UKRAINE

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Study of climate change impact on forest ecosystems, and the development of adaptation strategies in forestry

Ukraine has created and continues to develop a national legislative and regulatory basis relevant to the issue of climate change (Appendix 1). As Ukraine spans five different natural zones and the country is characterized by a variety of ecosystems, the impact of climate change on forests may manifest itself in different ways in different natural zones and at the sub-regional level. This is why contradictory opinions abound on the effects of climate change impact on forests. As an example, Professor Y. Didukh notes that a temperature increase by only 1°C in the conditions of Ukraine results in a 160 km shift in the latitudinal borders of the natural zones. The temperature increase caused by warming will result in increased moisture evaporation from the soil surface. This may result in desertification on the sand dunes of the forest zone (Polesye). In the forest-steppe and steppe zones, climate change will intensify the decomposition of humus and this will result in less humus content in soils and in decreased soil fertility. The level of water surfaces in the south of Ukraine may rise, so will the amount of precipitation, and this will aggravate flooding processes. This, in turn, will result in bogging and salinization of areas, with a negative impact on not only the forests and agricultural production, but also on the quality of life of the population.

The main results of the empirical observations and the climate change forecasts in Ukraine are presented in Appendix 2. One of the first results of a complex assessment of climate change effects on the forestry of Ukraine were obtained within the framework of the international US Aid Programme to developing countries with economies in transition, designated for climate change studies – US Country Studies Program.

The selection and analysis of various climate change scenarios, developed with the use of simulation studies, plays an important role in the research process. The climate change forecast for the conditions of Ukraine was made using four models: CCCM (Canadian Climate Centre Model; sensitivity to doubled atmospheric CO_2 concentration = 3.5°C), GFDL (Geophysics Fluid Dynamics Laboratory model; sensitivity to doubled atmospheric CO_2 concentration = 4.0°C), GISS (Goddard Institute for Space Studies model; sensitivity to doubled atmospheric CO_2 concentration = 4.2°C), and UKMO (United Kingdom Meteorological Office model; sensitivity to doubled atmospheric CO_2 concentration = 3.5°C).

According to the simulation results obtained, a temperature increase is forecast for all seasons of the year on the premise of doubled CO_2 concentration in the atmosphere. Thus, according to the scenarios, developed on the basis of CCCM and GISS simulations, the air temperature will increase most significantly in the winter, and according to GFDL and UKMO it will increase in the spring. According to the last two scenarios, the warming in Ukraine will increase from south to north and will be the greatest in the north, in the region of Ukrainian Polesye during the winter and spring seasons. Under all the 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 was examined through the assessment of changes at the level of forested regions of Ukraine, areas of main forest-forming species, and forest ecosystems on the territory of Ukraine, together with social, ecological and economic changes in the forestry sector. The forest climate indicators were modelled using D.V. Vorobjov's method. According to this method, the forest climate type is a function of heat and moisture

availability on the territory where the forest is growing. Heat availability (T) and moisture availability (W) are determined according to the following formulas:

- $T = \Sigma Ti$, where Ti is the sum of average monthly air temperatures for the months with above-zero temperatures; and
- $W = P/T - 0.0286*T$, where P is the amount of precipitation for the months with above-zero temperatures.

The generalization of the simulation results showed that due to the temperature mode change, humidity modes and climate continentality changes, the borders of the forest-growing regions and areas will change. Climate change will expand these areas and will contribute to the extension of species with large amplitude, while poorly adapted species with narrow ecological amplitude will diminish and possibly become extinct. Together with the changes in the areas of Ukraine's main forest-forming species, the changes in the forest-growing regions will determine the regional character of the changes in forest ecosystem structures and their biological productivity. At the forest phytocenose level, changes will be seen in dominant species replacement trends, in the storied structures of the timber stands, in growth dynamics and in the stability of plantations.

According to the climate change forecast under the CCCM simulation, considerable warming will take place. The greatest changes in average monthly temperatures are forecast for the southern part of the forest-steppe and steppe zones. The greatest decrease in precipitation is expected in the steppe zone, while the average yearly precipitation amount will increase in the north and north-west of the country. The climatic conditions determining the forest vegetation zones will move towards dryer and warmer types. Possibly, a zone of warm dry woods, widespread in central United States of America, will appear here and this will be quite unusual for Ukraine. The forest growth conditions in the steppe zone will be similar to the steppe conditions of Spain. The Crimean peninsula will see conditions appear that will be suitable for the growth of subtropical thorn woodland forests. The moderate warm dry forest zone will occupy the territory of the current forest-steppe zone and partially the territory of the forest zone. In the northern part of the country (forest zone of Polesye), a region with a considerably warmer climate will develop, which will result in unfavourable conditions for the main forest-forming species. Simulation of the dynamics of the areas of the main forest-forming species shows that as a result of climate change the forest acreage may decrease by 47%.

The GFDL climate change forecast model indicated that the climate will become considerably warmer throughout the Ukraine, and the greatest change will take place in the southern part of the forest-steppe and the steppe zones. Most of Ukraine will see a strong xerophytization of forest localities, especially in the south of the country, where precipitation will decrease by 180 mm. At the same time, precipitation in the northwest will increase by 20 mm. The temperature gradient between the warmest and the coldest month will increase considerably: 34°C in the west and >41°C in the northeast, i.e. the climate will become more continental. This will lead to the formation of a steppe and desert ecology on a considerable part of Ukraine; areas suitable for forest growth will remain only in the western part of Polesye. In the steppe and the forest-steppe zones, the climate will change from cold to moderately warm. When the borders of the non-forest territories shift towards the northwest, the growth conditions for the existing tree species will deteriorate and unfavourable climate conditions will be established for all major forest-forming species. Similar climatic conditions for the preserved forest lands may be found in the Almaty region, in Western Jungaria, in Altai and Winnipeg (Canada). The climate of the eastern Pyandj valley in Eastern Turkmenia corresponds to the climate of non-forested territories. According to the bioclimatic potential, the forecast of the GFDL simulation is the most favourable for forests, due to the increased continentality and strong climate aridization the average increase throughout Ukraine will decrease by 2 m^3/ha.

