are reported for administrative districts in the Czech Republic (Pyatok et al. 2004; Konicek and Batz 2005; Kaplan 2006) and in Slovakia (Konecna et al. 2003; 2004). Data for the Polish and the Hungarian part of the Carpathians were not available. Importance of L. dispar in Poland is however marginal.

The data shows the last outbreak which was observed in the period 2003-2005, culminating in 2004. In Slovakia, about 45 thousands ha of broadleaved forests were defoliated. The next outbreak is expected to commence in 2012-2013.

Gypsy moth (Lymatia dispar) in the Eastern Carpathians: Extent of defoliated forests in the period 1990-2010

Gypsy moth is known as a polyphagous herbivore. Quercus spp. are the primary host, although caterpillars feed on beech and other broadleaved trees, mainly in the vicinity of oak outbreak spots (Birinyi and Tüzün 2009). Information about infected surface that in Romania were taken from Stănescu et al. (2001) for period 1990-2000 and Stănescu et al. (2010) for period 2001-2010. Data for Ukrainian and Serbian parts were not available.

The first records on L. dispar outbreaks in Romania come from 1952. Large-scale defoliations were observed in the period 1952-1961 in oak forests in the southern Transylvania (Delibegovic, Munca at Olteni). Low intensity defoliations were observed also in year 1994. New outbreaks started in 1994, and later massive defoliations were observed at large areas in 1997, 2001, and 2007. Defoliations in 2007-2008 were more intense than those in 1997-1998, but were more extended (Forest and Nature 2006). Propensity of outbreaks during the last 50 years suggests that Lymatia dispar populations in Romania occur with period ca. 10 years. Defoliations are most intensive in forests of Quercus cerris and Q. petraea in the southern regions, and mostly absent in other parts.
Projected outbreak areas of Gypsy moth (Lymatricia dispar) in oak forests in the Carpathians: Period 1961-1990

Annex 64 Projected outbreak areas of Lymaria dispar in oak forests in the Carpathians: Period 2021-2050.

Projected outbreak areas of Gypsy moth (Lymaria dispar) in oak forests in the Carpathians: Period 2021-2050

**Climate change effects**

- Anticipated climate change may affect Gypsy moth distribution in terms of warmer climate conditions in the north and south (Kimmins et al., 2002) and in higher altitudes (Hillman and Turner, 1998). Outbreak areas are expected to expand significantly in the near future. However, further growth may be limited by distributional ranges of Quercus spp., which are the primary hosts. Warmer and prolonged growing seasons may have positive impact on the growth of Gypsy moth outbreaks at its northern limits (Thomas et al., 1999; Varhelye et al., 2007). The model’s limitations were reviewed elsewhere (Ponsinet et al., 1999).

- Changes in the Gypsy moth outbreaks were evaluated based on the model outputs by Ponsinet and Paniot (2007). Land cover data was taken from the PEREE3 database (Baller et al., 2012), which contains the model results of regional climate simulations performed with the CORIO3M model, with a resolution of 30 arc seconds. The PEREE3 database was used for the description of future climate. The CORIO3M model was used for the environmental data.

- Host plants distribution were taken from statistical mapping of tree species from Karpa (Karas et al., 2011). Original data were converted using the Corin Lumbanfedita.

**Modelling approach**

- Canonical Correspondence Analysis was used to identify environmental variables controlling species abundance. An extension plot suggested the plant’s positive correlation with air temperature and distribution of Quercus spp. and oak-stands.

- Identification of outbreak areas in each stage

- The weighted combination of these variables (arcsin square root of each variable) was used to identify stands providing suitable conditions for G. dispar outbreaks under both current and future climate. The respective weights were set from 1 (highest) to 0 (lowest) as temperature. In order to compute an index of future outbreak risk, the grid cells were classified using a fuzzy membership mapping from 0 to 1. The arbitrary threshold of 0.8 was used to identify outbreak areas.

- Extent of projected outbreak areas of Gypsy moth in oak forests in the Carpathians using climate data for period 2021-2050 at total extent of oak forest in given.
Projected outbreak areas of Gypsy moth (Lymatia dispar) in oak forests in the Carpathians: Period 2071-2100

Climate change effects

Anticipated climate change may affect Gypsy moth distribution in terms of range shift towards the poles (Holloway et al., 2007) and to higher altitudes (Hilger and Touréne, 2000). Outbreak areas are expected to expand, especially in the near future. However, forest growth may be limited by dissemination range of Quercus spp., which are the primary hosts. Warming and increased precipitation may have positive impacts on the growth of oak outbreak areas at its northern limit (Thomas et al., 1998; Vithanas et al., 2007). The southern limit may also move northward (Thomson et al., 1999).

Changes in the gypsy moth outbreaks were evaluated based on the model prepared by Hilger and Touréne (2000). Forecasts were taken from the FORESSE database (Daher et al., 2012), which contains the modeled results of regional disease simulations performed to enhance the ENSURE project (over the period 2000-2030). The Regional CRG (HERALD, RAC300) was used for the description of future climate—Begle. HERALD, RAC300 was used for the description of future climate—Begle.

Host plant-distribution was taken from statistical mapping of tree species from Kopf and Hurnik, 2009. Original data were corrected using the Canopy Landscape model.

Modelling approach

Canopy Correspondence Analysis was used to identify environmental variables surrounding oak stands. An estimation plot suggested the test's positive correlation with air temperature and distribution of Quercus spp. Therefore, these were used as input for the model. The variables were used as input for the model. The variables were used as input for the model. The variables were used as input for the model.

Identification of outbreak areas in oak stands

The weighted combination of these variables (10 maps), rescaled to a range from 0 to 1, was used to identify stands providing suitable conditions for L. dispar outbreak under both current and near future climate. The respective weights were set to a proportion of Quercus spp. seedbed temperature. In this way, we obtained a number of oak outbreak areas, totaling an area ranging from 8 to 12. The arbitrary threshold of 0.8 was used to identify outbreak areas.

