# Polish forest

# – its condition and processes

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**Forest Research Institute (Instytut Badawczy Leśnictwa, IBL)**

Andrzej Boczoń
Jakub Gryz
Michał Kalinowski
Paweł Staniszewski (SGGW)
Kazimierz Rykowski

## Table of Contents:

# Regulation of Hydrological Situation by the Forest In Poland, Foundations and Implementation of Small Retention Program in Forested Areas

*Dr Andrzej Boczoń*

## 1. The forest's natural features enabling regulation of the hydrological situation

### 1.1. Meteorological conditions

Covering of an area by a compact formation of high vegetation, as the forest phytocoenosis is, strongly modifies the local meteorological conditions, and the interior of the forest is characterized by specific microclimatic conditions. The stand makes a compact barrier against sunlight, blow-trough of the air and flow of water in the environment. Limitation of light energy reaching the soil appears in different distribution of temperatures from the one existing on the open areas. The structure of the stand, the specific composition strongly influences the amount of light energy that reaches the soil. According to data collected by Geiger (after Bac, Ostrowski 1969) the amount of light energy reaching the soil relative to light energy on the open area amounts from 3-35% in the leaved oak-stand and from 43-89% in the leafless status, in the pine stand amounts from 2-40% and in spruce stand amounts from 4-40%. Inside the forest the temperature of the air is characterized by attenuation of extreme values, in the wintertime the minimal temperatures are higher whereas in the summertime the maximal temperatures are lower than outside the forest. Tomanek (1960) communicates, that in wintertime the minimal temperature may be higher by 0,4°C, however the maximal temperature in summertime may be lower by 2,2°C. There are major differences observed also in the temperature of the soil, especially in its surface layer. It is mostly related to existence of forest cover, which forms an isolating layer on the surface of the soil, as well as minor solar beam inflow. Thereby the depth of the frost penetration into the soil is minor on the forested areas, the temperature of the soil is higher during winter and lower during summer, either the period of negative temperature is longer in spring with relation to the open areas. According to Tomanek's measurements the monthly average temperature of the soil with forest cover is higher by 1,4 °C in April and lower by 0,7°C in July compared to the temperature of the uncovered soil. However Charitonov reports , that the depth of the frost penetration into the soil in a compact oak stand amounts to 20 cm, while on cultivated areas it amounts to 120 cm (after Bac, Ostrowski 1969). The major thermal inertia causes later melting of the snow in the forest in spring. Witkiewicz (1966) reports , that in the European part of Russia the snow cover s remaining for longer time by 10-11 days in birch forests, and by 13-15 days inside the pine forest than outside the forest. Similarly Sokołowski (1962) shows a longer by 12 days and Tomanek (1967) by 9 days longer remaining of the snow cover in the forest ecosystems of Białowieża Forest. But simultaneously in connection with the interception of the snow-fall by stand-eave the snow layer in the forest reaches minor height than on the open areas (Olszewski, 1995). For example the interception of the snow in Bieszczady Mountains amounted to 49,9% in pine stands and 28,3% in beechen stands (Olszewski, 1975). The meaning of the stands for the interception of the water and snow has been showed in many countries, e.g., in Japan it has been measured, that the coniferous stands intercept 26% of the snow (Suzuki, Nakai 2007). The amount of the snow stopped by the treetops has been showed in table 1 (after Suzuki, Nakai 2007). There is also attention paid to the effect of lower wind speed that limits the melting. Olszewski (1974) has measured, that the wind in the forest reaches only 11% of the speed of the wind from the open ground.

