COST action FP0703 – ECHOES

Expected Climate Change and Options for European Silviculture

COUNTRY REPORT
Country report

Poland

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Introduction

Forest once covered almost the whole territory of Poland. Civilisation pressure has led to a considerable decrease in Poland's forest area. The forest cover in Poland in the end of 18^{th} century was about 40%. After the Second World War the forest area decreased to 20.8%. The deforestation and the poor species composition resulted in the decrease in biodiversity, soil erosion and the disturbance of water balance.

Polish forests are amongst the largest in Europe, in comparison with other countries (after France, Germany and Ukraine):

- their area is about 9,048 million hectares (ha) or 28.9 % of the Polish territory;
- their growing stock is about 1914 million cubic meters (m^3) of solid wood or about 206 m^3/ha;
- their current annual volume increment approximates 7.2 m^3/ha/year on average for the last 20 years;

Polish forests are diverse institutionally. Over 82% of their area belongs to public institutions including the State (78.1%) and more than communes (Milewski 2008). The other are private – 16.9%. National Parks cover 2% of forested area. Polish forests grow on the poorest soils. Most of them occur on coniferous sites (55.1%). The main tree species is Scots pine (*Pinus sylvestris* L.). This tree covers 69% of forest area in State forests and 63% in private forests. The pine has in Poland the optimal climatic and site conditions within its Euro-Asiatic natural range. However, in 1945-2007 the increase in broadleaved tree species was observed. The share of stands with the prevalence of broadleaved species has increased from 13.0% to 23.5%. Nevertheless, the proportion of broadleaved stands is still lower than it potentially could have been.

Stands in younger age classes III (41-60 years) and IV (61-80 years) prevail in the age structure of Poland's forests (25% and 19%, respectively). Stands older than 100 years account 14.2%. There is a rise in the average age of stands which is positive phenomenon. The average age of stands in the State Forests reached 60 years in 2007, and 40 years in private forests (Fronczak 2008).

I. Impacts

I.1. Observed impacts

Poland's forests are among Europe's most threatened, on account of the constant and simultaneous impact of many factors capable of encouraging unfavourable phenomena – and of bringing about negative changes – in the state of health of forests. The periodically intensified occurrence of even one of this list of factors (mass outbreaks of insect pests, drought, fire or epiphytoses) may lead to the overwhelming of the biological resistance of forest ecosystems and consequent catastrophic threats on local or even regional scales.

Precipitation

In general, it can be said that 66% of meteorological stations showed negative precipitation trends. An insignificant falling trend in precipitation levels can be observed; still, this does not exclude the possibility that such a trend was significant in certain shorter periods (Szczygieł et al. 2007). The classification of the particular years in terms of precipitation levels demonstrated that years with excessive precipitation represented 26% of which:

- the number of wet years represented 18.3%,
- the number of very wet years represented 7.1%,
- the number of extremely wet years represented 0.6%.

Statistically, the years with excessive precipitation levels repeated every 3.5-4 years. The extremely wet years were in 1939, 1941 and 1970. From the beginning of the 20th century the years with excessive precipitation levels occurred as follows:

- At the beginning of the century,
- In the second half of the 1920s,
- The turn of the 1930s and the 1940s,
- In the 1960s,
- At the beginning of the 1980s and in the years 1985-1987.

The years with insufficient precipitation levels represented 28%, of which:

- There were no extremely dry years,
- The number of very dry years represented 8%,
- The number of dry years represented 20%.

The most intensive droughts came in 1943, 1953 and 1982. Analyses indicate that years with insufficient precipitation levels tended to occur in the periods: 1904-1917, 1951-1959. The long term data on precipitation levels indicate that years with standard precipitation levels represented 46%. The number of years with excessive precipitation levels accounted for 26%. The number of years with insufficient precipitation was 28%. The mean precipitation loss was of 0.4-0.5 mm/year. The wettest years were observed in the decade of 1961-1970. The drought in 1992 covered the largest part of Poland. In the last twenty years, a series of dry years could be seen.

Air temperature

Analysis of air temperature trends shows large variations in its annual values throughout of Poland. This is normal effect of Polish climate, because Poland is situated in the transition between oceanic and continental climate. The trend line for the mean annual temperature changes has the value of the coefficient 0,0038. The values of the trends is statistically significant at the level of 0.005 for half the number of meteorological stations and insignificant for the other half. The annual air temperature trends at all meteorological stations demonstrated a growing trend. The greatest positive deviation from the standard value could be seen in October, December, January, March and May. In the period 1901-2005, 24 to 35% of years were hot (depending on the region of the country), whereas 15 to 18% of years were cold. The first half of the 20th century was characterised by the occurrence of a temperature deviation towards cold years, whereas after 1967 a deviation towards hot years could be seen. The last twenty years were the hottest in the period under study (Fig. 1).

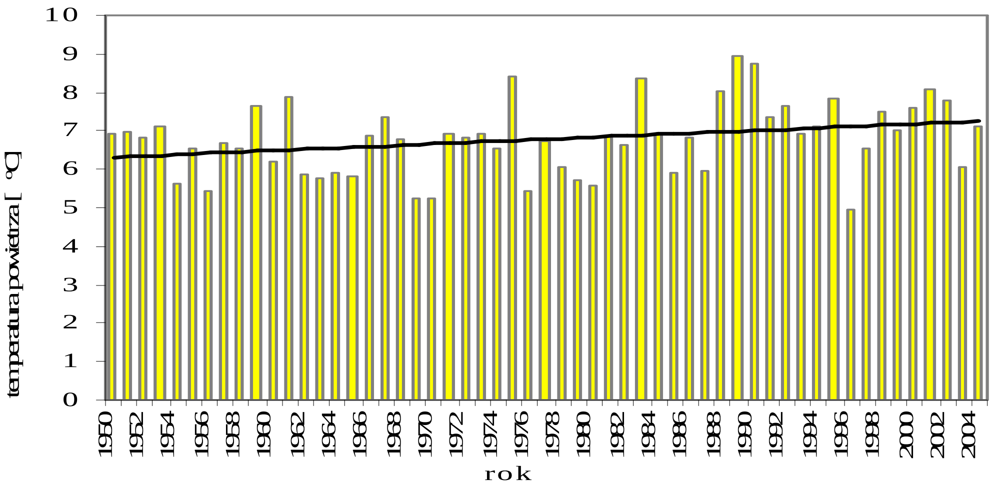

Fig. 1. Average air temperature in 1950-2004 in Bialowieza (Czerepko et al. 2009)