Projected outbreak areas of Gypsy moth (Lymatia dispar) in beech forests in the Carpathians: Period 1961-1990

Climate change effects

Anticipated climate change may affect Gypsy moth distribution in terms of range shift towards the pole (Penev et al., 2007) and to higher latitudes (Bilharz and Turcik, 2010). Outbreak areas are expected to relocate significantly in the near future. However, future growth may be limited to distributional range of Quercus spp., which are the primary hosts. Warmer and prolonged summers may have positive impact on the growth of each outbreak areas at its northern limits (Thomson et al., 1998; Youssef et al., 1997). The southern limit may also move northward (Thomson et al., 1998).

Changes in the gypsy moth outbreaks were evaluated based on the model proposed by Bilharz and Turcik (2009). Gypsy moth data was taken from the FORERE database (Bilharz et al., 2012), which contains the modified results of reported climate simulations performed within the frame of the EUAMERIS project.

Mean annual air temperature in the period 1961-1990

Projected effects of climate change in the Carpathians are expected to cause shifts in consecutive years in the distribution of L. dispar in the Carpathians. This is due to the shifting of Gypsy moth outbreaks towards the north, as well as towards higher altitudes, within the forest range of Quercus spp.
Annex 97 Projected outbreak areas of *Lymatia dispar* in beech forests in the Carpathians: Period 2021-2050.

Projected outbreak areas of Gypsy moth (*Lymatia dispar*) in beech forests in the Carpathians: Period 2021-2050

**Climate change effects**

Anticipated climate change may affect Gypsy moth distribution in some of Europe's deciduous forests (Plokhinsky et al., 2007) and is expected to be significant in the near future. However, further research is needed to determine the exact extent and impact on the species' distribution. The projected changes may lead to changes in host species distribution, with possible shifts in the geographic range of the moth. The northern limit may also shift northward (Thomasson et al., 1999).

**Modelling approach**

Correlation analysis was used to identify environmental variables controlling species abundance. An ordination plot suggested the moth's positive correlation with temperature and precipitation in the Carpathian region (Plokhinsky et al., 2007).

Identification of outbreak areas in beech stands

Under future climate conditions, the species may be less abundant in currently suitable areas, leading to a decrease in abundance. This suggests that the moth's distribution may shift, with possible shifts in host species distribution and shifts in the geographic range of the moth. The northern limit may also shift northward (Thomasson et al., 1999).

Projected outbreak areas in the period 1961-1990

**Change in mean annual temperature (2021-2050) - (1961-1990)**

(average of 4 RCMs)

Increase of mean annual temperature (°C)

- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0

08/09/2013 Page 261 of 280
Projected outbreak areas of Gypsy moth (*Lymantria dispar*) in beech forests in the Carpathians: Period 2071-2100
Annex 19 Differences in selected climate elements between future and reference climate.

Change in mean annual temperature (2071-2100) - (1961-1990)
Annex 110 Hydrological and ecological analysis of NATURA 2000 wetland habitat types.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Hydrology</th>
<th>Special requirements</th>
<th>Land use threats</th>
<th>Resilience (plasticity) of the habitat</th>
<th>References related to dynamics and ecology of the habitat</th>
<th>Relative vulnerability to climate change</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>1340* Inland salt meadows</td>
<td>fed by groundwater with high content of salts</td>
<td>content of the salts in the groundwater is very high, fluctuation of groundwater is necessary</td>
<td>drainage, abandonment, eutrophication from surrounded fields, changes of hydrological regime on landscape level</td>
<td>highly vulnerable to long-term decline of groundwater level, but well-adapted to droughts</td>
<td>Tóth 2010</td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td>1530* Pannonic salt steppes and salt marshes</td>
<td>fed by groundwater with high content of salts</td>
<td>content of the salts in the groundwater is very high, fluctuation of groundwater is necessary</td>
<td>drainage, abandonment, eutrophication from surrounded fields, changes of hydrological regime on landscape level</td>
<td>highly vulnerable to long-term decline of groundwater level, but well-adapted to droughts</td>
<td>Tóth 2010</td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td>Habitat</td>
<td>Hydrology</td>
<td>Special requirements</td>
<td>Land use threats</td>
<td>Resilience (plasticity) of the habitat</td>
<td>References related to dynamics and ecology of the habitat</td>
<td>Relative vulnerability to climate change</td>
<td>Note</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td>----------------------</td>
<td>-----------------</td>
<td>----------------------------------------</td>
<td>---------------------------------------------------------------</td>
<td>------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>3130 Oligotrophic to mesotrophic standing waters of plains to subalpine levels with vegetation belonging to Littorelletea uniflorae and/or Isoeto-Nanojuncetea</td>
<td>various, they might be fed by surface water from the rivers (lower altitudes) or from the springs or from melting snow (oligotrophic lakes in the mountains)</td>
<td>fluctuation of water level, bare land in dry periods</td>
<td>drainage, river regulations</td>
<td>habitat may profit from droughts</td>
<td></td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>3140 Hard oligomesotrophic waters with bentic vegetation of Chara formations</td>
<td>dependent on surface water with low content of nutrients</td>
<td>ephemeral habitat requiring oligotrophic surface water</td>
<td>drainage, eutrophication</td>
<td>sensitive to water quality, initial habitat in succession series</td>
<td>Hájková and Hájek 2004</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>Habitat</td>
<td>Hydrology</td>
<td>Special requirements</td>
<td>Land use threats</td>
<td>Resilience (plasticity) of the habitat</td>
<td>References related to dynamics and ecology of the habitat</td>
<td>Relative vulnerability to climate change</td>
<td>Note</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>--------------------------------</td>
<td>-----------------------------------</td>
<td>------------------</td>
<td>----------------------------------------</td>
<td>----------------------------------------------------------</td>
<td>------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>3150 Natural eutrophic lakes with Magnopotamion or Hydrocharition type vegetation</td>
<td>dependent on surface water with higher content of nutrient</td>
<td>habitat with relatively broad ecological requirements, sensitive mostly to water quality and amount</td>
<td>river regulation, changes of hydrological regime, eutrophication</td>
<td>dependent mostly on water amount, but also on content of nutrients, but in general dynamic habitat relatively well-adapted to extreme weather events</td>
<td>Oťahelová and Banásová 2005</td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td>3160 Natural dystrophic lakes and ponds</td>
<td>dependent on underground water from springs or on rain water</td>
<td>partly ephemeral habitat of pools on fens</td>
<td>drainage, changes in hydrological regime</td>
<td>highly dependent of water amount, droughts may be harmful for the habitat, if it is not related to spring with deep circulation</td>
<td>Madarás et al. 2012</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>3220 Alpine rivers and the herbaceous vegetation along their banks</td>
<td>dependent on running water and natural dynamics of mountain rivers</td>
<td>preserved river dynamics with occasional floods</td>
<td>river regulation, changes of hydrological regime</td>
<td>habitat dependent on extreme events - regular floods on mountain streams, river regulation or change of flow regime may be very harmful</td>
<td></td>
<td>low</td>
<td></td>
</tr>
</tbody>
</table>
### Table of Habitats and Climate Change Impacts