The climate change forecast according to the GISS model is also most favourable for forests. A moderately cold and humid forest climate spreads over the entire territory of Ukraine, except for the northern part of the Crimean peninsula and the southern part of the country, where a moderately warm dry climate will prevail. The climate continentality will decrease and this will favourably affect growth and productivity of forest vegetation. As to the bioclimatic potential change, this forecast is the most favourable one for forest growth and development, with forest crop growth across Ukraine increasing by 2.6 m^3/ha. However, it is relevant to note that the currently dominant species will continue to grow in the changing conditions, but during the adaptation period their condition may deteriorate.

The climate change forecast according to the UKMO simulation showed that in the forest and the forest-steppe zones of Ukraine the climate will become slightly more humid and the temperature mode will hardly change. In the steppe zone, especially in the Crimea, the climate will become significantly warmer and its humidity will change little. An unrealistic picture is formed in relation to the continentality of the climate: in the southern part of the steppe, the average monthly temperature gradient between the warmest and coldest months changes by ca 3°C per degree of latitude. In general, the distribution of forest and non-forest lands will not significantly change, although the variability of the climatic conditions will increase. The forest zone will shift towards the southeast; this will result in shrinking of the border between the steppe forest developments in favour of forest lands. Among new climatic conditions for Ukraine, one can note the appearance of a moderately cold wet forest zone. A moderately warm dry forest zone will be formed in the south of the country. The areas of main forest-forming species will decrease drastically. In general they will shift to the northwest, conditioned by the increase of climate continentality. As to change in bioclimatic potential, this forecast takes an intermediate position among the others. In the north of the country (in the forest zone) growth, on average, will increase by 0.07 m^3/ha, in the forest-steppe by 0.13 m^3/ha, in the steppe by 0.93 m^3/ha, and on average throughout Ukraine by 0.38 m^3/ha.

A multi-criteria forest sector assessment matrix has been developed in order to assess the effects of climate change on forestry, incorporating the principles, criteria and indicators that characterize ecological, social and economic aspects of forestry. A semantic model of functional response of the forest sector to the climate change was also developed, which enabled statistical data logging that characterizes the forest sector and the forestal climatic indicator dynamics change simulation, represented by a geographical information system (GIS) as well as the creation of maps of forest-typological indicators.

The generalized results of the climate change impact assessment on the forest sector show that when the GISS and UKMO scenarios are implemented, the revenues of the forest sector of Ukraine will increase by 28.2% and 10.3%, respectively, while under GFGL and CCCM scenarios revenues will decrease by 43.1% and 39.8%, respectively. Such different results from the four (CCCM, GFDL, GISS and UKMO) simulations indicate that these simulations have not been sufficiently adapted for Ukraine. In order to improve the forecasts it is necessary to verify these simulations through consideration of the climate of Ukraine. Such work should be conducted in parallel with the development of national models and climate change scenarios. The experts of the Ukrainian Research Institute for Hydrometeorology have selected for Ukraine the most appropriate 10 out of 23 global general atmosphere circulation simulations, which were used in the Coupled Model Intercomparison Project, Phase 3 (CMIP3 model). However, even these selected models generate differently directed forecasts for precipitation in the 21st century, and are significantly different. The least significant changes in the precipitation mode are forecast by the use of the B1 scenario. Except for the middle of the century, when precipitation may decrease by 0.3%, for all other decades an insignificant precipitation increase is forecast, up to 2.3%, with a final value of 1.8±5.1%. As far as the temperature is concerned, all the simulations forecast a tendency to increase in the 21st century, but the degree of such increase is very different for

different simulations. For the next decade, the simulations forecast both temperature increases up to a maximum of 0.7°C (B1; CGCM3.1-T47), and a decrease of 0.8°C (A1B; UKMO-HadGEM1). By the end of the 21st century, all the simulations forecast average temperature increases for the entire territory of Ukraine relative to 2001–2010, ranging from 0.7° up to 3.0°C (with an average value of 2.0±0.8°C) for scenario B1; ranging from 2.4° up to 4.2°C (with an average value of 3.1±0.7°C) for A1B; and ranging from 2.6° up to 4.6°C (with an average value of 3.8±0.8°C) for A2.

The use of several simulations combined (a set of simulations) is also one of the simulation improvement methods. The research by Professor A.Z. Shvidenko on assessment of climate impact using a number of scenarios of an international group of climate change experts (IPCC scenarios A1F1, A2, B2, B1) shows that during the period to 2030, growth conditions will deteriorate for the eastern European forests. The main effects of this impact will be:

- The growing areas of several species will change due to changes in natural zone borders, and in certain cases certain productive species will disappear completely.
- The modes, the types, the intensity and the impact frequency of various perturbation factors (insects, diseases, fires, etc.) will change.
- Changes will take place in the balance of nutritional elements.
- Certain (mostly negative) changes in stability and viability of forest ecosystems will take place, mostly in the productivity of forest tree and non-tree plants.
- The effectiveness of forest ecosystem ecological functioning will also change, in particular influences on biochemical cycles, biological diversity, etc.
- There will be changes in forest species reproduction cycles, succession dynamics, and forest ecological and social functions.

These effects will have an impact on the forests of Ukraine to various degrees. In particular, effects will depend on the natural zone and on forest growth conditions. So far, Ukraine has little actual data on climate change impact on forest plantations (in terms of changing reserves, sustainability, dieback and restoration of forests) as no special climate change studies have been conducted in forests.

As the anticipated climate changes in their entirety will negatively affect both the forest and the forests' ecological functions, forestry should use measures to adapt and to attenuate the impact of climate change. At present, adaptation measures for the economy sectors (including the forest sector) are under development. The Ministry for the Environment of Ukraine (Minprirody of Ukraine) in 2009 initiated a scientific study “The research of the economy sectors’ vulnerability to the climate change and the definition of adaptation measures”. In addition, the Technical Aid to the Commonwealth of Independent States (TACIS) – Support to Kyoto Protocol Implementation project started in late 2008, with the aim of developing climate change mitigation strategies and the corresponding adaptation measures. According to the national action plan for the implementation of the Kyoto Protocol provisions within the UNFCCC, in 2010 it is planned to develop a national action plan to adapt to climate change, and in 2011 to develop corresponding regional action plans, which take into consideration country regional specifics.