A standardized tree-ring width chronology of the Scots pine (*Pinus sylvestris* L.) along with different types of documentary evidence (e.g. annals, chronicles, diaries, private correspondence, records of public administration, early newspapers) have been used to reconstruct air temperature in Poland (Przybylak 2005). The ground surface temperature (GST) history has been reconstructed based on the continuous temperature logs from 13 wells, using a new method developed recently by Harris and Chapman (1998; Journal of Geophysical Research 103: 7371-7383) which is compared with the functional space inversion (FSI) method applied to all available Polish temperature-depth profiles analysed before. Response function calculations conducted for trees growing in Poland (except in mountainous regions) reveal a statistically significant correlation between the annual ring widths of the Scots pine and the monthly mean air temperatures, particularly from February and March, but also from January and April. Therefore, it was only possible to reconstruct the mean January-April air temperature. The following periods featured a warm late winter/early spring: 1530-90, 1656-70 (the warmest period), 1820-50, 1910-40, and after 1985. On the other hand, a cold January-April occurred in the following periods: 1600-50, 1760-75, 1800-15, 1880-1900, and 1950-80. Reconstructions of thermal conditions using documentary evidence were carried out for winter (December-February) and summer (June-August) from 1501 to 1840 and, therefore, their results cannot be directly compared with reconstructions based on tree-ring widths. Winter temperatures in this period were colder than air temperature in the 20th century. On the other hand, 'historical' summers were generally warmer than those occurring in the 20th century. Such situations dominated in the 16th and 17th centuries, as well as at the turn of the 18th and 19th centuries. Throughout almost the entire period from 1501 to 1840, the thermal continentality of the climate in Poland was greater than in the 20th century. GST reconstructions show that its average pre-instrumental level (1500-1778) is about 0.9-1.5 ℃ lower than th e mean air temperature for the period 1951-81. Lower amplitude of GST warming (0.9 ± 0.1 ℃) results from the individual and simultaneous inversions of well temperature data using the FSI method. A very good correspondence of the results has been found between series of annual mean GSTs from the FSI method and mean seasonal air temperatures reconstructed using documentary evidence (Przybylak 2005).

The observation of climate show that Polish winters are warmer, winter comes later and ends quickly, and the vegetation season is longer. There is no spring floods, which were common in the past. The Baltic sea has not frozen since 40. of 20th century. In the south of Poland we has started to grow African sorghum. The climate of Down Silesia now is similar to the climate of Hungarian Tokay - famous of cultivating the vineyard. The shift of tropic zone to the north causes more often affluence of the hot tropic air to Poland, where it collides with the cold air from the Arctic. The consequence of this is the intensification of storms and creation of tornado during summer. The most dangerous is the low pressure from Genoas, that causes the greatest flood.

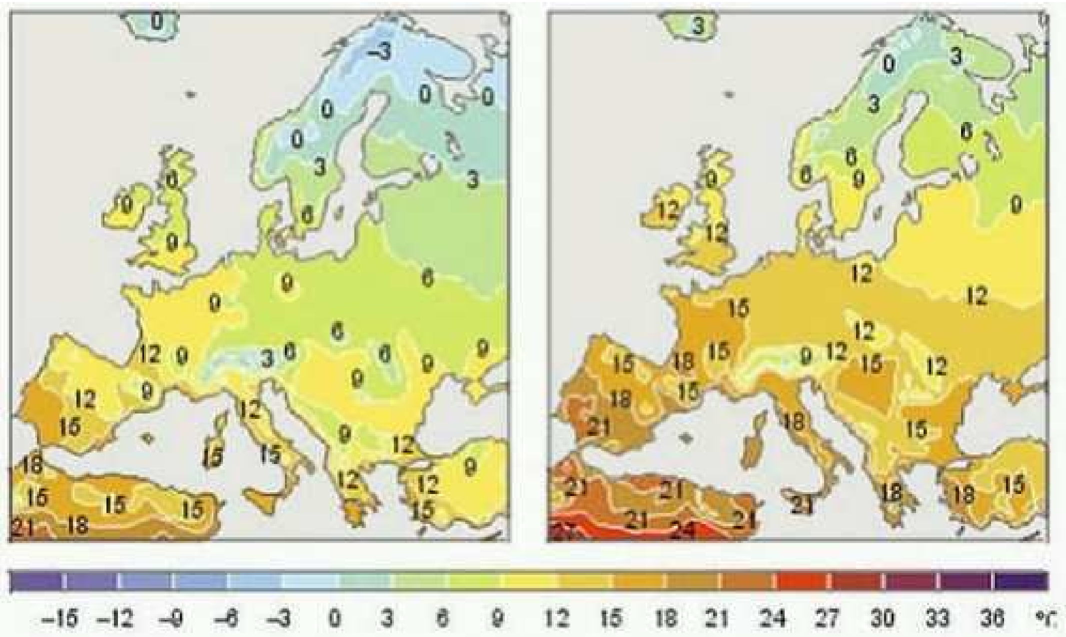

Fig. 1. Changes of the temperature in Europe. Left is presented the mean annual temperature nowadays, right at the end of 21st century.