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Hydrology</th>
<th>Special requirements</th>
<th>Land use threats</th>
<th>Resilience (plasticity) of the habitat</th>
<th>References related to dynamics and ecology of the habitat</th>
<th>Relative vulnerability to climate change</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>3230 Alpine rivers and their ligneous vegetation with Myricaria Germanica</td>
<td>dependent on running water and natural dynamics of mountain rivers</td>
<td>preserved river dynamics with occasional floods</td>
<td>river regulation, changes of hydrological regime</td>
<td>habitat dependent on extreme events - regular floods on mountain streams, river regulation or change of flow regime may be very harmful</td>
<td>Hrivnák et al. 2010</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>3240 Alpine rivers and their ligneous vegetation with Salix eleagnos</td>
<td>dependent on running water and natural dynamics of mountain rivers</td>
<td>preserved river dynamics with occasional floods</td>
<td>river regulation, changes of hydrological regime</td>
<td>habitat dependent on extreme events - regular floods on mountain streams, river regulation or change of flow regime may be very harmful</td>
<td>Hrivnák et al. 2010</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>3260 Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation</td>
<td>dependent on clean, non-polluted running water</td>
<td>clean oxygenized running water</td>
<td>river regulation, changes of hydrological regime, eutrophication</td>
<td>habitat strongly dependent on natural river dynamics, river regulations may be very harmful</td>
<td>Hrivnák et al. 2010</td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td>Habitat</td>
<td>Hydrology</td>
<td>Special requirements</td>
<td>Land use threats</td>
<td>Resilience (plasticity) of the habitat</td>
<td>References related to dynamics and ecology of the habitat</td>
<td>Relative vulnerability to climate change</td>
<td>Note</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------</td>
<td>------------------------------------------------------</td>
<td>-----------------------------------------</td>
<td>-----------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>3270 Muddy river banks with Chenopodium rubri p.p. and Bidention p.p. vegetation</td>
<td>dependent on natural river dynamics bare river banks due to low river flow in dry periods</td>
<td>dependent on river dynamics - bare land of the river banks during drogths</td>
<td>river regulation, changes of hydrological regime</td>
<td>habitat may profit from droughts (more bare river banks), but it may be threatened by river regulations</td>
<td></td>
<td></td>
<td>Loučková 2012</td>
</tr>
<tr>
<td>4080 Sub-Arctic willow scrub</td>
<td>based on areas of snow accumulation and avalanche tracks</td>
<td>moisture from snow</td>
<td>relatively stable habitat, any long-term change of soil moisture may be harmful</td>
<td></td>
<td>Veselá 1995</td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td>6410 Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Molinion caerulea)</td>
<td>fed by fluctuating groundwater, low content of nutrients in the soil</td>
<td>fluctuating groundwater level</td>
<td>well-adapted to significant changes in soil moisture during the season, land use are the most serious threats</td>
<td>Halada et al. 2008</td>
<td></td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>Habitat</td>
<td>Hydrology</td>
<td>Special requirements</td>
<td>Land use threats</td>
<td>Resilience (plasticity) of the habitat</td>
<td>References related to dynamics and ecology of the habitat</td>
<td>Relative vulnerability to climate change</td>
<td>Note</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td>----------------------</td>
<td>------------------</td>
<td>---------------------------------------</td>
<td>------------------------------------------------------</td>
<td>----------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>6430 Hygrophilous tall herb fringe communities of plains and of the montane to alpine belts</td>
<td>fed by groundwater or influenced by floods</td>
<td>soil saturated by groundwater</td>
<td>abandonment, intensification of agriculture, drainage</td>
<td>well-adapted to significant changes in soil moisture during the season, change of land use and eutrophication are the most serious threats</td>
<td></td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>6440 Alluvial meadows of river valleys of the Cnidion dubii alliance</td>
<td>dependent on regular floods regular floods</td>
<td></td>
<td>abandonment, changes of flood regime, transformation to arable land</td>
<td>habitat very well adapted to extreme flood events</td>
<td>Banásová et al 1994, Šeffer et al. 1999, Jarolímk et al. 2000</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>7110* Active raised bogs</td>
<td>dependent mostly on rain water</td>
<td>sufficient water supply from rainfall</td>
<td>drainage, changes in hydrological regime, eutrophication</td>
<td>vulnerability to droughts, risk of fast mineralization of peat after a drop of groundwater level</td>
<td>Hájková et al. 2011, Jakab et al. 2010, Magyari et al. 2001, Hájková et al. 2012</td>
<td>high</td>
<td></td>
</tr>
</tbody>
</table>
## Table: Special requirements, Land use threats, and Resilience (plasticity) of the habitat

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Hydrology</th>
<th>Special requirements</th>
<th>Land use threats</th>
<th>Resilience (plasticity) of the habitat</th>
<th>References related to dynamics and ecology of the habitat</th>
<th>Relative vulnerability to climate change</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>7120 Degraded raised bogs (still capable of natural regeneration)</td>
<td>dependent mostly on rain water</td>
<td>sufficient water supply from rainfall, restoration of hydrological regime (stabilization of groundwater level)</td>
<td>drainage, changes in hydrological regime, eutrophication</td>
<td>vulnerability to droughts, risk of fast mineralization of peat after a drop of groundwater level, lower plasticity than type 7110 due to degradation caused mostly by drainage</td>
<td>Štechová et al. 2012</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>7140 Transition mires and quaking bogs</td>
<td>dependent on mineral-poor groundwater</td>
<td>groundwater nearby the surface during the whole year, low contents of nutrients in the water</td>
<td>drainage, changes in hydrological regime, eutrophication, abandonment</td>
<td>vulnerability to droughts, risk of fast mineralization of peat after a drop of groundwater level</td>
<td>Štechová et al. 2012</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>7150 Depressions on peat substrate of the Rhynchosporion</td>
<td>fed by mineral-poor groundwater</td>
<td>groundwater nearby the surface during the whole year, low contents of nutrients in the water</td>
<td>drainage, changes in hydrological regime, eutrophication</td>
<td>vulnerability to droughts, risk of fast mineralization of peat after a drop of groundwater level</td>
<td></td>
<td>high</td>
<td></td>
</tr>
</tbody>
</table>
### Habitat