**Table 1.** Water balance data from the present study and studies of other forests in different climates (Lunberg et al, 2004, after Suzuki, Nakai, 2007)

| Sites with different forest types | Sublimation or difference of snow accumulation between open sites and the forest (mm water equivalent) | Precipitation or snow accumulation at an open site (mm water equivalent) | Ration of sublimation to gross precipitation 9%) |
|---|---|---|---|
| Fir, Hitsujigaoka, Japan | 110 | 241 | 46 |
| Pine, Hitsujigaoka, Japan | 107 | 241 | 44 |
| Spruce, Hitsujigaoka, Japan | 85 | 241 | 35 |
| Larch, Hitsujigaoka, Japan | 73 | 241 | 30 |
| Birch, Hitsujigaoka, Japan | 6 | 241 | 2 |
| Fir, Jyozankei, Japan | 136 | 380 | 36 |
| Fir Nopporo, Japan | 80 | 267 | 30 |
| Spruce Shikotsukohan, Japan | 87 | 251 | 35 |
| Deciduous broadleaf species, Shikotsukohan, Japan | 23 | 251 | 9 |

| | | | |
|---|---|---|---|
| Spruce, Makkari, Japan | 156 | 511 | 31 |
| Alder, Makkari, Japan | 21 | 511 | 4 |

**1.2. The interception of precipitation and throughfall**

The precipitation penetrating to the soil is the only source of water for the forest vegetation in fresh and dry habitats. Therefore it is important to quantify the amount of water that penetrates the respective layers of the vegetation.

Long-term measurements of water circulation parameters, including measurements of interception had been performed in fir and beechen stand in experimental forest of MZLU in Brno (Kantor, Klima, 1997). Within the examined period of 21 hydrological years (1974/1975 – 1995/1996) the volume of intercepted precipitation amounted from 20,2% (124,3 mm) to 36,4% (268,9 mm) of total amount of precipitation on open area, whereas no interdependence has been noticed between the amount of total precipitation on open area and the volume of intercepted precipitation. Long-term research on interception had been also performed by Chlebek and Jarabac (1987) in the Czechoslovakian Beskides of that time. In the stands of spruce in years 1963-1986 the yearly average interception amounted to 70%, in the winter semester (XI-IV) 57%, and in summer semester to 77%. The spectrum of values of the yearly interception oscillated from 55% at precipitation on the open ground amounting to 1031,7 mm in 1982 to 81% at precipitation of 1329,8 mm in 1974 and 992,5 mm in 1975. The interception was measured also in the Czech mountains in 29 year old birch stand (*Betula alba*) and in 27 year old rowan stand (*Sorbus aucuparia*). During summer periods in years 1984-1986 the volume of interception of birch stand performed within limits of 22,4%-28,2%, while in the case of the rowan stand from 19,4%-24,5% (Fojt, 1989).In the Bieszczady Mountains Olszewski and Orzeł (1975) were concerned with interception. In the regions of Solina they have made survey of precipitation on the open area, under the eaves of beech and under the eaves of pine. For the period from 01.01.1969 to 31.12.1970 they have obtained interception amounting to 40,5 % in the case of beech and to 40,9% in the case of pine.

Comprehensive research concerning throughfall and interception of stands has been conducted in France within the framework of CATAENAT network (Ulrich et al., 1995). The results of measurements carried out in this investigation are presented in table 2. The highest amounts of interception have been measured in spruce and fir stands, however the maximum value – 51,2% has been measured in 20 year old Douglas fir stand. Values of interception not exceeding 20% have been noted in an almost 100 year old beech stand and in 60 year old oak stand.

Compilation of yearly interception values measured in stands composed of tree species occurring also on the area of Poland has been presented in the publication of Peck and Mayer (1996) based upon findings of different authors. There can be found minimal, maximal and intermediate values of interception for respective species (table 3), but also interception values for stand of different age (table 4). The Douglas fir stand manifests the highest average interception (42%) and also a wide range of measured values – from 30% to 54%. The lowest average interception has been showed in beech stands – 5%-, but attention should be paid on the high variability of interception in these stands: the minimal value amounted to 5% whereas the maximal one amounted to 48%. The smallest differences occurred in the case of birch stands, wherein the interception amounted within the limit of 20% to 22%. It can be noticed in this compilation, that the leafy stands are characterized by lowest yearly interception, what possibly can be the effect of lowest interception during the leafless period. In the case of interception values in different ages no explicit dependences can be found and the findings indicate a large variability of obtained results (table 4).