The level of ground water also changed in last years. Analysis of the trends in Bialowieza Primeval Forest (Czerepko et al.) shows decrease in the level of ground water in the last 19 years (Fig. 2).

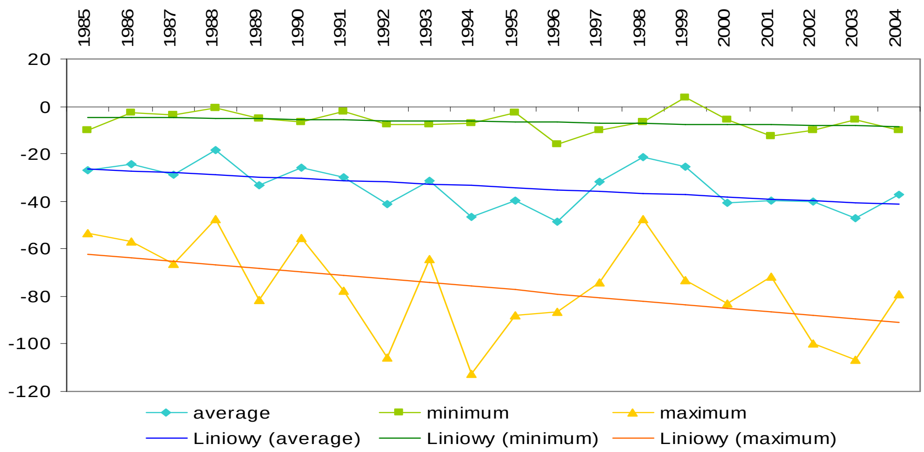

Fig. 2. Average annual level of ground water in following communities *Ribeso nigri-Alnetum, Circaeo-Alnetum, Vaccinio uliginosi-Pinetum* in Bialowieza Primeval Forest.

The precipitation forecast suggests that this phenomenon should not change significantly in the future - probably it increases. However, the scheme of precipitation will change – very heavy rains will occur in winter, and lack of rains with long periods of droughts and risk of fires will be observed during summer. Summer rains, if they occur, will be very intensive with increasing flood risk. Flood after snow melting will be replaced by flood connected with huge precipitations. The greatest flood after intensive rains was in Poland in 1997. Many towns like Wroclaw were completely flooded (Fig. 3).

Fig. 3. Wroclaw during the flood in 1997

Climate change will very likely increase the length and severity of the fire season, as well as the extension of areas of risk. Extreme conditions are likely to increase in many areas and with it the probability of large fires. Recurrent droughts and reduced precipitation are likely to endanger ecosystem regeneration after fire.

Poland belongs to countries where the risk of **forest fires** is very high because of stand species composition, age, site and climate. Polish forests are wide opened for public so the risk of forest fire grows with the number of people visiting the forested area. The main reason of forest fire in Poland is man. Most of Polish forests are coniferous and they are more vulnerable by fire than broadleaved forests. From 1948 to 2006 a total number of fires was 232,320 on the area of 307,938 ha. Both the number of fires and area burnt showed a rising trend, with some deviations depending on the weather conditions. The trend of the number of fires was greater than the trend in the area burnt. It is the result of the effectiveness of the organisation of the fire protection system in Poland. In 1948 to 1950 the burnt area was 3.25 ha. In 1971 to 1980, 1.43 ha, but in 1991 to 2000 only 1.30 ha.

Table 1 Number of fires and burnt area of forests in Poland in 1990-2007

Year	Total number of fires	Burnt area of forests
1990	5756	7341
1991	3526	2567
1992	11858	43755
1993	8821	8290
1994	10245	9171
1995	7367	5306
1996	7523	14120
1997	6528	6598
1998	5946	4019
1999	9405	8307
2000	12428	7013
2001	4480	3333
2002	10101	5093
2003	17088	2150
2004	7006	3781
2005	12169	5826
2006	12140	7164
2007	7049	2455

The number of forest fires increased in years with hot summers (Table 1). However, the burnt area decreased in last years. The highest risk of forest fire occurs in early spring and summer. Accumulation of fuel at the beginning of spring and dry litter in summer are the reasons of forest fires.

The number of fires increased in last twenty years. In 1992 the weather conditions caused several catastrophic forest fires affecting an area of more than 2000 ha. The most danger of fire are Scots pine stands. The highest number of forest fires is recorded in the central part of Poland (Masovia region – 1662 forest fires in 2008). The other regions are Great Poland (the surrenders of Poznań – 910 forest fires in 2008) and Silesia (707 forest fires in 2008). The most severely affected Scots pine stands grow on very poor site types.

The other most important climate change impact is **wind**. Climate change will increase the number of storms. In 2007 stands growing in the south-west part of Poland were damaged by the hurricane “Cyril”. The speed of wind was almost 150 km/h. Two years ago over 273 000 ha of stands were damaged by wind. The most vulnerable are Norway spruce (*Picea abies* Karst.) stands growing in the mountain regions and Scots pine stands occurring in almost whole country. In 2002 during 15 minutes 33,000 ha of Polish forest were damaged by wind. The most damaged were stands in the Pisz Forest Directorate, where 12,000 ha was heavily damaged and 2.5 mln m^3 of timber were cut (Rykowski et al. 2009).

Another very important impact of climate change is the increase in summer **droughts**. Considerable area of central part (Great Poland nearly 60 km^2 - what means 1/5 of the country) is threatened by desertification. The cause of the process is the specific geographical position of this area in the transition zone of climates: oceanic and continental. This region characterises the small precipitation (sum of precipitation is lower than 500 mm/year) and high evaporation. Droughts make worse the situation especially in this region of Poland. Moreover, Poland is one of the poorest countries of water resources. The index - 1800 m^3/year/person is the lowest in Europe. Polish Government predict to spend 300 million PLN for the programme of small retention to 2020. Polish forests are threatened by the changes of water ratio, especially flood.