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Hydrology</th>
<th>Special requirements</th>
<th>Land use threats</th>
<th>Resilience (plasticity) of the habitat</th>
<th>References related to dynamics and ecology of the habitat</th>
<th>Relative vulnerability to climate change</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>7210* Calcareous fens with Cladium mariscus and species of the Caricion davallianae</td>
<td>dependent on highly-mineralized groundwater</td>
<td>highly-mineralized groundwater nearby the surface during the whole year</td>
<td>drainage, changes in hydrological regime, eutrophication</td>
<td>habitat is strongly dependent on mineralized groundwater, drop of water level may promote fast changes</td>
<td></td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td>7220* Petrifying springs with tufa formation (Cratoneurion)</td>
<td>dependent on highly-mineralized underground water</td>
<td>outflow of mineralized groundwater with high content of calcium</td>
<td>drainage, changes in hydrological regime, eutrophication</td>
<td>habitat is strongly dependent on mineralized groundwater, drop of water level may promote fast changes</td>
<td></td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td>7230 Alkaline fens</td>
<td>dependent on underground water</td>
<td>Underground water level close to the surface during the whole year, minimal fluctuations, calcium-rich water (4 points)</td>
<td>drainage, abandonment, eutrophication, changes of hydrological regime</td>
<td>vulnerability to droughts, risk of fast mineralization of peat after a drop of groundwater level</td>
<td>Hájek et al. (2008), Grootjans et al. (2005)</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>Habitat</td>
<td>Hydrology</td>
<td>Special requirements</td>
<td>Land use threats</td>
<td>Resilience (plasticity) of the habitat</td>
<td>References related to dynamics and ecology of the habitat</td>
<td>Relative vulnerability to climate change</td>
<td>Note</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td>----------------------</td>
<td>-----------------</td>
<td>--------------------------------------</td>
<td>----------------------------------------------------------</td>
<td>------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>7240* Alpine pioneer formations of Caricion bicoloris-atrofuscæ</td>
<td>fed by underground water</td>
<td>outflow of groundwater, sufficient soil moisture during vegetation season</td>
<td>changes of hydrological regime, development of tourism infrastructure</td>
<td>relatively stable habitat, any long-term change of soil moisture may be harmful</td>
<td></td>
<td>medium</td>
<td></td>
</tr>
<tr>
<td>8310 Caves not open to public</td>
<td>created by underground water</td>
<td>preserved water regime on landscape level, no water pollution</td>
<td>Pollution</td>
<td>habitat is less dependent on climate change, because caves has special climate, but it may be influenced by the change of water regime</td>
<td>Siklosy et al. 2009, Rimbu et al. 2012</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>9190 Old acidophilous oak woods with Quercus robur on sandy plains</td>
<td>fed by stagnating rain water (slow run-off of rain water due to a high clay content in the soil)</td>
<td>sufficient rainfall, fluctuating of rainfall</td>
<td>changes of hydrological regime, changes of forest management</td>
<td>habitat is adapted to the fluctuations in hydrological regime, dominant oak may be threatened by droughts</td>
<td>Jamrichová et al. 2013</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>Habitat</td>
<td>Hydrology</td>
<td>Special requirements</td>
<td>Land use threats</td>
<td>Resilience (plasticity) of the habitat</td>
<td>References related to dynamics and ecology of the habitat</td>
<td>Relative vulnerability to climate change</td>
<td>Note</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>----------------------------------------------</td>
<td>-----------------------------------------------------------</td>
<td>-------------------------------------------------------</td>
<td>----------------------------------------</td>
<td>-----------------------------------------------------------</td>
<td>------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>91D0* Bog woodland</td>
<td>fed by stagnant rain water</td>
<td>groundwater nearby the surface during the whole year, low contents of nutrients in the water</td>
<td>drainage, changes of hydrological regime, eutrophication</td>
<td>vulnerability to droughts, risk of fast mineralization of peat after a drop of groundwater level</td>
<td></td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>91E0* Mixed ash-alder alluvial forests of temperate and Boreal Europe (Alno-Padion, Alnion incanae, Salicion albae)</td>
<td>dependent on regular dynamic floods</td>
<td>changes of flood regime, drainage, intensive forestry, change of tree species composition</td>
<td>habitat very well adapted to extreme flood events</td>
<td></td>
<td></td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>Habitat</td>
<td>Hydrology</td>
<td>Special requirements</td>
<td>Land use threats</td>
<td>Resilience (plasticity) of the habitat</td>
<td>References related to dynamics and ecology of the habitat</td>
<td>Relative vulnerability to climate change</td>
<td>Note</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>--------------------------------------------</td>
<td>----------------------</td>
<td>------------------</td>
<td>----------------------------------------</td>
<td>----------------------------------------------------------</td>
<td>-------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>91F0 Riparian mixed forests of Quercus robur, Ulmus laevis, Fraxinus excelsior or Fraxinus angustifolia, along the great rivers of the Atlantic and Middle-European provinces (Ulmenion minoris)</td>
<td>dependent on occasional floods</td>
<td>occasional floods</td>
<td>changes of flood regime, intensive forestry, change of tree species composition</td>
<td>habitat adapted to flood events</td>
<td></td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>91I0* Euro-Siberian steppe oak woods</td>
<td>dependent on stagnating rain water in spring</td>
<td>stagnating rain water in spring, dry conditions during the summer</td>
<td>change of hydrological regime, intensive forestry activities</td>
<td>habitat is adapted to the fluctuations in hydrological regime, dominant oak may be threatened by droughts</td>
<td>Jakubowska-Gabara 1996</td>
<td>low</td>
<td>only partially considered as wetland (oak woods with Potentilla alba)</td>
</tr>
<tr>
<td>Habitat</td>
<td>Hydrology</td>
<td>Special requirements</td>
<td>Land use threats</td>
<td>Resilience (plasticity) of the habitat</td>
<td>References related to dynamics and ecology of the habitat</td>
<td>Relative vulnerability to climate change</td>
<td>Note</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>----------------------------------</td>
<td>--------------------------------</td>
<td>--------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
<td>----------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>9410 Acidophilous Picea forests of the montane to alpine levels (Vaccinio-Piceetea)</td>
<td>influenced by high groundwater level</td>
<td>groundwater close to the surface</td>
<td>intensive forestry activities</td>
<td>vulnerable to changes in water regime, but better adapted to fluctuations of water regime than habitats on organic soils</td>
<td></td>
<td>low</td>
<td>only partially considered as wetland (spruce forests with high groundwater level)</td>
</tr>
<tr>
<td>31A0* Transylvanian hot-spring lotus beds</td>
<td>dependent on geo-thermal water</td>
<td>warm mineralized water</td>
<td>changes of hydrological regime</td>
<td>habitat dependent on local hot springs, weak relation to climate change</td>
<td></td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>92A0 Salix alba and Populus alba galleries</td>
<td>dependent on regular floods</td>
<td>changes of hydrological regime</td>
<td>habitat very well adapted to extreme flood events</td>
<td></td>
<td></td>
<td>low</td>
<td></td>
</tr>
</tbody>
</table>
Annex 121 Region mean NPP climatologies for EM1. Bold numbers indicate best estimates (multimodel averages) for the 3 time slices.