**Table 2.** Bulk precipitation and throughfall (Ulrich et al*.,* 1995)

| Species | Age | Bulk precipitation [mm] | Throughfall [mm] | Interception [%} |
|---|---|---|---|---|
| Quercus robur | 95 | 742 | 539 | 27,4 |
| | 100 | 916 | 650 | 29,0 |
| Quercus paetrea | 45-50 | 1107 | 805 | 27,3 |
| | 60-65 | 886 | 746 | 15,8 |
| Fagus silvatica | 50 | 1528 | 1004 | 34,3 |
| | 90 | 943 | 645 | 31,6 |
| | 80-100 | 2921 | 2618 | 10,4 |
| Pinus sylvestris | 42 | 1061 | 703 | 33,7 |
| | 48-58 | 930 | 576 | 38,1 |
| | 70 | 808 | 520 | 35,6 |
| Pieca abies | 26 | 1702 | 954 | 43,9 |
| | 33 | 1208 | 663 | 45,1 |
| | 37 | 1418 | 1014 | 28,5 |
| | 65 | 1391 | 820 | 41,0 |
| Abies alba | 30-60 | 1366 | 755 | 44,7 |
| | 60-80 | 1606 | 1264 | 21,3 |
| | 60-90 | 1439 | 998 | 30,6 |

| | | | | |
|---|---|---|---|---|
| | 80 | 1036<br>1012 | 771<br>603 | 25,6<br>40,4 |
| Pseudotsuga | 20<br>23 | 826<br>1545 | 403<br>1313 | 51,2<br>15,0 |

**Table 3.** Interception according to different authors (Peck, Mayer 1996)

| Species | Annual interception [%] | | |
|---|---|---|---|
| | average | min | max |
| Picea | 32 | 14 | 49 |
| Pinus | 28 | 14 | 37 |
| Daglezja | 42 | 30 | 54 |
| Larix | 32 | 26 | 36 |
| Fagus | 20 | 5 | 48 |
| Quercus | 21 | 10 | 34 |
| Betula | 21 | 20 | 22 |

**Table 4.** Changes of the interception with the age of tree stands (Peck i Mayer 1996)

| Age | Annual interception per species [%] | | | |
|---|---|---|---|---|
| | Picea | Pinus | Fagus | Quercus |
| 10-18 | 28 | 26 | - | 8 |
| 20-35 | 35 | 27 | 15 | 21 |
| 40-54 | 29 | 27 | 16 | 20 |
| 60-70 | 38 | 24 | 36 | 15 |
| 80-94 | 35 | 27 | 25 | 12 |
| 100-117 | 25 | 25 | 25 | 11 |
| 120 | 28 | 19 | 21 | 11 |
| 140-150 | 25 | 17 | - | 12 |
| 160-165 | 22 | 18 | - | 17 |
| 180 | - | - | 25 | - |
| 220 | - | - | - | 12 |

The presented results of the measurements carried out by different authors show a large variability of interception within the species and among species as well. It is possible that this variability is a result of the variability of precipitation on one side (different duration, different intensity, different size of drops), as well as of the differences characterizing the stands.

### 1.3. Retention capability of the forest cover and of the organic layer of the forest soil

The organic layer of the soil has an ability to hold large amounts of water, therefore it is of major importance for the circulation of water. Especially the retention capability of the sandy soils is relative to their organic matter content. Laboratory research on retention capabilities of organic layers of the soil were conducted by Kucza *et al.* (2003). The findings of the investigation carried out on the retention of the organic monoliths indicate a great differentiation of retention capability depending on the duration of pauses between the appearance of precipitations. The retention capability increases with the longer distances between two rainfalls. This differentiation can reach different amounts depending on the actual reserve. In the case of mineral soils it is findable that the actual retention capability depends only on the amount of the maximal reserve and of the actual reserve.

Modification and increase of the organic layer of the soil through the selection of appropriate species-compositions of stands for the purpose of improvement of rainwater retention capability can be of importance in mountain areas. In such places the increased amount of water held in the soil is necessary first of all not for improvement of growth circumstances of the trees, since because of high rainfall amounts in that regions those are provided with good water supply, rather for the purpose of limitation of water overflow which in the case of accumulation in water courses leads to immersions and floods. On the lowlands we can observe that owing to the low opportunities for flow of precipitation water to lower regions of soil profile conditioned to evapotranspiration, thickening of the organic layer of the soil can cause only increasing of retention in it's top layers.