Taking into consideration that the forests of Ukraine perform primarily ecological and social functions, adaptation measures should be based on sustainable development principles and cover not only the forest sector, but also the related economic sectors, particularly the energy sector, industry, agriculture and tourism. The adaptation strategy should aim to minimize the negative consequences of climate change, and to support ecological and productive functions of the forests through supporting their role in the biochemical cycles, biodiversity, agricultural landscape protection, soil and water protection, production of wood and non-wood forest products, recreational and other social services.

Various aspects of climate change impact on forest ecosystems have been studied by local scientists, including on acerose leaf and leaf-eating insects. V.L. Meshkova has developed a phenology theory, according to which the differences in the population dynamics of acerose leaf and leaf-eating insects are explained by differences in speed and conditions of seasonal development of phytophages and the feed species, as well as on the entomophages and phytophages, and that in turn is determined by the ratio of period and speed of air heating and soil thawing in the spring. Here, forest insects serve as a good indicator of climate change and the research of their development dynamics becomes of valuable theoretical and practical value. For the development of poikilothermic organisms, it is not the temperature that is the critical value, but its rate of increase in spring. The measures of the temperature increase speed are the dates of the established transition over 0, 5, 10 and 15°C. In comparison with the period 1961–1990, the dates of stable air temperature transition above 0°C became earlier by 20 days in the steppe, by 15 in the forest-steppe and by 19 in Polesye. The stable air temperature transition dates over 5°C became earlier in these zones by 6, 2 and 3 days, and the transition over 10°C by 3, 7 and 5 days, respectively. Reflecting this, earlier appearance of larvae feeding in the early spring was noted. Thus, the birth of the armyworm of the winter geometer moth and the larvae of red conifer sawfly in the Kharkov region in the 1970s to 1980s was noted not earlier than the third week of April, but during the outbreak in 2001–2003 it was 10–13 April. At the same time, the dates of stable autumn transition of air temperature over 10°C were noted earlier: by one day in the steppe zone, by two days in the forest-steppe zone, but unchanged in Polesye. The dates of stable air temperature transition over 5°C have greatly changed in the steppe, where this phenomenon takes place six days earlier, while in the forest-steppe and in Polesye it is two days earlier.

For climate condition comparison of various regions or with the same region during different years, a climatogram creation method is used that takes into consideration precipitation distribution during the year and its connection with seasonal temperature changes. The climatograms according to Valter-Bremer-Gossen (or Valter's diagrams) allow one to describe the ecological conditions of a certain point or a region, comparing the measurements of average multiple year indicators for different time intervals. They were used to compare different climate change scenarios and the impact of such changes of acerose leaf and leaf-eating insects. The main factors influencing the development of acerose leaf and leaf-eating insects during climate change are:

- The change in survivability of the acerose leaf and leaf-eating insects (may take place as the result of the direct impact of changed weather conditions, increased or decreased optimal temperature period duration, frequency of late spring or early autumn frost, changes in the viability of the forage plants and of the entomophages, or competition with other species for food and habitat).
- Larval feeding conditions change (under the influence of climate change, species viability changes, as do their development speed and their reproductive potential).
- Changes in an area's borders (as the result of changes in hibernation conditions, hot periods, increased survivability of insects as a result of developments during earlier stages or due to decreased action of regulatory abiotic or biotic factors, lack of feeder crops within the limits of the previous area, and development de-synchronization with food sources).
- A seasonal development change in insects (due to vegetation period change).
- The dendroflora stability levels change because of damage caused by the insects (insect injuriousness level change).

The results of the climate change impact on the acerose leaf and leaf-eating insects allow one to conclude that, due to the earlier coming of spring, the acerose leaf and leaf-eating insect incubation shifted to an earlier date. A tendency toward greater tree vulnerability caused by insect infestations from spring to late summer has been observed. Insect miner species have spread significantly over the last few years, and are the insects that produce several generations during a year and are natural successors to open leaf-eating insects, playing an important role in weakening

trees. Increased aridity also weakens trees and aggravates insect damage; decreased continentality contributes to decreased vulnerability of the trees to winter frosts and to summer heat.

The study on climate change effects on Ukraine's forest resources was conducted within the framework of the EU Inco Copernicus programme (SCEFORMA project). The European forest institute, EFISCEN, conducted a forest resources dynamics scenario analysis for Ukraine's forests under climate change. The EFISCEN Model provides the opportunity to study the development of forest resources by classifying plantations by age, reserves and increment; it also allows taking into consideration parameters affecting forests, such as forest management activities, and environment changes in terms of plantation increment changes. The increment change calculation is performed on the basis of the national forest monitoring data, obtained through the ICP Forests Level I station network and the European intensive forest monitoring stations network (EU-EVROFLUX). Thus, the climate change scenarios were taken into consideration that had been were obtained on the basis of six different simulations tested at 13 experimental sites in Europe (within the framework of the project LTEEF-II) (www.efi.int/portal/virtual_library/databases/efiscen/projects/lteef-ii). These scenarios were used to forecast changes for Ukraine's forests, similar to those described earlier for GISS and UKMO models.

The base information was used to characterize this country's forests as of 1 January 1996, the condition of the forests and the probable forest harvesting levels, which were simulated for stable climatic conditions and for climate change to 2050. The simulation results showed that if forest harvesting levels are maintained within the framework of the existing forest management system, then by 2050, due to change in the age structure of the forests, the yearly forest harvesting volumes might amount to 11 million m^3/yr. If the forest harvesting modes are adapted to climate change and are directed at multi-functional forest use, than by 2050 the yearly stable forest harvesting volumes could reach 22 million m^3/yr, due to more effective use of the forest increment.

The results of the EFISCEN model for simulation and for assessment of various forest management strategies (modes) impact on the state of forest resources and on the accumulation of CO_2 in the forests of the State Forest Management Committee (Goskomles) of Ukraine are presented in Table 1.

Table 1. Forest resources dynamics forecast under current and multi-functional forest management.