<table>
<thead>
<tr>
<th>Period</th>
<th>Inner Western Carpathians (1)</th>
<th>Outer Western Carpathians (2)</th>
<th>Outer Eastern Carpathians North (3)</th>
<th>Outer Eastern Carpathians South (4)</th>
<th>Transylvanian Plateau (5)</th>
<th>Western Romanian Carpathians (6)</th>
<th>Southern Carpathians (7)</th>
<th>Serbian Carpathians (8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBSERVED CLIMATE</td>
<td>1961-1990</td>
<td>NPP [gC m⁻² year⁻¹]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALADIN-ARPEGE</td>
<td>2021-2050</td>
<td>973</td>
<td>924</td>
<td>906</td>
<td>911</td>
<td>907</td>
<td>932</td>
<td>859</td>
</tr>
<tr>
<td>HIRHAM5-ECHAM5</td>
<td>2021-2050</td>
<td>923</td>
<td>900</td>
<td>932</td>
<td>973</td>
<td>859</td>
<td>829</td>
<td>832</td>
</tr>
<tr>
<td>RCA-ECHAM5</td>
<td>2021-2050</td>
<td>940</td>
<td>1003</td>
<td>951</td>
<td>873</td>
<td>911</td>
<td>905</td>
<td>892</td>
</tr>
<tr>
<td>RCA-HadCM3Q0</td>
<td>2021-2050</td>
<td>938</td>
<td>1008</td>
<td>947</td>
<td>849</td>
<td>879</td>
<td>904</td>
<td>914</td>
</tr>
<tr>
<td>REMO-ECHAM5</td>
<td>2021-2050</td>
<td>899</td>
<td>988</td>
<td>924</td>
<td>838</td>
<td>866</td>
<td>880</td>
<td>851</td>
</tr>
<tr>
<td>REGCM-ECHAM5</td>
<td>2021-2050</td>
<td>925</td>
<td>991</td>
<td>941</td>
<td>851</td>
<td>905</td>
<td>903</td>
<td>876</td>
</tr>
<tr>
<td>multimodel mean</td>
<td>2021-2050</td>
<td>908</td>
<td>977</td>
<td>925</td>
<td>810</td>
<td>887</td>
<td>883</td>
<td>867</td>
</tr>
<tr>
<td>ALADIN-ARPEGE</td>
<td>2071-2100</td>
<td>987</td>
<td>1036</td>
<td>910</td>
<td>931</td>
<td>985</td>
<td>950</td>
<td>975</td>
</tr>
<tr>
<td>HIRHAM5-ECHAM5</td>
<td>2071-2100</td>
<td>943</td>
<td>1081</td>
<td>930</td>
<td>811</td>
<td>876</td>
<td>851</td>
<td>872</td>
</tr>
<tr>
<td>RCA-ECHAM5</td>
<td>2071-2100</td>
<td>1072</td>
<td>1155</td>
<td>1091</td>
<td>967</td>
<td>1026</td>
<td>1025</td>
<td>992</td>
</tr>
<tr>
<td>RCA-HadCM3Q0</td>
<td>2071-2100</td>
<td>1097</td>
<td>1174</td>
<td>1102</td>
<td>979</td>
<td>1041</td>
<td>1056</td>
<td>1035</td>
</tr>
<tr>
<td>REMO-ECHAM5</td>
<td>2071-2100</td>
<td>1053</td>
<td>1130</td>
<td>1066</td>
<td>960</td>
<td>1002</td>
<td>1010</td>
<td>973</td>
</tr>
<tr>
<td>REGCM-ECHAM5</td>
<td>2071-2100</td>
<td>1039</td>
<td>1142</td>
<td>1074</td>
<td>924</td>
<td>1009</td>
<td>1027</td>
<td>1004</td>
</tr>
<tr>
<td>multimodel mean</td>
<td>2071-2100</td>
<td>997</td>
<td>1101</td>
<td>1020</td>
<td>875</td>
<td>947</td>
<td>950</td>
<td>934</td>
</tr>
</tbody>
</table>

Annex 132 The same as Annex 21 but for EM2.