Poland belongs to the countries where the unfavourable events, like **outbreaks** and **pathogens**, occur very often. Following unfavourable events were recorded in forest environment as a result of stress:

1. activity of new or little known species of insects and pathogens, which have not damaged forest stands yet;
2. shortening of periods between outbreaks of the most danger insect;
3. creation of new and extension of old outbreak area;
4. deterioration of health state of deciduous tree species.

In the period 1961 to 1990 the increase in the number of pests was observed. During 1961-1970 the outbreaks of 38 insect species were documented. The treatments covered the area of 600 000 ha. In 1981-1990 the outbreaks of 56 insect species were found. The greatest outbreaks of insects was in 1979-1984 and in 1992-1994, and the secondary pests in 1981-1985 and 1993-1994. The most damaged were Scots pine stands by *Lymantria monacha* (nun moth). In 1997-2006 the area of nun moth outbreaks covered 1487 thousands ha. The outbreak of pine beauty moth (*Panolis flammea*) was observed in 1997-2002. Pine sawfly (*Neodiprion* spp.) outbreaks were found in the area of 600 thousands ha. The activity of *Melolontha* (European cockchafer) increased in the last years. In 1994-2004 the area of protection against cockchafer covered 62 thousand ha. The most threatened stands by the insect were in the north (Masuria Lakes), north-west (Pomerania) and south part of Poland (The Sudety and Beskidy Mountains). However, Norway spruce forests are damaged by bark beetles (*Ips typographus, I. anutinus, I. duplicatus, Pityogenes chalcographus, polygraphus polygraphus*). Most of the damaged stands are localised in the Sudety and Beskidy Mountains. Broadleaved stands are most damaged by oak tortrix moths and geometers, which were present over 113,834 ha (or three times the area in 2002).

In 2007, infectious diseases were reported in a total of 505,100 hectares of stands, what means a rise in area by nearly 37,800 hectares of stands as compared with 2006. The increase in the areas subjected to fungi was only noted in oak and ash stands. The danger fungi is *Lophodermium pinastri,* which damage Scots pine forests especially in the west part of Poland. The risk of root pathogens increased in last years.

In 2007 disturbances caused by multiply factors were observed on the area of 82,610 ha. The significance of diseases of the assimilatory apparatus grew, as did the phenomenon of dieback among oaks and birches – manifested in a more than 50% increase in the area suffering damage. Oak dieback became a more intensive phenomenon (up 13,000 ha), while that of birch affected 1,350 ha more than in the previous year, and dieback of ash 1,200 ha more.

One of the main impact of climate change are changes in the species composition of stands and forest floor. Table 2 presents changes in bog and alder communities in Bialowieza National Park during the last 30-40 years. All of the differences are significant.

Table 2. Changes of main features of bog and alder communities in last 30-40 years in Bialoweiza Primeval Forest (Czerepko et al. 2009)

Feature	Old picture	New picture	Difference
Layer A	61.6	54.5	-7.1*
Layer A2	7.8	18.5	10.7*
Layer B	4.7	19.4	14.7*
Layer C	39.6	55.7	16.1*
Layer D	59.2	51.3	-7.9*
No. of tree and shrub species	6.0	6.5	0.5*
No. of herb species	19.6	20.5	0.9*
No. of moss species	11.8	10.6	-1.2*
Total	37.6	37.7	0.1

* significant difference - Wilcoxon test

Another example of the impact of climate change on stand structure is presented in table 3. In Bialowieza Primeval Forest many changes of species composition of forest floor has been observed.

Table 3. Changes of the quantity of 147 plant species of forest floor in last 30-40 years in Bialowieza National Park (Czerepko et al. 2009)

Group of species	Number of species	Examples
Without changes in the average cover	91	*Pleurozium schreberi, Dryopteris cartusiana, Dicranum udulatum, Sphagnum fallax*
Significant increase in the average cover	21	*Vaccinium myrtillus, Oxalis acetosella, Stellaria nemorum, Maianthemum bifolium, Athyrium filix-femina*
Significant decrease in the average cover	35	*Callitriche cophocarpa, Spagnum magellanicum, Lemna minor, Rhytidiadelphus triquetrus*

Most of the species did not change their cover in Bialowieza National Park. However, 21 species increased the average cover. Number of plants which decreased the average cover was 35.

The most damaged broadleaved forests are oak stands, especially in the north-eastern part of Poland. The process of oak decline covered the area of 55,.318 ha. The decline of European ash has been observed since 2001 in whole country. The decline of alder stands was observed in last years. Since 1999 the area of declining alder stands has increased. The main reason of alder decline is *Phytophthora*.

I.2.Expected impacts

Prediction of future climate based on the models suggests that during 100 years the mean annual temperature can increase by 4-5 ℃. January can be warmer about 5 ℃. In summer the temperatures can be expected over 35 ℃ or 40 ℃. The temperatures in Poland in 2090 will be the same as in Italy, Greece or Spain now. In those countries the temperatures will be similar to the Sahara Desert. Winter temperatures over 0 ℃ will cause the lack of snow. The four seasons will be replaced by two ones: rainy season in winter with temperatures over 0 ℃ and dry season in summer with heavy rains between droughts and temperatures up to 40 ℃. Tropical storms with tornados and hails will occur in Poland especially in the Masuria

Lakes. The intensity of storms will rise the concentration of dust in the air. The power of wind will increase by 25% in next 20 years. The other phenomenon that will occur more often is tornado. Until now tornados were very rarely observed in Poland (from one to four tornados per year). However, in 2006 fifty tornados (according to European Severe Weather Database Institute) were in Poland. For the first time in Poland was observed the tornado at F4 category (according to 6 steps scale of Fuljity) in August 2008 (Fig. 4). The speed of whirlwind was from 330 to 415 km/h what was comparable with the tornado in the US. Many buildings and forests were damaged. It is predicted that if the temperature of the Atlantic Ocean increases the greater contrast between temperature of warm air from ocean and cold air from the continent will be found, what will result in the creation of high and low pressure centres. The difference of pressure will cause higher flow of air. The effect of this changes will be more frequent tornados in winter time.