Indicators	Forest management mode	2010	2015	2020	2025	2050
Annual increment, m^3/ha	Existing	4.9	4.7	4.6	4.4	3.7
	Multi-functional	5.0	4.8	4.7	4.5	4.2
Average reserves, m^3/ha	Existing	267	280	293	305	353
	Multi-functional	265	277	287	295	308
Carbon reserves, t/ha	Existing	95	99	104	108	125
	Multi-functional	94	98	102	104	109
Total reserves, million m^3	Existing	1455	1526	1597	1662	1924
	Multi-functional	1444	1510	1564	1608	1679
Carbon reserves, million tonne	Existing	515	540	565	588	680
	Multi-functional	511	534	553	569	594

The assessment of the consequences of various climate change scenario implementation for forestry was developed in a study within the framework of the International US Aid for climate change research in the developing countries and in the countries with economies in transition (US Country Studies Program). The scenario analysis results were used in the creation of the first

national report. The comparison of various scenarios showed that the most favourable changes for forestry are expected under the GFDL model scenario implementation, and the most favourable scenario for the implementation would be GISS and UKMO models. If the CCCM model scenario is realized, then the most vulnerable functions of the forests will be: recreation, preservation of biodiversity, and maintenance of social functions, which will decrease by 62%, 60% and 56%, respectively, in comparison with the present state. Under this scenario, the least vulnerable activity will be transfer of agricultural lands to be used as forest lands on the territories that are highly contaminated by radionuclides, as well industrial supply of biomass to the wood and paper industry, and the absorption of CO_2 that will decrease rather insignificantly in comparison with the current state of affairs (by 11% and 15% respectively).The following measures are recommended to be used as adaptation strategies options for the forest sector during the climate change:

Forestry-based: The improvement of forest protection methods against wildfires; the application of more advanced measures aimed at forest protection against pests; the introduction of resistant tree species, supporting the highest productivity in the forecast climatic conditions.

Scientific and technical: The development of forest condition diagnostic and forecasting methods; modernization of the information support system to be used for making forest management decisions; the development of the scientific and methodological knowledge base for forest protection against pests and diseases; increased scientific research work dealing with the selection and introduction of new forest species, resistant to the forecast climate changes.

Legal and administrative: Development of regulatory mechanisms that establish the principles of the forest management system, and which take into account the effects of climate change; increase in forest user responsibility for forest preservation; creation of a stimulus system aimed at supporting forest management activity directed at supporting social and ecologically important functions of the forests.

Financial: Establishment of insurance and reserve funds to be used for compensation of forest management activity expenses under the conditions of climate change.

It is crucially important that adaptation strategies be based on principles of sustainable forest management. For the implementation of sustainable forest management principles in practice, it is necessary to conduct personnel training and support sustainable forest management systems. For this purpose, forest certification can be used as a practical tool.

According to the results of research conducted in different countries, forest biomass and soils contain about 50% of the total carbon of the land ecosystems; thus forests at present absorb slightly more than a quarter of the total anthropogenic emissions, and this is considered one of the most important ecosystem services in the context of changing climate. The correlation between the anthropogenic emissions and the absorption of GHGs by the forests in Ukraine differs considerably from the average statistical global indicators. The forests of Ukraine during 1990–2008 absorbed on average less than 10% of the total amount of anthropogenic emissions, and this is related to the considerable emissions of GHGs in the country and to low forestation levels. Only 15.7% of the territory of Ukraine is covered with forests (at least three times less than the average forestation level in Europe).

As absorption of GHGs by forests is one of the most important methods to decrease atmospheric GHG concentrations and to reach the goals set by UNFCCC, Ukraine has to broaden its research in this field. The system approach principles were used for the development of theoretical foundations and for the regulatory-informational support system, used for the assessment of the forest phytomass above-ground components, as well as mathematical simulations and algorithms

for GHG inventory and for the carbon balance forecast. The scientific, methodological and practical issues related to GHG inventory in forest management and in land use are discussed in a number of works.

Forest cultivation and forest restoration activities are extremely promising for Ukraine in its efforts to implement the resolutions of UNFCCC and its Kyoto Protocol. Historically, it turned out that Ukraine has a significant potential for the execution of joint projects in national forestry. Ukraine, being one of the less-wooded countries in Europe, has the priority task to increase the forest cover of its territory. The specific proportion of forest land in different natural zones of the country varies from 3.9% to 51%, but in none of these natural zones does it reach an optimal level, i.e. the level when the forest influences in the most effective way the climate, soil, and water quality, and delivering to society important resources, such as wood and non-wood products. According to the UkrNIILHA calculations, the optimal forest coverage on average for Ukraine equals 20%. In order to reach such a level of forest coverage, it will be necessary to create about 2 500 000 ha of new forests. According to the data of the Ukrainian Academy of Sciences, about 10 million hectare of land have to be transferred from agricultural lands to be used for forest cultivation and for the organization of groves according to ecological and economic considerations.

The state target programme "Ukraine's forests 2010–2015" makes provision for the cultivation of new forests covering about 430 000 ha. According to the preliminary results, these new forests by 2015 will contain about 1.5 million tonne of carbon.

Within the framework of "The Initiative for Climate Change Issues" activity, there were training and educational programmes developed for forest management specialists as well as methodological materials for project preparation, aimed at increasing GHG absorption during forest management activities. Several seminars were conducted in various regions of the country, where local specialists together with national and international experts identified potential forest cultivation projects in the formats approved for joint Kyoto Protocol projects. The first practical work on forest cultivation and on forest restoration with the purpose of absorbing GHGs were conducted within the framework of preparation and development of the BioCarbon project "The Creation of Protective Forest Plantations on Lands Contaminated by Radionuclides in the Conditions of Ukraine's Polesye". In Ukraine's forest zone (Polesye) on the land contaminated by the radionuclide of Kiev and Zhitomirsky regions there were several carbon-sequestration plantations created on an about 4 400 ha.

The results of this special research testify that the creation of new forests in Ukraine, especially in the forest-steppe zone, is an effective and low-cost method to absorb CO_2. Relatively low expenses for the creation of the new forests in Ukraine and favourable natural conditions for their growth and development create attractive perspectives for the implementation of CO_2 sequestration projects in forestry. Ukraine has considerable potential for the execution of forest management measures, aimed at attenuating climate change and this potential can be realized at a relatively low cost.