<table>
<thead>
<tr>
<th>Period</th>
<th>Inner Western Carpathians (1)</th>
<th>Outer Western Carpathians (2)</th>
<th>Outer Eastern Carpathians North (3)</th>
<th>Outer Eastern Carpathians South (4)</th>
<th>Transylvanian Plateau (5)</th>
<th>Western Romanian Carpathians (6)</th>
<th>Southern Carpathians (7)</th>
<th>Serbian Carpathians (8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBSERVED CLIMATE</td>
<td>1961-1990</td>
<td>NPP [gC m⁻² year⁻¹]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALADIN-ARPEGE</td>
<td>2021-2050</td>
<td>475</td>
<td>599</td>
<td>527</td>
<td>482</td>
<td>483</td>
<td>500</td>
<td>425</td>
</tr>
<tr>
<td>HIRHAM5-ECHAM5</td>
<td>2021-2050</td>
<td>496</td>
<td>593</td>
<td>521</td>
<td>490</td>
<td>463</td>
<td>458</td>
<td>439</td>
</tr>
<tr>
<td>RCA-ECHAM5</td>
<td>2021-2050</td>
<td>496</td>
<td>599</td>
<td>541</td>
<td>410</td>
<td>436</td>
<td>457</td>
<td>408</td>
</tr>
<tr>
<td>RCA-HadCM3Q0</td>
<td>2021-2050</td>
<td>454</td>
<td>546</td>
<td>488</td>
<td>415</td>
<td>404</td>
<td>445</td>
<td>391</td>
</tr>
<tr>
<td>REMO-ECHAM5</td>
<td>2021-2050</td>
<td>483</td>
<td>599</td>
<td>525</td>
<td>495</td>
<td>480</td>
<td>453</td>
<td>438</td>
</tr>
<tr>
<td>REGCM-ECHAM5</td>
<td>2021-2050</td>
<td>525</td>
<td>608</td>
<td>568</td>
<td>526</td>
<td>524</td>
<td>528</td>
<td>446</td>
</tr>
<tr>
<td>multimodel mean</td>
<td>2021-2050</td>
<td>493</td>
<td>593</td>
<td>536</td>
<td>464</td>
<td>470</td>
<td>490</td>
<td>428</td>
</tr>
<tr>
<td>ALADIN-ARPEGE</td>
<td>2071-2100</td>
<td>525</td>
<td>618</td>
<td>554</td>
<td>532</td>
<td>530</td>
<td>553</td>
<td>471</td>
</tr>
<tr>
<td>HIRHAM5-ECHAM5</td>
<td>2071-2100</td>
<td>466</td>
<td>583</td>
<td>488</td>
<td>346</td>
<td>399</td>
<td>445</td>
<td>404</td>
</tr>
<tr>
<td>RCA-ECHAM5</td>
<td>2071-2050</td>
<td>528</td>
<td>626</td>
<td>530</td>
<td>469</td>
<td>484</td>
<td>492</td>
<td>441</td>
</tr>
<tr>
<td>RCA-HadCM3Q0</td>
<td>2071-2050</td>
<td>532</td>
<td>601</td>
<td>557</td>
<td>464</td>
<td>465</td>
<td>497</td>
<td>427</td>
</tr>
<tr>
<td>REMO-ECHAM5</td>
<td>2071-2050</td>
<td>460</td>
<td>548</td>
<td>503</td>
<td>334</td>
<td>370</td>
<td>425</td>
<td>380</td>
</tr>
<tr>
<td>REGCM-ECHAM5</td>
<td>2071-2050</td>
<td>488</td>
<td>588</td>
<td>537</td>
<td>442</td>
<td>457</td>
<td>478</td>
<td>418</td>
</tr>
<tr>
<td>multimodel mean</td>
<td>2071-2100</td>
<td>512</td>
<td>611</td>
<td>552</td>
<td>465</td>
<td>483</td>
<td>514</td>
<td>442</td>
</tr>
</tbody>
</table>

08/09/2013 Page 278 of 280
### Annex 143 The same as Annex 21 but for EM3.

<table>
<thead>
<tr>
<th>Period</th>
<th>Inner Western Carpathians (1)</th>
<th>Outer Western Carpathians (2)</th>
<th>Outer Eastern Carpathians North (3)</th>
<th>Outer Eastern Carpathians South (4)</th>
<th>Inner Eastern Carpathians (5)</th>
<th>Transylvanian Plateau (6)</th>
<th>Western Romanian Carpathians (7)</th>
<th>Southern Carpathians (8)</th>
<th>Serbian Carpathians (9)</th>
<th>NPP ([gC \text{ m}^{-2} \text{ year}^{-1}])</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OBSERVED CLIMATE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1961-1990</td>
</tr>
<tr>
<td>2021-2050</td>
<td>276</td>
<td>333</td>
<td>291</td>
<td>280</td>
<td>266</td>
<td>293</td>
<td>249</td>
<td>254</td>
<td>217</td>
<td></td>
</tr>
<tr>
<td>2061-2090</td>
<td>231</td>
<td>296</td>
<td>250</td>
<td>197</td>
<td>207</td>
<td>229</td>
<td>197</td>
<td>183</td>
<td>169</td>
<td></td>
</tr>
<tr>
<td>2011-2040</td>
<td>265</td>
<td>316</td>
<td>273</td>
<td>258</td>
<td>244</td>
<td>268</td>
<td>225</td>
<td>238</td>
<td>201</td>
<td></td>
</tr>
<tr>
<td>2051-2080</td>
<td>261</td>
<td>321</td>
<td>282</td>
<td>226</td>
<td>233</td>
<td>252</td>
<td>209</td>
<td>200</td>
<td>177</td>
<td></td>
</tr>
<tr>
<td>2061-2090</td>
<td>240</td>
<td>291</td>
<td>252</td>
<td>218</td>
<td>215</td>
<td>236</td>
<td>203</td>
<td>200</td>
<td>186</td>
<td></td>
</tr>
<tr>
<td>2011-2040</td>
<td>264</td>
<td>325</td>
<td>289</td>
<td>240</td>
<td>267</td>
<td>232</td>
<td>212</td>
<td>234</td>
<td>203</td>
<td></td>
</tr>
<tr>
<td>2051-2080</td>
<td>295</td>
<td>344</td>
<td>369</td>
<td>285</td>
<td>274</td>
<td>298</td>
<td>256</td>
<td>251</td>
<td>217</td>
<td></td>
</tr>
<tr>
<td>2061-2090</td>
<td>256</td>
<td>325</td>
<td>280</td>
<td>233</td>
<td>241</td>
<td>268</td>
<td>234</td>
<td>238</td>
<td>203</td>
<td></td>
</tr>
<tr>
<td>2011-2040</td>
<td>284</td>
<td>340</td>
<td>305</td>
<td>283</td>
<td>273</td>
<td>303</td>
<td>253</td>
<td>245</td>
<td>198</td>
<td></td>
</tr>
<tr>
<td>2051-2080</td>
<td>281</td>
<td>339</td>
<td>312</td>
<td>273</td>
<td>275</td>
<td>303</td>
<td>258</td>
<td>244</td>
<td>223</td>
<td></td>
</tr>
<tr>
<td><strong>multimodel mean</strong></td>
<td>266</td>
<td>323</td>
<td>284</td>
<td>255</td>
<td>246</td>
<td>272</td>
<td>232</td>
<td>228</td>
<td>198</td>
<td></td>
</tr>
</tbody>
</table>