Fig. 4 Blotnica Strzelecka – village in Poland damaged by the tornado F4 in August 2008

Climate change will influence the water resources in Poland. Lack of potable water and water for agriculture will be the result of climate change. Increasing mean annual air temperature will decrease the quality of water and will intensify the processes of eutrophication.

The other threat of climate change (especially for the Baltic seaside) is an increase of sea level. Until now the sea level has increased by 1.5 – 2.9 mm per year. It is predicted that the level of sea will increase from 0.1 to 1 m till 2080. As the consequence an area of 1,800 km^2 will be flooded (Pruszak and Zawadzka, 2005).

Number of storms increased from 11 in 1960 to 38 in 80. of the last century. It is said that the number of stormy days will increase even 50%, and the speed of wind will increase by 16% (Report WWF, 2006).

The southern part of Gdansk Bay is threatened by the erosion, what means that the valuable natural ecosystems can be damaged. The most threatened is Hel Peninsula. The delta of the Odra river is also threaten, especially by the water rising and flood. Habitats of Szczecin Bay, which are the part of Natura 2000, will be damaged. The most danger is Wolin Island - very valuable in the European scale.

The cost of protective or adaptation actions is very difficult to evaluate. Until now only the cost of coast protection has been estimated. The cost of protection of the Polish coast is estimated about 6 milliard dollars, when the sea level rises 1 m. No action will cost Polish Government 30 milliard.

Climate and water on the planet Earth are intimately linked. Water influences the climate, and is influenced by the climate. Every change in the climatic system induces a change in the water system, and the other way round. Climate change has been observed and even a stronger change is projected for the future by climate models. The weight of observational evidence indicates an ongoing intensification of the water cycle, with increasing rates of evaporation and precipitation. Climate change will alter the future world’s freshwater resources in several aspects, such as freshwater availability, quality, and destructive potential. The likelihood of deleterious impacts, as well as the cost and difficulty of adaptation, would increase with the extent and the speed of global climate change. One of the effects of climate change is that hydrological extremes become more extreme. This leads to emergence of hotspots and vulnerable areas, and the need for difficult adaptation. Globally, the negative impacts of climate change on freshwater systems are very likely to outweigh their benefits (Kundzewicz 2008).

The results of model simulations show dramatic changes in the occurrence of contemporary main tree species in Europe, at the assumption that the atmospheric CO_2 concentrations will double (Sykes and Prentice 1995). It is of special significance for Poland because the majority of tree species has natural ranges cross Poland’s territory. The changes concern main tree species that lose their ecological optima and will be exposed to all consequences, starting from biochemical and physiological changes, which reveal themselves first in phenology and then in productivity. Potential forest ecosystem response to climate change are changes in forest location, structure and productivity. According to the forecasts Norway spruce will change its ecological optimum and in the pessimistic variant (2xCO_2) spruce will totally disappear from Poland shifting to the north and east of Europe. Similar observation have been made in the mountains, where climate warming alters the recent vegetation zone system. Expansion of some herb layer will be observed. For instance sweet woodruff, wild raspberry, purple toothwort gradually migrate to higher altitudes within their range. The mountain forests with predominant coniferous species will be affected by climate change in the first and their condition will deteriorate (Thuiller 2005). The forecast suggests that nearly one third of global forests will change from coniferous to broadleaved forests due to increased temperature, water availability and increased concentration of CO_2 (Kowalski 1993). The other very important phenomenon of climate change is the upward shift of timber line in the mountains. In the future our famous mountain pasture can be afforested, what will negatively influence the upper mountain ecosystems.

Global productivity

The growth and productivity of Polish forests increased in last years, what is the consequence of the extension of the growing season and the improvement of the photosynthesis because of the atmospheric CO_2 rise, 'fertilization effect' (deposit of eutrophicating compound). Forests in regions with low water reserve will decrease their productivity, firstly in west part of Poland. Research under controlled conditions has shown that for plants growing in the atmosphere with a double concentration of CO_2 the young plants produce approximately 40% more biomass, and the older and mature plants produce nearly 26% biomass. In the woody species the combined effect of warming and CO_2 concentration increase may give a positive results. The relatively positive results of biomass production may cause changes in other elements of the forest ecosystems, such as species composition, or resistance to health-threatening factors.

The higher frequency of extreme events (droughts, forest fires, windthrough) should have a negative influence on the future productivity.

I.3.Impact monitoring

The present shape of forest monitoring rises from the need for recording changes in forest condition in the 70s, when the process of forest dieback markedly accelerated. High concentrations of air pollution were admittedly considered the main cause of the phenomenon.

The programme for the monitoring of air pollution effects on forests (called technical monitoring) was established in 1985 in accordance with the Resolution No. 7 of the State Forests Council of 21 March 1984 and by Order of the Director-General of the State Forests of 16 December 1985. The servicing of the measurement points was secured by the administration staff of the State Forests. Laboratory works were done at first by the Bureau of Forest Management Planning and Geodesy (using soil laboratories), later taken over by the Laboratory of Physical and Chemical Analyses of the Forest Research Institute. Initially, the measurements of air pollution were conducted on more than 2000 measurement points using the contact method. Gradually, the number of points were reduced to reach 1400 in 1994, when the network of measurement points and the method applied were changed.