Current and planned research activity on climate change impact on forests and forestry

The Ministry for the Protection of Environment (www.menr.gov.ua) is the national coordinator for activity dealing with climate change in Ukraine (including research). Using state budget funds and other financing sources (including foreign), the Ministry of Natural Resources (Minprirody) of Ukraine organizes the execution of scientific research on the basis of an open tender. In 2009, within the framework of a public contract, a certain number of researches on climate impact issues were to be performed, including a "Study of Vulnerability of the Sectors of Economy to

Climate Change and the Definition of Protective Measures", "Analysis of the potential decrease in GHG emission for the period beyond 2012", and "Development of a National Strategy Project for Ukraine on the Issues of Climate Change for the post-Kyoto Period". Activities also included work related to the creation of a GHG inventory for the next national communication of Ukraine to the Secretariat of UNFCCC.

At present Ukraine does not have a separate research programme to study the scale and effects of climate on forest ecosystems and on forestry in the country. A number of issues, related to climate change problems in forestry are being studied in the main forest institution of Ukraine, the Ukrainian Scientific-research Institute for Forest Management and Agricultural Melioration, named after G.N. Vysotsky (UkrNIILHA, www.uriffm.org.ua). UkrNIILHA reports to the State Committee on Forestry of Ukraine (Goskomleshoz) and to the National Academy of Sciences of Ukraine. This institute performs fundamental and applied studies at local, regional, national and international levels. The scientific research plan for the next five years stipulates study of various issues dealing with climate change influence on the national forests.

In order to study the climate change impacts on forest ecosystems, UkrNIILHA conducts studies on the improvement of dynamic simulation of forest growing conditions for climate change assessment, which is based on the forest climate typology classification of Professor D.V. Vorobjov. Applied means for the analysis of forest growing condition changes during climate change are also being developed, which are based on GIS technologies. In the future, climate change issues will be studied within the framework of various aspects of forest management studies; in particular, these issues will be included in the prospective plans for scientific and research works, performed by UkrNIILHA and covering the issues of forest monitoring, forest protection, forest cultivation and forest restoration.

However, there are certain problems with the source climate data and with the climate change indicators scenarios (temperature and precipitation change forecasts for the country), which should be received from the climatologists to be used in forest management studies. The Ukrainian Scientific-research Hydrometeorological Institute (www.uhmi.org.ua) performs research and development of the national climate change forecasts. It was expected that 2010 would see new and improved national forecasts, with climate change scenarios developed for the entire country. Such forecasts and scenarios are then supposed to be used for research in different sectors of the economy, and in particular in forestry.

One of the barriers delaying research on climate change impact on forests is an outdated information system for the forest management industry of Ukraine. The database is not sufficiently developed and precludes GIS use in forestry management. The forestry management databases with forest survey descriptions and the forest maps are interlinked, they are not topological, and they have no geographical connection, with the information stored in formats that are not compatible with modern GIS technology. The forestry management information on the nation's forests have different levels of completeness, the best information exists for forests under the management of Goskomles (State Committee for Forests) of Ukraine (about 68% of the country's forests). For all other forests, information is poor, making it more complicated to perform analyses at a national level. The most complete official forest statistics for all of Ukraine's forests reflects their state as of 1 January 1996, and these data have formed the basis for research on climate change impact on the forests of Ukraine; hence there is an urgent need to update all the databases in order to properly adjust all the relevant preliminary assessments.

Because of the need to assess the scale of climate change impact on the forests, UkrNIILHA has developed scientific and methodological approaches to modernize the forestry management information support systems. Such approaches include the development of inventory and forest monitoring methods, implementation of new information and geo-information technologies,

including mobile geo-information systems, modern instruments for measurement, software-hardware systems, and means of remote Earth probing. In order to improve the forestry management information support systems in Ukraine it is crucial to use a modern knowledge base and current information gathering and management technologies. International cooperation plays an important role in this regard. In view of the requirement to harmonize information gathering and processing systems, which provide the information about forests, Ukraine is developing a forest monitoring system and performing preparatory work to conduct a national forest inventory based on selective statistical methods. At this stage, one very important element for the development of forest inventory and monitoring systems for Ukraine is the use of foreign and international expertise in developing such systems. In this regards, FAO support is of utmost importance for Ukraine, coupled with support within the framework of international cooperation from other organizations.

In 2007, Ukraine, with UNDP, developed a project idea and submitted an application for execution through GEF, on "The Improvement of Adaptation Opportunities of Ukraine's Forest Sector to Climate Change". Project premises included:

- Cooperation in the execution of a complex forest ecosystems and forestry management vulnerability assessment in Ukraine on the basis of new knowledge and modern simulations.
- Assistance in the development of a national forestry management adaptation strategy of Ukraine under climate change.
- Assistance in the improvement and modernization of the forest inventory and monitoring system of Ukraine.

Unfortunately, application was not approved for funding. Irregular and insufficient financing of scientific research is one of the main obstacles to implementing a system-based study of climate change in forestry.

Priority directions for future research

The studies so far conducted on problems associated with climate change impact on the forests of Ukraine have predominantly been within the framework of international programmes and projects (Appendix 3). Thus, as a rule, the studies were performed in the format of pilot research with the use of different methods and simulations, which were not always verified and adapted to the conditions of Ukraine. The forest statistics and forest organization data used for these studies were outdated, and so the validity of the results are dubious now.

Nevertheless, the studies conducted allowed the development of a number of methods, approaches and simulations that enable significant improvement in the quality of climate impact assessment on the forests, and created good pre-requisites for a more detailed study of the climate impact effects in forestry in Ukraine. At the present time, the necessity exists to conduct climate impact studies at a new methodological level, with the use of new scientific and statistical data, simulations, knowledge and experience, obtained during the previous years.

The existing plans for scientific research in Ukraine include the study of separate aspects of climate change effects in the forestry sector, but thus far there are no complex scientific research programmes on issues of climate change impact on forest ecosystems and on the forestry of Ukraine. Separate studies on this issue are insufficiently coordinated and are poorly linked with other work in this area being conducted at international level.