### Annex 154 The same as Annex 21 but for EM4.

<table>
<thead>
<tr>
<th>Period</th>
<th>Inner Western Carpathians (1)</th>
<th>Outer Western Carpathians (2)</th>
<th>Outer Eastern Carpathians North (3)</th>
<th>Outer Eastern Carpathians South (4)</th>
<th>Inner Eastern Carpathians (5)</th>
<th>Transylvanian Plateau (6)</th>
<th>Western Romanian Carpathians (7)</th>
<th>Southern Carpathians (8)</th>
<th>Serbian Carpathians (9)</th>
<th>NPP ([gC \text{ m}^{-2} \text{ year}^{-1}])</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OBSERVED CLIMATE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1961-1990</td>
</tr>
<tr>
<td>2021-2050</td>
<td>786</td>
<td>845</td>
<td>797</td>
<td>728</td>
<td>746</td>
<td>741</td>
<td>721</td>
<td>753</td>
<td>667</td>
<td></td>
</tr>
<tr>
<td>2061-2090</td>
<td>836</td>
<td>908</td>
<td>865</td>
<td>808</td>
<td>853</td>
<td>835</td>
<td>800</td>
<td>827</td>
<td>734</td>
<td></td>
</tr>
<tr>
<td>2011-2040</td>
<td>773</td>
<td>848</td>
<td>821</td>
<td>690</td>
<td>757</td>
<td>765</td>
<td>765</td>
<td>733</td>
<td>687</td>
<td></td>
</tr>
<tr>
<td>2051-2080</td>
<td>794</td>
<td>861</td>
<td>823</td>
<td>758</td>
<td>800</td>
<td>794</td>
<td>771</td>
<td>797</td>
<td>705</td>
<td></td>
</tr>
<tr>
<td>2061-2090</td>
<td>770</td>
<td>824</td>
<td>771</td>
<td>669</td>
<td>752</td>
<td>724</td>
<td>704</td>
<td>744</td>
<td>641</td>
<td></td>
</tr>
<tr>
<td>2011-2040</td>
<td>741</td>
<td>807</td>
<td>767</td>
<td>717</td>
<td>752</td>
<td>727</td>
<td>712</td>
<td>750</td>
<td>666</td>
<td></td>
</tr>
<tr>
<td>2051-2080</td>
<td>766</td>
<td>819</td>
<td>777</td>
<td>723</td>
<td>755</td>
<td>741</td>
<td>709</td>
<td>735</td>
<td>666</td>
<td></td>
</tr>
<tr>
<td>2061-2090</td>
<td>792</td>
<td>846</td>
<td>818</td>
<td>748</td>
<td>784</td>
<td>752</td>
<td>733</td>
<td>774</td>
<td>672</td>
<td></td>
</tr>
<tr>
<td>2011-2040</td>
<td>792</td>
<td>835</td>
<td>810</td>
<td>769</td>
<td>795</td>
<td>769</td>
<td>755</td>
<td>789</td>
<td>699</td>
<td></td>
</tr>
<tr>
<td>2051-2080</td>
<td>750</td>
<td>825</td>
<td>787</td>
<td>730</td>
<td>756</td>
<td>741</td>
<td>701</td>
<td>728</td>
<td>650</td>
<td></td>
</tr>
<tr>
<td>2061-2090</td>
<td>771</td>
<td>838</td>
<td>809</td>
<td>738</td>
<td>783</td>
<td>783</td>
<td>716</td>
<td>746</td>
<td>660</td>
<td></td>
</tr>
<tr>
<td><strong>multimodel mean</strong></td>
<td>779</td>
<td>840</td>
<td>805</td>
<td>735</td>
<td>779</td>
<td>759</td>
<td>737</td>
<td>760</td>
<td>678</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>Inner Western Carpathians (1)</th>
<th>Outer Western Carpathians (2)</th>
<th>Outer Eastern Carpathians North (3)</th>
<th>Outer Eastern Carpathians South (4)</th>
<th>Inner Eastern Carpathians (5)</th>
<th>Transylvanian Plateau (6)</th>
<th>Western Romanian Carpathians (7)</th>
<th>Southern Carpathians (8)</th>
<th>Serbian Carpathians (9)</th>
<th>NPP ([gC \text{ m}^{-2} \text{ year}^{-1}])</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OBSERVED CLIMATE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1961-1990</td>
</tr>
<tr>
<td>2021-2050</td>
<td>823</td>
<td>878</td>
<td>851</td>
<td>795</td>
<td>838</td>
<td>820</td>
<td>782</td>
<td>811</td>
<td>723</td>
<td></td>
</tr>
<tr>
<td>2061-2090</td>
<td>823</td>
<td>855</td>
<td>835</td>
<td>724</td>
<td>787</td>
<td>804</td>
<td>797</td>
<td>772</td>
<td>728</td>
<td></td>
</tr>
<tr>
<td>2011-2040</td>
<td>831</td>
<td>878</td>
<td>836</td>
<td>744</td>
<td>810</td>
<td>798</td>
<td>777</td>
<td>777</td>
<td>727</td>
<td></td>
</tr>
<tr>
<td>2051-2080</td>
<td>779</td>
<td>814</td>
<td>793</td>
<td>752</td>
<td>795</td>
<td>791</td>
<td>748</td>
<td>772</td>
<td>712</td>
<td></td>
</tr>
<tr>
<td>2061-2090</td>
<td>707</td>
<td>759</td>
<td>736</td>
<td>672</td>
<td>715</td>
<td>711</td>
<td>687</td>
<td>703</td>
<td>651</td>
<td></td>
</tr>
<tr>
<td>2011-2040</td>
<td>811</td>
<td>837</td>
<td>823</td>
<td>841</td>
<td>810</td>
<td>780</td>
<td>768</td>
<td>779</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>2051-2080</td>
<td>811</td>
<td>851</td>
<td>830</td>
<td>824</td>
<td>824</td>
<td>804</td>
<td>772</td>
<td>808</td>
<td>707</td>
<td></td>
</tr>
<tr>
<td>2061-2090</td>
<td>850</td>
<td>878</td>
<td>868</td>
<td>806</td>
<td>803</td>
<td>820</td>
<td>795</td>
<td>825</td>
<td>716</td>
<td></td>
</tr>
<tr>
<td>2011-2040</td>
<td>805</td>
<td>841</td>
<td>813</td>
<td>790</td>
<td>810</td>
<td>800</td>
<td>753</td>
<td>789</td>
<td>717</td>
<td></td>
</tr>
<tr>
<td>2051-2080</td>
<td>799</td>
<td>850</td>
<td>821</td>
<td>762</td>
<td>803</td>
<td>785</td>
<td>752</td>
<td>765</td>
<td>709</td>
<td></td>
</tr>
<tr>
<td><strong>multimodel mean</strong></td>
<td>804</td>
<td>844</td>
<td>820</td>
<td>763</td>
<td>804</td>
<td>793</td>
<td>764</td>
<td>790</td>
<td>712</td>
<td></td>
</tr>
</tbody>
</table>
FINAL Report for SR 2 - In-Depth Study on the impacts of
climate change threats on ecosystems