In 1989, the Forest Research Institute launched the monitoring of changes in the level of forest health condition (biological monitoring) by establishing 1500 First-Level Permanent Observation Plots (POPs I) and making first observations of morphological features of sample tree crowns. In the same year, Poland joined the International Co-operative Program "Assessment and Monitoring of Impact of Air Pollution on Forests" and the results of the national monitoring of air pollution effects on forests were published in the "Forest Condition in Europe" report. Second-level Permanent Observation Plots (POPs II) being the main element to the structure of the forest monitoring system were established in 1994 in pine and spruce stands where measurements of stand volume and annual stand volume increment were performed. They are subject to a research programme with a considerably expanded scope of observations and analyses. In 1998, the monitoring of the biological diversity of forest-floor vegetation, as well as the assessment of the frequency and vitality of natural regeneration on POPs II was conducted. The year 1999 saw the first monitoring of carabid beetles on 45 POPs II under the programme. In 1999, measurements of the volume and annual volume increment of pine, spruce, oak and beech stands on 148 POPs II were repeated.

A broad spectrum of analytical work has been done with a view to determine carbon content in different tree fragments and different forest ecosystem elements. The target is to create allometric equations and verify empirical equations and calculation coefficients in order to determine the amount of tree biomass in the main forest tree species. The methods of determining the amounts of carbon accumulated in stands and forest complexes, as well as changes in carbon accumulation and its dynamics associated with a given form of management will also be the effect of this analysis (Strzeliński et al. 2008). The work on carbon content in herb layer on 530 forest biological monitoring plots in a 16x16 km grid was covered by an independent program. This is one of the most difficult elements of carbon balance in forests. The attempt at estimating the net exchange of CO_2 between forest and atmosphere is a new approach to explaining the interactions between climate change and forest ecosystem (Olejnik 2008). To this end, a 34 m high measurement station was established in Tuczno Forest District (central-west Poland) in about 20 m high Scots pine stand, where special equipment has been installed. An eddy covariance method is used to measure CO_2 flow. The main instrument used in this method include a spectrometric gas analyzer ultrasonic anemometer for measuring wind and direction. The equipment required by the eddy covariance technique has to measure the concentrations of water vapor, carbon dioxide and the vertical wind velocity component at a pace of 20 times per second.

I.4. Impact management

For most of the recent extreme events (1992 - fire; 1997 - flood; 2002 - windstorm) the impacts were managed by General Directory of State Forests and each forest department involved in forest management. After the events national scientific expertises were rapidly carried out especially by scientists from the Forest Research Institute. After flood by Gorzelak et al. 1998 and after windstorms by Rykowski et al. 2009. These expertises led to publications in professional and scientific newspapers. Some guidelines were also published in order to summarize the main lessons of the crisis management and the way to avoid one other or, at least, to diminish the potential impacts.

II. Adaptation

II.1. General adaptation strategy or policy

Poland has an influence on climate change in the world. It belongs to the group of 20 countries emitting the greatest amount of CO_2. Its emission increased in 2004-2005 about 2 million t. The production of electricity and heat are based on coal (90%). Poland, China, Australia and Republic of South Africa are mostly connected with coal. Polish government do almost nothing to switch on renewable energy and increase the energetic effectiveness (WWF Report, 2006). Only 3% of electric energy comes from renewable resources like wind, biomass, sun or geothermal resources. However, the potential of using the kinds of energy is 10 times higher. Another problem of Polish energetics is the centralisation of production. Energy is produced in huge power stations instead of small local installations. Most of the energy is produced in power stations which waste the heat. Poland is the “leader” of countries that use 2 times more energy than the average of 25 countries of the EU. Polish Government has prepared new document titled “Energetic policy till 2030”. This document presents the conception of energetics development in Poland.

II.3. Forest adaptation measures

The State Forests fulfills the settlements laid down in the Forestry Principles and Agenda 21 adopted at the Earth Summit in Rio de Janeiro, the Declaration of European Forestry Ministers concerning the Protection of European Forests (Strasbourg 1990, Helsinki 1993, Lisbon 1998, Vienna 2003) and the Kyoto Protocol (1997) concerning the role of forests in carbon sequestration. After Poland’s accession to the European Union (2004), the State Forests has also come under an obligation – within the relevant competence limits – to implement the European NATURA 2000 program.

Polish forests are managed according to National Policy on Forests adopted by the Government in 1997 and National Policy on Ecology (1991 and 1994). Polish forest should be managed according to the principles of sustainable forest management. The principles were created during the third Ministerial Conference in Helsinki (1993). In 1995 the Director General of the State Forests edited the Ordinance No.11, which presented the ecology based improvement of forest management, introduction to practice the principle of balancing and optimizing all forest functions especially protection on biodiversity. They are managed according to the convention of climate protection and biodiversity. Three categories of actions are undertaken in forest management:

1. The preservation of the status quo in a local carbon balance, maintaining its amount at the initial level.

2. The increase in carbon absorption and accumulation through restocking and landscape afforestation, plantation management, as well as revitalization and reconstruction of degraded forests.
3. Carbon substitution - replacement with timber of fossil fuels and materials whose production involves huge amount of energy and release lots of CO_2 to the atmosphere.

Poland prepared two resolutions during the Ministerial Conference in Warsaw (2007). The second resolution “Forest and water” has initiated a new approach to the management of natural resources. This resolution concentrates on regulation functions of forests, especially water cycle in nature, and stresses the necessity of common management. Catchments as a main unit of water management can be the main unit of forest management. In this way forest management could play a role as a tool creating the landscape. In Poland, this solution could be used in neuralgic regions for the water balance. Resolution “Forest and water” is one of the regulations being against the increasing deficit of water, especially potable water in the Earth. The resolution refers to the expansion of protected functions in forestry as protection against flood, erosion and drought.

The deterioration health condition of spruce stands in the mountain areas and the situation reminding ecological disaster in the Sudety Mountains over the two decades of 20th century mobilized the Katowice Regional Directorate of the State Forests to elaborate number of preventative measures for the Beskid Śląski and Beskid Żywiecki forests. In 2003 the program for the Beskidy Mountains was developed and implemented as an element of the Regional Operational Program for the National Policy on Forests. The document includes the strategy of protective and silvicultural treatments for the Beskidy forests, seeking improvement of the current situation in stand conversion. Nearly 3,000 hectares of spruce forests were subjected to conversion in the framework of the Program.