In order to reinforce research on the issues of climate change in the forestry of Ukraine, a complex programme is needed involving climate change impact studies on forest ecosystems and on the forestry sector, where the priority directions for the research should be determined clearly,

together with responsible executors and financing sources. The following are topics that might be considered a research priority:

- The development of methods and forecast simulations and scenario analysis of climate change impact on forest ecosystems and on forestry, by
    - improvement of the climate change forecast simulations methods for Ukraine and for its separate regions, the development of regionalization methods for global models for Ukraine (downscaling); and
    - improvement in the scenario analysis methods, the development of regional forecasts and climate change impact scenarios for forest ecosystems and the forest sector of Ukraine, based on empirical, statistical and numeric simulation and forecasting methods.
- The development of both land-based and remote forest inventory and monitoring for the improvement of information and the analytical forest management base in face of climate change Activities would include
    - a complex inventory, monitoring and forest resources assessment programme, which should also be used for land-use changes and for obtaining regular integrated assessments of climate change effects;
    - scientific and methodological foundations should be developed as well as the methods and the technologies for national selective statistical inventory and for monitoring of Ukraine's forests through the use of remote Earth probing for the assessment of climate impact on the forests of the country and for measuring emission and absorption of GHGs in the forest sector;
    - applying modern GIS technologies to develop operational forest ecosystem mapping methods that could also be used for the development of digital maps of carbon reserves in forest lands; and
    - developing quantitative assessment methods of carbon build-up in forest ecosystems through the use of cutting-edge technologies over a network of representative monitoring sites in the national forests.
- The improvement of forest ecosystem vulnerability assessment methods during climate change, and the study of their adaptation capabilities. Activities could include
    - integral assessment methods developed to assess the effects of climate change on forest ecosystems, their productivity, biodiversity and role in ecological, economic and social functions;
    - a complex assessment of Ukraine’s forest ecosystem vulnerability, performed during the climate change period, using of current forest statistics, improved models and scenarios; and
    - improvement in assessment methods for GHG emissions during wildfires.
- The justification and development of forest management adaptation strategies and of forest management measures for climate change impact mitigation, through:
    - the development of adaptation strategies and measures to mitigate the impact of climate change in the forestry of Ukraine;
    - improvement of the assessment methods of the sources and the absorbents of GHGs in the forests of Ukraine;
    - development of forest cultivation locations and forest restoration identification methods on the basis of mobile GIS and modern geographical positioning systems; and
    - development of recommendations on the organization and implementation of forestry projects, directed increasing carbon absorption in accordance with the flexible mechanisms of the Kyoto Protocol and the “green investments scheme”, with due consideration for economic, ecological and social effects.

The execution of the abovementioned studies would serve as the basis for the development of cooperation between Ukrainian institutes and specialists and international research organizations and donors that support implementation of such projects (for example, FAO, UNDP, IPCC, GEF, World Bank, EBRD). Besides the research projects, such cooperation would support knowledge and technology exchange, the development of the potential for improvement of research opportunities (including technical assistance, transfer of modern technologies), improvement of awareness and communication capabilities. An important element would be support to seminars, training, conferences, thematic publications and the creation of Internet resources on climate change issues in forestry.

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Appendix No. 1. National legislation and regulatory documents on climate change issues

The Supreme Council (Parliament) of Ukraine ratified the UNFCCC on 29 October 1996, and in accordance with UN rules, Ukraine became a Party to the Convention on 11 August 1997. The Kyoto Protocol to UNFCCC was ratified by Ukraine on 4 February 2004.

The national regulatory and legislative base, related to the climate change issues is constantly developing and improving. To date, the Government and state administration bodies have adopted about 30 regulatory and legislative documents, dealing with the execution of the requirements of UNFCCC and its Kyoto Protocol, which regulate activity in Ukraine, related to climate change issues.

By Decree of the Cabinet of Ministers of Ukraine dated 14.04.1999, No. 583, an interdepartmental commission was created for enforcement of UNFCCC. The representatives of the Cabinet of Ministers of Ukraine, of the Supreme Council of Ukraine, of the secretariat of the President of Ukraine, of ministries and departments, and of the National Academy of Science of Ukraine are part of this commission. A number of special Government decrees were adopted with the purpose of coordinating execution of Ukraine's obligations under UNFCCC and its Kyoto Protocol. The Decree of the Cabinet of Ministers of Ukraine, dated 18 August 2005, is an important government document in the context of climate change issues, No. 346, which approved the National plan of activities for the implementation of Kyoto Protocol provisions (this plan was amended by order of the Cabinet of Ministers of Ukraine dated 5 March 2009, No. 272). The national activity plan for the Kyoto Protocol provisions implementation is directed at addressing the following tasks:

- Improvement of the national GHG emission and absorption assessment system.
- Preparation and timely submission to UNFCCC Secretariat of GHG emission and absorption reports.
- The creation of favourable conditions to implement the "flexible mechanisms" of the Kyoto Protocol in Ukraine.
- The creation of a national GHG emission and absorption reporting system.
- The development of regulatory and legislative documents for GHG emission and absorption quantity regulation.
- Establishing a GHG emission units forecast for the period to 2012.
- Maintaining databases for joint execution of projects.
- Preparation and publication of national reports on climate change issues.
- Development of National plans on adaptation and climate change impact mitigation.
- The participation of Ukraine in UNFCCC Conferences of the Parties.

- Evaluation of GHG emission reduction potential to 2020, strategic forecast and the assessment of climate change impact on various economy sectors, on the population and ecosystems.
- Creation of a data bank on ecologically safe technologies that allow reducing emission volumes and increasing GHG absorption volumes.
- Implementation of measures on training and qualification improvement within the scope of UNFCCC and its Kyoto Protocol, for State employees, preparing personnel, and informing the public on climate change issues.