The forest cover is the last barrier for the rain on it's way to the ground and for the increasing of the ground water resources. It is of special importance in the case of poorly decomposed covers of mor and moder type, that covers the forest ground during the whole year. In the case of mull type forest cover, specific for the fertile habitats the cover interception is of relatively minor importance, since the fast decomposition process that characterizes this type of cover results in its small thickness or even entire absence. The water retention capacity is of significance only in the period immediately after the fall of the leaves continued to the early spring, but by the reason of the fact that the forest vegetation does not use the groundwater at that time, the significance of the retention capacity for the accessibility of groundwater in the vegetation season is narrow.

In the study of Homa (2002) it has been shown that there is a close relativity between the retention capacity of the forest cover and its initial retention. The knowledge of the initial retention of the cover allows to determine its maximal retention. In this study the initial retention of forest cover was determined on the basis of general daily meteorological data : precipitation, average air temperature and average air aridness, and also on the thickness of the forest cover layer and its volumetric density. The calculated and measured values of the initial retention of the mor type cover occurred in the limits of 5-14mm.

### 1.4. The water-use of different tree species of the forest

From the beginning of the studies on transpiration of trees the different species have been compared inter se. The one of the first comparisons of different tree species have been conducted in the region of Innsbruck by Pisek and Cartellieri (Ermich, 1957) using the method of rapid weighing of freshly cut twigs. Small trees about 3-4 m height have been measured. Trees of six species have been examined, from amongst the maximal daily transpiration has been measured for the birch tree – 8,05 g $g_{\text{fresh mass of leaves}}^{-1}$ , while the oak tree used 7,6g $g_{\text{fresh mass of leaves}}^{-1}$ (table 5).

**Table 5.** Water uptake by trees according to different authors (Ermich, 1957).

| Species | Eidemann g $g_{\text{fresh mass of leaves}}^{-1}$ daily | Pisek i Cartellieri g $g_{\text{fresh mass of leaves}}^{-1}$ daily | Polster g $g_{\text{fresh mass of leaves}}^{-1}$ daily | Iwanow g $g_{\text{fresh mass of leaves}}^{-1}$ per hour |
|---|---|---|---|---|
| Larix | 22,6 | 3,2 | 3,24 | |
| Pinus sylvestris | 13,2 | 2 | 1,88 | |
| Picea bies | 7,3 | 1,42 | 1,39 | |
| Pseudotsuga | 9,5 | | 1,33 | |
| Abies alba | 5,1 | | | |
| Betula pendula | 45,1 | 8,6 | 9,5 | 0,464 |
| Quercus robur | 20,6 | 7,6 | 6,02 | 0,374 |
| Fagus sylvatica | 19,6 | 2,5 | 4,83 | |
| Fraxinus excelsior | | | | 0,502 |
| Populus tremula | 36,5 | | | 0,434 |
| Tilia cordata | 23,4 | | | 0,43 |
| Ulmus | | | | 0,402 |
| Acer platanoides | 16,1 | | | 0,326 |

Investigations of similar type has been conducted by Polster in the region of Tharand on 7-8 year old small trees and Iwanow in the region of Moscow. Polster has examined 7 forest tree species, 3 deciduous species and 4 coniferous species (Ermich, 1957). Also in his studies the birch tree reached the maximal values of daily transpiration – 9,5 g $g_{fresh\ mass\ of\ leaves}^{-1}$ . However the oak utilized 6,02 g $g_{fresh\ mass\ of\ leaves}^{-1}$ .

Iwanow limited his research to the measurement of transpiration of deciduous trees, he examined seven tree species. In his study the maximal value of transpiration rate was reached by the ash tree, which has utilized 0,502 g $g_{fresh\ mass\ of\ leaves}^{-1}$ within an hour. However the lowest transpiration rate was manifested by the maple tree – 0,3226 g $g_{fresh\ mass\ of\ leaves}^{-1}$ . In this study for the oak tree there has been measured a value of 0,3747 g $g_{fresh\ mass\ of\ leaves}^{-1}$ .