The basis for all the afforestation activities in Poland is the National Program for the Augmentation of Forest Cover adopted by the Council of Ministers in June 1995. Initially the Program anticipated an increase in forest cover to 30% by 2020 and to 33% by 2050. In its first implementation phase (1995-2000) the National Program assumed afforestation on 50,000 ha of the land.

II.4. Research studies on forest adaptation

“Climate change and forest ecosystem: carbon stock in Polish forests and the direction of forest management adaptation” (realized by FRI - financed by GDSF)

III. Mitigation

III.1. Carbon accounts

It is estimated that Polish Forests contain 736 million tons of carbon accumulated in forest biomass of which 562 million tons accumulates in the aboveground biomass, 168 million – in the belowground biomass and 6 million - in dead wood.

Polish forests play and will play an important role in the carbon absorption process. It is manifested in an increase over the last decade in the forest area (162,000 ha in the State Forests) and timber recourses (276 million m^3 in the State Forests), progress in land afforestation under the National Program for Augmentation of Forest Cover, the extent and effectiveness of silvicultural treatments.

It is estimated that accumulation of carbon in Polish forests can increase about 300-470x10^6 tons.

It is possible to increase carbon accumulation in Polish forest as a result of stand conversion towards species composition better adapted to habitats (approximately 20-25 tC/ha). The other proposition is the introduction of underwood (improvement of growing stock – approximately 1.1 m^3/ha/year and carbon accumulation). The introduction of beech under the canopy can increase the carbon accumulation about 0.4 tC/ha/year. Changes of the management system from clear-cutting to shelterwood system may also increase carbon accumulation. It is known that clear cuts release about 24 tC/ha, on poor soils about 15 tC/ha. Tending cuts, especially thinning, can also increase carbon storage. Afforestation of post-agricultural lands may be another way of the increase in carbon storage (Rykowski 2008).

We can assume that forest management may increase carbon accumulation as a result of stand conversion about 200-215 x 10^6 tC; as a result of the introduction of underwood about 16-20x10^6 tC, and due to afforestation – 80-240x10^6 tC.

The total amount of accumulated carbon in forests depends on species composition in a stand.

III.2.Forestry as a source of bioenergy

During the Ministerial Conference in Warsaw Poland presented 2 resolutions. The first is about the relation between forest, wood and energy. The second takes into account the relation between forest and water. Timber plays double role: as a source of renewable energy and the substitute of raw material, like steel, which production needs huge amount of energy from fossil fuel. Wood is natural renewable material, which exploitation is practically unable to be run down and its production positively influence the environment.

Promotion of timber as a substitute for energy-consuming raw materials and products, as well as a direct source of energy – cooperation with the building, timber and power industries. The replacement of fossil fuels by sustainable biofuels reduce the CO_2 emissions proportionally to the value of substituted fossil fuels. The new biofuel plantations will bring long-term positive results, if they substitute the current plantations.

The development of the wood processing industry contributions to the increase of waste production. In the case of wood, the term ‘waste’ is today not quite true, as sawdust, shavings and chips have become full-value energy raw materials, burnt. Wood chips, that is 5 cm long pieces of wood are a good source of energy. This fuel is suitable for burning in modern boilers. Sources of green energy are found not only in forest resources but also in energy tree plantations. In Poland, the Polish Biomass Chamber estimates that, by 2010, the domestic energy sector will need 2.5 million m^3 of biomass or approximately 5% of total burnt fuels. There are “green certificates” in use in Poland which are documents certifying that part of the energy delivered to the market comes from renewable fuels. The Polish Biomass Chamber estimates that in 2010 every 20th ton of fuel in the industrial energy sector will come from the biomass.

Wood cannot be the only source of supply. The production of biomass in energy tree plantations could be a solution. The Ministry of the Economy’s Ordinance of 19 December 2005 on a detailed scope of obligations to obtain the certificates of origin and present them for the redemption, pay a substitute fee or purchase electricity and heat produces from renewable energy sources follows this direction. By 2014, 60% of biomass for energy production will have come from those plantations.

It is estimated that the State Forests may appropriate about 6 millions m^3 of timber annually for energy purposes. A further 8 millions m^3 of timber annually may be in supplies of waste materials produced during the manufacturing process in the wood-processing industry.

Energy production from renewable fuels in Poland has on the whole been developing well.

The State Forests can offer the application of timber in many forms, such as waste wood, chips, briquettes, pellets, etc. Power Plant Complex Ostroleka SA is the pioneer in burning biomass on a large scale. In 1995, The Heat and Power Plant Ostroleka started to use as fuel tree bark – the waste material produces by the adjacent large Pulp and Paper Plant.

In 1997, the existing steam boiler was upgraded and transformed into a modern fluidal bed boiler and, three years later, it was adapted also for chips. Today, the Power Plant Ostroleka boasts the country' largest exclusively biofuel-fired boiler. As a result, the Power Plant has reduced coal consumption by about 23,000 tons per year. The amount of ashes has dropped down by 4,000 tons per year. So, the emissions of pollutants dropped down significantly: CO_2 about 46,000 tons, SO_2 about 280 tons, and NO_3 about 100 tons annually. Significant quantities of green energy have been produced by the Power Plant in Polaniec. Timber is the main fuel used there in the co-burning process.