According to many experts, the State legislation and the existing regulatory basis for climate change issues creates good pre-requisites to reach the goals set by UNFCCC and its Kyoto Protocol. Detailed information on national legislation and on regulatory documents on climate change issues can be found at:

- www.menr.gov.ua/cgi-bin/go?node=ZAK%20baza%20UN
- neia.gov.ua/nature/control/uk/publish/category;jsessionid=667AC1E80076F4673EF6F83AAC2DCC69?cat_id=108499
- www.informkioto.org.ua/main/ua/258.htm

Appendix No. 2. Climate change in Ukraine: empirical data and forecasts

Climate observations in Ukraine started in the 18th century, and significant empirical material was accumulated during the period of such instrument-based observations, as well as providing long-term data on various climatic system indicators. The Ukraine Climate Cadastre was formed in the 1990s and holds information on meteorological data. The Decree of the Cabinet of Ministers of Ukraine No.650 dated 28 July 1997 approved "The Climate Programme of Ukraine", that stipulates how the climate monitoring system should be conducted, as well as the use of the information obtained for multiple purposes.

The results of the climate dynamics study in Ukraine during the period of instrument-based observations show that global climate change tendencies manifest themselves in regional specifics of Ukraine's climate. According to the data of the Hydrometeorological Centre over the last hundred years, the average yearly temperature in Ukraine has increased by about 1°C, while on average the temperature on this planet during the same period has increased by 0.6°C. This warming of the national territory manifests itself rather incoherently. Near the ground, temperatures have increased in those locations in those months that were previously cold, and the near-ground temperature in locations with higher temperatures has practically not changed. Ukraine's climate warming shows a similar pattern to global trend parameters, with an increase 0.4–0.6°C over 100 years. This warming is characterized by the heterogeneity (non-monotonicity) of the near-ground temperature increase. Periods of significant temperature increases have been followed by periods of decrease. During this 100-year period, the most pronounced temperature increase trend was noted in the northeastern part of Ukraine (about 1°C); in the northwestern and central parts this trend amounted to 0.7–0.9°C; while in the southern part it was 0.2–0.3°C. The most intensive temperature increase was noted during winter (1.2°C) and spring (0.8°C), while the summer temperature increase amounted to 0.2–0.3°C.

Precipitation over the last 100 years showed precipitation distribution levelling-off. In those regions where precipitation was insignificant (southeast of the country), precipitation increased by about 15%, and in the regions with greater precipitation (northwest) precipitation decreased by about 5%. During this process there was a decrease in the climate's continentality and more occurrences of extreme weather events (rainstorms, floods, unseasonal thawing, early frosts, and squalls).

More significant temperature changes were observed in particular regions of the country. According to Yeremeyev and Yefimov (2003), for the period from 1961 to 1996, statistically the average air temperature increased considerably in the northwestern and southeastern subregions

of Ukraine, by 2.7–7.8°C, and in the northwest by 1.0–1.7°C. Because of the air temperature increase, the number of days with subzero temperatures decreased by 5–10%. Air humidity increased considerably, by 10–25%. As the analysis of the statistically extreme events showed, the re-occurrence of anomalously high average monthly temperatures before the end the 20th century increased two- to three-fold in comparison with the beginning of the century, and the number of anomalously cold winters decreased.

According to the climate indicators analysis, Ukrainian climatologists came to the conclusion that a new climate was being formed in Ukraine: the winters became less cold and had little snow, and the summer became colder. Sometimes sharp air temperature falls occur, by up to 10–12°C in a 24-hour period. During such periods, as a rule, atmospheric disturbances appear, as well as extreme events (rainstorms, thunderstorms, hail, strong winds, hurricanes, etc.). In the future, anomalously cold winters are forecast, with abrupt temperature falls and, with a lack of snow cover, droughts can be expected.

During the period of instrument-based observations, atmospheric precipitation in Ukraine did not significantly change, but the intensity of did change. The data show 11, 22, 28 and 30-year periods of increased and decreased moisture modes. Precipitation for Ukraine in general increased by 20–50 mm in winter, but in the western part of the country it decreased by 20–30 mm. In the spring, precipitation increased by 10–20 mm and remained without change in certain areas. The precipitation neither changed nor decreased in summer: in the west by 40–50 mm, in the east and southeast by 10–30 mm and in the Crimea by 20–35 mm. Precipitation in autumn in the west of the country, decreasing by 40–50 mm, and in the centre and south of Ukraine it increased by 10–20 mm. Territorially, precipitation changed: in the northern and western regions and in the Crimea annual precipitation decreased by 50–100 mm; and in the east by 10–30 mm. There were virtually no changes observed in precipitation on the Azov sea coast (northeastern part of the country). It can be concluded that there are no clear trends obvious in precipitation distribution characteristics in time and space.

Regional precipitation change analysis for the south showed that there was increased precipitation in the Kherson region during the last decade, causing a transformation of the water balance of the territory and increased negative events, such as erosion, soil salinization and inundation. Certain positive climate change effects were also noted in this region: there was increased productivity of the agricultural land due to the increased moisture.

It is rather difficult to forecast temperature changes for the middle latitudes, as the forecasts of probable precipitation amounts and air temperature change are vague. It is even more difficult to forecast climate change impact on natural ecosystems, as both positive and negative effects may manifest themselves. For example, several researchers forecast that more favourable conditions are being formed for winter wheat as a result of the climate change. However, many specialists in the agrarian sector believe that the climate changes will lead in general to deterioration in agricultural crop growth conditions.

Different climate change forecasts for eastern Europe show that the main climate change tendencies in the future will be linked to the temperature increase and to precipitation decreases, and, as a consequence, will lead to increased aridity. The comparison of today's climate indicators (for the period 1950–2000) with the climate indicators forecast to 2020 led to the following conclusions for Ukraine:

- The temperature will increase considerably all over the country, especially in its southern part. The yearly average temperature will increase by 20% (from 7.5°C to 9.0°C). A similar trend is expected for the day temperatures during the growth period (April-September).

- Total precipitation will decrease on average for the year and in the growing period, especially in the southern part of the country.
- Changes will occur in the natural zones, in particular there will be expansion of the mixed forests zone (Polesye) and the formation of semi-desert zone in the southern part of the country when warming increases by 2–3°C.
- There could be catastrophic desertification of Ukraine's southern regions (if the global warming level exceeds 3–4°C), which will intensify erosion processes, lead to depletion of freshwater resources, and decreased precipitation.
- The levels of the Black and Azov seas will rise.
- There will be a potential demographic crisis, with intensification of migration processes.