Eidemann in lysimetric studies conducted in Eberswalde has measured the transpiration of 13 forest tree species (5 coniferous species and 8 deciduous species). Among the examined coniferous trees the highest daily transpiration was manifested by the larch – 22,6 $cm^3$ $g_{fresh\ mass\ of\ leaves}^{-1}$ , but the lowest value was reached by the fir – 5,1 $cm^3$ $g_{fresh\ mass\ of\ leaves}^{-1.}$ Amongst the deciduous trees the highest transpiration rate was measured in the birch – 45,1 $cm^3$ $g_{fresh\ mass\ of\ leaves}^{-1.}$, while the lowest value was measured in the beech – 9,6 $cm^3$ $g_{fresh\ mass\ of\ leaves}^{-1}$ .

A comparison of similar type has been accomplished by Polster (1961) based on the results of his own and other authors' studies. This comparison is showed in table 6 the transpiration is presented in grams of water evaporated by one gram of fresh mass of leaves or needles.

**Table 6.** Daily transpiration of trees (Polster 1961)

| Species | Transpiration [$g_{water} \cdot g_{fresh\ mass\ of\ leaves}^{-1}$] |
|---|---|
| Populus alba | 13-14 |
| Elaeagnus angustifolia | 13-14 |
| Aigeiros | 9-15 |
| Betula pendula | 8,1 |
| Quercus robur | 6,0 |
| Corylus avellana | 4,2 |
| Fagus silvatica | 3,9 |
| Larix decidua | 3,8 |
| Pinus cembra | 2,2 |

| | |
|---|---|
| Pinus strobus | 2,1 |
| Pinus sylvestris | 2,0 |
| Picea abies | 1,4 |
| Pseudotsuga menziesii | 1,3 |

Despite of the different sets of tree species examined and usage of different units of water utilization by the researchers, it can be noticed that there is a high compatibility in the classification of the species regarding to the transpiration rate. Among the coniferous species the maximum amount of water is utilized by the larch tree, while among the deciduous species the birch tree (or the ash tree – but only Iwanow has measured the transpiration rate in this species), whereat the deciduous trees utilize higher amounts of water that the coniferous trees. The oak tree is a species that utilizes intermediate amounts of water, it transpirates less than the birch tree but more than the maple tree. Despite of this compatibility of the species regarding the quantity of water needs, though a great differentiation can be observed concerning the value of water consumption reported for the same species by different authors. Furthermore expressing the water consumption by the trees counted over a gram of dry or fresh mass of leaves does not indicate various conditions that influence the consumption of water by the whole trees, since the total mass of leaves of examined trees is unknown, and this is a distinguishing feature of health state of the tree, its position in the stand, and also a great variety of tree growth determining factors.

Highly interesting research on the forest tree transpiration has been conducted by Ladefoged (1963) in the fifties of XX century in Denmark in the forests of Arhus and Mols. Trees of II class of age of the following species have been examined during this study: common beech, chestnut oak, ash, common birch, sycamore, gray alder, cottonwood, common spruce. The characteristic features of the examined trees together with the results of transpiration study are collected in table 7. These investigations indicate a great variability of individual trees of the same species, and also among the species. The author shows the dependence-relation between the transpiration rate and the position of the tree in the stand canopy. The dominant trees develop the greatest number of leaves therefore the evaporative surface is the greatest in these trees, thereby the amounts of transpired water are maximal. However the trees growing under the canopy of the stand are characterized by reduction of assimilatory complex what involves limited transpiration. Similar relativeness is noticed also by other authors. Strelcova has conducted measurements in mature fir, spruce and beech stand, wherein it has measured that i the circumstances of unlimited access to ground water the common beech trees of the upper layer of the canopy transpired maximally 370 $dm^3$ of water daily, whereas the beech trees of the lower layer of the canopy only 83 $dm^3$. However in the whole growing season one tree of the upper layer of the canopy has evaporated over 14500 $dm^3$ of water, while the a tree from the lower layer of the canopy only less than 3300 l.