III.3. Processes, instruments and strategies

The most important is to protect the existing carbon resources and their consolidation. In natural forests the carbon cycle is closed. For the strategy of managing this terrestrial carbon pool, the most essential thing is to preserve the achieved equilibrium status. The largest number of management tools are provided by sustainable forest management, which enables stock growth, sustainable wood utilization and carbon preservation in products as a result of substitution of other materials. Retention of carbon resources in the existing forests can be achieved by improving management techniques. Reduction of the carbon losses in the logging processes, what means the use of technologies reducing the impact of logging operations on carbon release, is the most important factor. The conventionally performed logging generally cause a high amount of damage. Following strategies are proposed by Polish forestry:

1. Afforestation of post-agricultural land and wasteland; change of afforestation techniques by avoiding intensive soil preparation; promotion of natural regeneration and seeding.
2. Widespread introduction of sustainable forest management principle:
    - Promotion of natural regeneration,
    - Limitation of clear cuts,

- Limitation of tending intervention (mechanical soil preparation),
- Increase intensity of tending cuts,
- Soil protection and increase of organic matter retention in forest ecosystems (introduction of underwood, second storey),
- Application of environmentally friendly forest utilization technologies,
- Abandonment of burning splash,
- Use of bio-oils in forest equipment.

3. Extension of wood products' life cycle – their period of use should be equal or exceed the production period.
4. Increase of utilization to 70-75% of increment.

The positive effect of carbon accumulation as a result of afforestation is not always clear. It depends on the afforestation technique, particularly on soil preparation. After the afforestation of post-agricultural areas, carbon increment is not high, and can even be negative (Dovydenko 2004). The carbon accumulation process in afforested, post-agricultural soils proceeds in two stages. In the first stage carbon is emitted to the atmosphere. In the second stage carbon is accumulated in soil during the further processes of stand growth. The carbon emission is associated with soil preparation operations during afforestation, which affect its structure, like furrowing, deep ploughing. The period of carbon reduction in soil is followed by its growth and accumulation. When a stand is close to maturity the increment and sequestration rate slows down and can even drop to zero. The possible amount of carbon accumulated as a result of afforestation is diverse and depends on the species, site and management (Rykowski 2008).

Polish forestry faces an extraordinary effort towards continuous augmentation of forest cover and maintaining forest utilization at a level below wood increment. Since 1946 forest area has increased about 2.5 million ha. The usage has never reached the increment level, oscillating between 55 and 70%.

Changes of the forest management in Poland and the evolution of forestry towards sustainable forest management (The State Policy on Forest, 1997) foster climate protection activities and activate efforts increasing carbon accumulation in forest ecosystems. The appropriate silvicultural treatments under the SFM program, which improve productivity, may increase the accumulation of carbon in forest ecosystems (Bernadzki 1993).

III.4. Research studies on mitigation

State Forests, the main administrator of Polish forests, has started a series of research application programs aimed to fulfill the obligations resulting from the Framework Convention on Climate Change and the possibilities of using the agreements laid down in the Kyoto Protocol. A legislative proposal has been prepared to support the reduction of greenhouse gases and other emissions.

In addition to the need for content measurements and estimation techniques for carbon sequestration in forests, there is another issue to be dealt with - forest management adaptation to climate change. This program analyses first of all the silvicultural and forest management planning activities which affect the possibilities of adaptation of forest management practice to the changing environmental conditions and which may shape the size of carbon pool in forests and the rate of its sequestration.

"Carbon balance in the biomass of major forest tree species in Poland" (financed by GDSF) is carried out for the needs of reporting on the status of absorption of carbon dioxide by Polish forest. The project will last till September 2010. Eight main forest trees species in Poland (pine, spruce, fir, larch, oak, beech, birch and alder), as well as 12 major underwood species (rowan, alder buckthorn, hazel, bird cheer, black cherry, black elder, common dogwood, grey willow, eared willow, goat willow, hornbeam and juniper) will be subjected to research. Precise measurements will be carried out on 300 experimental plots, representing different age classes, habitats, and economic importance of tree species. After the completion of field and laboratory work, empirical equations and conversion coefficients will be developed to determine tree, shrub and herb vegetation biomass, as well as the carbon assimilated in the stands of main forest tree species. These equation will in turn be used to estimate the amount of carbon accumulated in the biomass of the stands under study. Also attempts will be made to determine the dynamics of changes in carbon sequestration depending on different business assumptions. Forest management planning databases and other findings will be used in the research. Many research institutes participate in the Project.

"Interrelationship between climate changes and forest ecosystems in Poland - Exchange of CO_2 between forest ecosystems and the atmosphere" is carried out by the Department of Agrometeorology of the Poznan University of Life Societies. The aim of the project is to provide knowledge on relationships between climate changes and forest ecosystems in Poland, as well as data on the exchange of CO_2 between forest ecosystems and the atmosphere. Similar projects are implemented in many countries in the world (i.e. France, Finland, Germany). The study is carried out in Tuczno Forest District in pine 52-years-old stands. The measurement are done at 34 m tall tower to determine the exchange of CO2 between forest and the atmosphere. An Eddy Covariance technique was applied. It is one of the most –up-to- date and the most precise technique in the world. The spectrometric gas analyzer and ultrasonic anemometer for measuring wind velocity and direction measure the concentration of steam, carbon dioxide and vertical wind velocity component at a pace of 20 times per second, just above tree crowns. It is already known that in the first quarter of 2008, each hectare of the ecosystems under study absorbed 3295 kg of CO_2, or 899 kg of carbon (Fronczak 2008b).

IV. Conclusions

Although carbon dioxide is known as one of the main factors of the greenhouse effect, and so of increasing temperatures. But it is also essential for green-plant photosynthesis. Increased atmospheric CO_2 results in an increase in photosynthesis rates (through CO_2 fertilization), which could potentially balance the effect of temperature increase (Thuiller 2007). Long-term observations and re-surveys of previously sampled sites are very important to study the impact of climate change on forest ecosystems (Taberlet and Cheddadi 2002). An alternative is to identify desired future states, and then use models for 'backcasting' to identify strategies for achieving those states.

Before the end of the COST Action ECHOES, this Polish report will be up-dated.

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