According to the forecasts, obtained with the help of regional digital simulation of atmospheric circulation and semi-empirical climate change simulation and the GHG emissions scenarios, by 2050 the average regional near-ground temperature may increase by 1.5–2.0°C, in January by 2.0°C in the south of the country, by 2.8°C in the north and on average for the country it will increase by 0.5–1.0°C in July. As far as precipitation is concerned, after 2040 a certain increase in precipitation is forecast during the winter period and the summer precipitation will be within the historical norms, but extreme events can be expected to occur.

Appendix No. 3 – International cooperation of Ukraine on climate change issues

Ukraine cooperates with many countries and with many international organizations on climate change issues. One of the first international cooperation projects on climate change studies in Ukraine was the US Country Studies Program, a programme dedicated to climate change studies in developing countries and in countries with economies in transition (www.gcrio.org/CSP/webpage.html). This programme started in Ukraine in 1994 and a complex study of the climate change issues for Ukraine's ecosystems and economy was conducted, including research on climate change impacts on national forests and forestry.

On 28 January 1999, a Memorandum of Cooperation on climate change issues was signed between the Government of Ukraine and the Government of Canada. A second Memorandum of Understanding between the Government of Ukraine and the Government of Canada on cooperation on climate change issues, including projects executed according to Article 6 of the Kyoto Protocol, was signed on 7 December 2005 in Montreal. The Canadian-Ukrainian ecological cooperation programme was executed in 1999–2003. Several studies were performed within the framework of this programme on UNFCCC implementation issues, on joint execution of projects, on GHG monitoring and inventory systems, and on mitigation of climate change impact (www.climate.org.ua/canada/Can_Webua.html).

On 8 December 1999, a Memorandum of Cooperation on climate change issues was signed between the Government of the United States of America and the Government of Ukraine. With the support of the international development agencies of the United States of America and Canada in 1999–2003, Ukraine launched a centre on "Initiative on Climate Change Issues". The activity of this centre was directed at providing assistance to Ukraine in the execution of its obligations under UNFCCC, the development of climate preservation policies, assistance in the search for investments for projects, aimed at GHG emission reduction and at increasing absorption of GHGs (see www.climate.org.ua/index.html). With the purpose of preparing the projects on absorption of GHGs within the framework of the Initiative, several educational modules on "Carbon Absorption in Agriculture" were developed, experts in different regions of the country were trained, and several project proposals were prepared for activities in the forest centre, aimed at reducing GHG emissions and at increasing their absorption.

In 2001–2003, within the framework of the joint programme of the World Bank and Switzerland, "The National Strategic Study in Ukraine on Joint Execution" project was developed. This project's objective was the development of analysis of international GHG emission reduction instruments via joint execution mechanisms for the state organizations. Several joint execution projects were identified in the forest sector of Ukraine.

In 2001, the Joint Workgroup for the identification of cooperation opportunities on global climate change issues was created within the framework of partnership and cooperation between Ukraine and the EU. This Workgroup exchanges information on activities on climate change issues carried out in Ukraine and in the EU; this group coordinates the efforts of Ukraine and the EU on execution of their obligations under UNFCCC and the Kyoto Protocol.

As a result of cooperation with the European Commission, from May 2004 to October 2006 a project was executed: "Technical support for the process of obligations execution by Ukraine and Belarus in the sphere of reducing global climate change impact" (www.climate-change-ukraine.info). Works under this project was directed at the creation of organizational and technical potential for the participation of Ukraine and Belarus in UNFCCC and the Kyoto Protocol.

On 20 May 2003, a Memorandum of Cooperation on UNFCCC execution issues was signed between the governments of Ukraine and Denmark. On behalf of Ukraine this Memorandum was signed by the Minister of the Environment (Minprirody) of Ukraine and on behalf of Denmark by the Minister of Ecology of Denmark. The forestry potential of Ukraine was assessed within the framework of this cooperation. The GHG emissions unit reduction was also investigated. The scientific and methodological principles were developed for data gathering and preparation, where this data will be used for national reporting purposes under UNFCCC and the Kyoto Protocol.

In 2004, a Memorandum of Understanding was signed between the Ministry of the Environmental Protection (Minprirody) of Ukraine and the UNDP on cooperation on climate change issues. Several issues of Ukraine's forest sector adaptation were studied within the framework of this cooperation.

A Memorandum of Cooperation was signed on 7 June 2006 between the Government of Ukraine and the Kingdom of the Netherlands on issues of UNFCCC and Kyoto Protocol execution, in particular on GHG emission reduction according to Article 6 of the Kyoto Protocol.

On 15 March 2007, an agreement was signed in Paris between the Government of Ukraine and the French Republic on cooperation in the execution of joint projects according to the Kyoto Protocol.

On 14 June 2008, A Memorandum of Cooperation was signed between the Government of Ukraine and the Government of Japan on assistance in the execution of the UNFCCC and the Kyoto Protocol in accordance with Articles 6 and 17 of the Kyoto Protocol. Within the framework of this Japan-funded project a website was created: "Public information on Kyoto Protocol Implementation" (www.informkioto.org.ua/main/ua).

On 11 December 2008, a Memorandum was signed between the Ministry of the Environment, Agricultural and Maritime Issues of Spain and the National Agency of Ecological Investments of Ukraine on activities related to Articles 6 and 17 of the Kyoto Protocol.

In March 2009, the Federal Ministry of the Environment, Environmental Protection and Security of Nuclear Installations of Germany invited the Ministry of Environmental Protection (Minprirody) of Ukraine to participate in a climate protection initiative that supports projects

related to the development of natural reserves, which unambiguously create a positive impact on the climate.

On 18 June 2009, a Memorandum was signed between the Ministry of the Environment of Italy and the National Agency on Ecological Investments of Ukraine on issues of joint project implementation under the Kyoto Protocol.

An information centre was created in Ukraine with support from the British Council on climate change issues. This centre takes care of issues of informing the public, developing cooperation and supporting climate protection activities (www.climateinfo.org.ua).

The scenario analysis and forecast for Ukraine's forest sector during climate change were performed within the framework of an international "Scenario Analysis of Sustainable Wood Production under Different Forest Management Regimes – SCEFORMA" project that was conducted within the framework of the EC INCO-Copernicus research programme (www.efi.int/portal/research/projects/?todo=3&projectid=129).