**Table. 7.** Maximum transpiration of trees (Ladefoged, 1963)

| Species | No | Crown class | Age | Height [m] | DBH [cm] | Leaf Area (for Picea fresh foliage) | | Max water consumption per: (for Picea fresh foliage) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Total [$m^2$] (Picea – kg) | LAI | $m^2$ (kg) leaf area $ml \cdot h^{-1}$ | $m^2$ leaf area $dm^3$ $.doba^{-1}$ | $m^2$ growing area $dm^3$ . $doba^{-1}$ |
| Fagus sylvatica | 1 | D | 27 | 11,8 | 13,0 | 69,3 | 7,1 | 66 | 0,6 | 4,4 |
| | 2 | D | 27 | 12,1 | 14,5 | 59,5 | 6,7 | 75 | 0,7 | 4,8 |
| | 3 | C | 32 | 11,6 | 12,1 | 42,2 | 7,7 | 64 | 0,7 | 5,1 |
| | 4 | C | 26 | 11,9 | 10,6 | 33,5 | 4,7 | 61 | 0,6 | 2,5 |
| | 5 | I | 27 | 10,6 | 8,7 | 18,5 | 5,2 | 59 | 0,6 | 2,9 |
| | 6 | D | 28 | 12,4 | 16,1 | 87,8 | 3,8 | 84 | 0,7 | 3,1 |
| | 7 | D | 28 | 12,0 | 13,1 | 37,8 | 4,6 | 137 | 1,2 | 5,3 |
| | 8 | C | 28 | 11,2 | 12,4 | 34,2 | 2,5 | 75 | 0,7 | 1,6 |
| | 9 | D | 36 | 10,0 | 10,9 | 23,4 | 3,3 | 125 | 1,4 | 4,7 |
| | 10 | D | 36 | 10,1 | 11,7 | 30,9 | 6,4 | 85 | 1,1 | 6,8 |
| Quercus petrea | 1 | D | 24 | 11,5 | 10,6 | 22,0 | 2,1 | 200 | 2,1 | 4,3 |
| | 2 | D | 25 | 11,8 | 12,2 | 38,8 | 3,9 | 113 | 1,0 | 3,8 |
| | 3 | C | 24 | 10,6 | 10,5 | 23,1 | 4,7 | 123 | 0.9 | 4,4 |
| | 4 | I | 25 | 10,6 | 8,0 | 12,1 | 6,4 | 100 | 1,0 | 6,4 |
| | 5 | I | 23 | 10,2 | 9,2 | 13,2 | 3,8 | 71 | 0,8 | 2,9 |
| | 6 | D | 27 | 13,8 | 17,0 | 85,3 | 4,7 | 145 | 1,4 | 6,8 |
| | 7 | D | 27 | 13,2 | 14,9 | 59,6 | 4,0 | 165 | 1,7 | 6,4 |
| | 8 | D | 40 | 9,2 | 14,3 | 39,2 | 3,6 | 220 | 2,3 | 8,3 |
| | 9 | D | 40 | 8,6 | 13,2 | 39,6 | 4,6 | 196 | 2,1 | 9,4 |
| Fraxinus excelsior | 1 | D | 27 | 12,2 | 11,2 | 23,6 | 2,4 | 122 | 1,2 | 2,9 |
| | 2 | C | 27 | 9,6 | 10,1 | 15,7 | 2,5 | 123 | 1,3 | 3,2 |
| | 3 | C | 26 | 11,5 | 8,6 | 15,3 | 4,9 | 117 | 1,1 | 5,6 |
| | 4 | I | 25 | 10,3 | 9,5 | 13,1 | 2,8 | 68 | 0,6 | 1,8 |
| | 5 | D | 28 | 12,3 | 16,7 | 123, | 4,1 | 139 | 1,4 | 5,7 |
| | 6 | D | 27 | 12,0 | 15,6 | 67,5 | 3,5 | 258 | 2,5 | 8,5 |
| | 7 | C | 27 | 11,0 | 10,7 | 28,8 | 2,4 | 193 | 1,8 | 3,9 |
| Betula pendula | 1 | D | 28 | 12,0 | 15,9 | 58,2 | 6,3 | 230 | 2,4 | 15,3 |
| Acer platanoides | 1 | D | 25 | 12,7 | 13,2 | 66,9 | 5,9 | 49 | 0,5 | 2,8 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | I | 28 | 10,1 | 10,1 | 39,7 | 8,6 | 25 | 0,4 | 2,5 |
| Alnus | 1 | D | 19 | 11,3 | 16,0 | 58,2 | ---- | 98 | 0,8 | ----- |
| Populus | 1 | D | 18 | 12,9 | 18,0 | 67,6 | 5,8 | 196 | 1,9 | 11,1 |
| Picea abies | 3 | D | 33 | 11,5 | 15,4 | 14,1 | ---- | 109 | 1,2 | |
| | 4 | D | 33 | 15,1 | 16,1 | 12,7 | ---- | 71 | 0,8 | |
| | 5 | C | 33 | 14,7 | 16,4 | 12,7 | ---- | 89 | 1,0 | |
| | 6 | D | 33 | 16,0 | 16,2 | 8,75 | ---- | 97 | 1,3 | |
| | 7 | D | 33 | 9,4 | 13,8 | 9,65 | ---- | 66 | 0,8 | |
| | 8 | D | 33 | 9,2 | 12,6 | 8,13 | ---- | 115 | 1,3 | |