Annex 165 The same as Annex 21 but for EM5.
Period

NPP [gC m-2 year -1]
Outer Eastern Outer Eastern
Western
Inner Western Outer Western Carpathians
Carpathians
Inner Eastern Transylvanian
Romanian
Southern
Serbian
Carpathians (1) Carpathians (2)
North (3)
South (4)
Carpathians (5) Plateau (6) Carpathians (7) Carpathians (8) Carpathians (9)
809
872
823
778
787
803
776
766
745

OBSERVED CLIMATE

1961-1990

ALADIN-ARPEGE
CLM-HadCM3Q0
HadRM3Q0-HadCM3Q0
HIRHAM5-ECHAM5
HIRHAM5-ARPEGE
RACMO-ECHAM5
RCA-ECHAM5
RCA-HadCM3Q0
REMO-ECHAM5
REGCM-ECHAM5
multimodel mean

2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050

956
796
875
905
853
885
927
920
891
914
892

1043
945
983
989
923
975
983
984
973
974
977

971
829
885
916
873
910
936
929
911
928
909

891
667
794
721
748
762
871
838
836
849
798

933
731
823
836
809
852
901
867
858
897
851

951
745
830
807
810
848
892
865
877
897
852

924
773
843
817
815
834
876
887
843
868
848

929
736
881
815
829
820
895
897
840
863
850

859
700
792
747
790
765
815
838
776
813
790

ALADIN-ARPEGE
CLM-HadCM3Q0
HadRM3Q0-HadCM3Q0
HIRHAM5-ECHAM5
HIRHAM5-ARPEGE
RACMO-ECHAM5
RCA-ECHAM5
RCA-HadCM3Q0
REMO-ECHAM5
REGCM-ECHAM5
multimodel mean

2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100

961
890
924
984
854
939
1037
1062
1025
1013
969

1061
1041
1054
1054
938
1071
1113
1131
1094
1100
1066

989
926
915
993
883
1007
1052
1065
1032
1046
991

907
713
800
844
700
838
937
959
943
917
856

957
798
861
938
767
910
990
1010
977
987
920

963
814
838
942
801
889
996
1034
989
1013
928

943
829
857
911
785
880
962
1006
947
979
910

955
790
882
906
766
853
962
1009
955
937
901

871
748
807
812
780
805
882
908
884
898
840

Annex 176 The same as Annex 21 but for EM6.
Period

NPP [gC m-2 year -1]
Outer Eastern Outer Eastern
Western
Inner Western Outer Western Carpathians
Carpathians
Inner Eastern Transylvanian
Romanian
Southern
Serbian
Carpathians (1) Carpathians (2)
North (3)
South (4)
Carpathians (5) Plateau (6) Carpathians (7) Carpathians (8) Carpathians (9)
789
871
827
756
775
766
739
755
689

OBSERVED CLIMATE

1961-1990

ALADIN-ARPEGE
CLM-HadCM3Q0
HadRM3Q0-HadCM3Q0
HIRHAM5-ECHAM5
HIRHAM5-ARPEGE
RACMO-ECHAM5
RCA-ECHAM5
RCA-HadCM3Q0
REMO-ECHAM5
REGCM-ECHAM5
multimodel mean

2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050
2021-2050

801
743
762
741
707
739
774
759
732
755
751

876
811
834
808
763
799
829
815
814
826
817

834
782
794
757
737
760
800
785
777
803
783

784
670
736
649
693
703
737
744
718
728
716

818
724
771
726
723
737
770
768
744
775
755

800
739
755
690
697
718
735
735
731
740
734

764
727
730
667
677
681
708
720
679
703
706

797
704
764
690
716
707
752
758
711
729
733

697
651
662
605
631
634
640
661
612
635
643

ALADIN-ARPEGE
CLM-HadCM3Q0
HadRM3Q0-HadCM3Q0
HIRHAM5-ECHAM5
HIRHAM5-ARPEGE
RACMO-ECHAM5
RCA-ECHAM5
RCA-HadCM3Q0
REMO-ECHAM5
REGCM-ECHAM5
multimodel mean

2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100
2071-2100

774
776
782
734
659
762
767
795
761
765
757

822
804
826
777
707
792
809
833
805
813
799

803
789
789
760
691
781
789
821
774
791
779

757
706
713
727
642
752
760
771
748
740
732

792
753
771
761
676
771
782
811
769
776
766

765
772
759
750
669
758
754
782
753
757
752

728
752
740
703
642
719
715
752
697
713
716

764
738
734
737
661
738
759
787
744
732
739

672
690
678
670
606
688
654
668
668
662
666

08/09/2013

Page 280 of 280