The results of measurements of transpiration in a 220 year old stand of fir *Abies amabilis* are presented in the table 8 (Martini et al., 2001). In this research the authors have used a special equipment for measuring the water-flow in the tree trunk. The amount of the flowing water and the water transpired by the treetop is almost equal. In this study it can be clearly seen, that social position of the tree influents both the size of the trees, and thereby the volume of produced mass of timber, and the amount of water collected by the trees as well.

**Table 8.** Sap flow of *Abies ammabilis* in trees with different position in forest (Martin et al., 2001)

| DBH [cm] | Height [m] | Projected crown area [$m^2$] | Leaf area [$m^2$] | Maximum daily sap flow [$kg \cdot dzień^{-1}$] | Tree position |
|---|---|---|---|---|---|
| 78,0 | 41,6 | 39,9 | 460,8 | 281,3 | dominant |
| 54,1 | 37,4 | 23,1 | 241,0 | 101,4 | codominant |
| 31,5 | 25,9 | 14,8 | 70,9 | 9,2 | overtopped |

The prevalent and preeminent trees have the best growth conditions in the stand and this is why, in the circumstances of good access to water, are in a position to reach the greatest size, also these trees are able to develop the greatest number of leaves and also these trees use the largest amounts of water. The maximal water intake of these trees exceed several times the water amount collected by the trees of the general layer of the canopy, and the water amount collected by the stifled trees practically has no significance for the total water use of the stand. There is a clear mutual dependence-relation between the size of the tree, leaf-surface area and the amount of collected (transpirated) water. The advantageous growth conditions for the trees of the upper layer of the canopy are caused by the better micrometeorological conditions of the photosynthesis and transpiration, especially better access to the sunlight and thereby higher temperature and lower air-humidity. Also in the case of individual trees or single bough or even single leaves, the variability of micrometeorological conditions play a great role in the transpiration. The micrometeorological conditions, that exert influence on the water steam outflow from the leaf vary together with the place which is occupied by the leaf in the treetop. The upper parts of the treetop and the external layers of the leaves exposed to solar radiation manifest a significantly higher transpiration rate, caused by higher water steam deficit in the air and greater amount of sunlight what stimulates opening of the stomata (Čermak 1995). Differentiation of the transpiration between the upper and lower part of the treetop is emphasized by variation of the density of leaves. The well insolated upper part of the treetop has over three times more leaves than the shaded lower part (Čermak, 1998). The transpiration rate of the great trees with a dense treetop decreases by about 20%, when the neighboring trees throw shade on them (Čermak, 1995).

In the studies using special methods for measuring the speed of the water that flows in the tree trunk the following results of daily and seasonal water intake of Scots pine have been obtained. Cienciala et al. (2002) have investigated 70 year old pines growing in monoculture on poor sandy soils of North Sweden. The authors communicate that the pines growing inside the forest transpirated 70 mm of water in the growing season, while the pines growing on the timber line – 107 mm. In the studies conducted in Belgium (Nadieshdina et al., 2007) the daily water intake of 72 year old pines amounted to 4,2 $dm^{3}$. Whereas in research conducted in Germany in 3 objects Neuglobsow (65 year old stand), Taura (41 year old stand) and Rosa (61 year old stand), the seasonal water intake of the stands amounted respectively to 121, 84 and 91 mm. The daily water intake on the objects of Taura and Rosa did not exceed 0,90 $mmd^{-1}$, only on the object of Neuglobsow was higher, on the turn of June and July amounted to about 1,4 $mmd^{-1}$ (Rust et al., 1995).

Mołchanow (1960) has been concerned with studies on the influence of the age, bonitation and density on the transpiration rate of stands. He showed that 33-65 year old pine stands have transpired the highest amounts of water per year (up to 250 mm). Also the bonitation of stands is of major importance. The stands of the same age but with different bonitation have transpired for instance : at the age of 65 years I bon – 236 mm, II bon – 173 mm to 217 mm, V bon. – 119 mm.

### 1.5. The Transpiration of the Undergrowth

Most of the studies upon amounts of water utilized by the stands were limited to the tree layer, since because of their size reached the trees are considered to be the main consumers of water. Below there will be mentioned the results of few studies on the transpiration of herbal vegetation of the forest undergrowth.

In lisymetric studies conducted in Eberswalde in Germany, the water intake of the undergrowth of typical pine stand ecosystems in north-east part of Germany has been examined (Müller et al*.,* 1998). Four types of pine forests have been distinguished, with undergrowth mostly consisted of the following species:

I - *Vaccinium myrtillus* ( 35% of cover ), *Deschampsia flexuosa* (60%), *Plerozium schreberi* (25%), *Scleropodium purum* (20%);

II – *Rubus idaeus* (70%), *Avenella flexuosa* (15%), *Scleropodium purum* (60%);

III – *Avenella flexuosa* (85%), *Pleurozium schreberi* (5%),;

IV – *Calamagrostis epigejos* (70%), *Brachytecium salebrosum* (70%).

The obtained results indicate that the highest amount of water is collected by the undergrowth with the majority of *Calamagrostis epigejos,* the total water demand of which has reached 33% of total yearly precipitation, a little less water is required by *Avenella flexuosa* , it has collected about 30% of yearly precipitation, the undergrowth with blackberry bush *Rubus idaeus* has collected about 25% of yearly precipitation water income, the smallest water demand characterized the undergrowth with blueberry bush *Vaccinium myrtillus* and *Avenella flexuosa* – the water collection did not exceed 20% of total yearly precipitation. The total yearly precipitation amounted from 629 to 669 mm.

The transpiration of the undergrowth in pine stands of North Germany has been demonstrated also in the studies of Dietmar Lüttschwager's team (1999). The experiment has been carried out in three stands, with the following characteristics:

I – The region of Rösa, average yearly precipitation – 566 mm, average yearly air temperature 8,87$^{o}$C, the type of the ecosystem (vegetation group) *Calamagrostio-Cultopinetum sylvestris,* 61 year old pine stand, the number of trees per ha – 935, average height 16,0 m, average trunk circumference 20,7 cm,

II – The region of Taura, average yearly precipitation – 565 mm, average yearly air temperature 8,87$^{o}$C, the type of the ecosystem (vegetation group *Deschampsio-Cultopinetum sylvestris,* 45 year old pine stand, the number of the trees per ha – 935, average height 18,0 m, average trunk circumference 20,6 cm, III – The region of Neuglobsow, average yearly precipitation – 586 mm, average yearly air temperature 8,18$^{o}$C, the type of the ecosystem (vegetation group) *Myrtillo-Cultopinetum sylvestris,* 65 year old pine stand, the number of the trees per ha – 1043, average height 20,1 m average trunk circumference 21,0 cm.

On each experimental area in regards to the time-related variation of species composition in the undergrowth, for the most important species the LAI index was defined in the same period that the transpiration measurements have been made. The results of these examinations together with the percentage of each species in the transpiration rate of stand are presented in table 9.

In the case of the German studies, the investigation area and the forest ecosystems of which are quite similar to the ones occurring in Poland, it can be noticed that *Calamagrostis epigejos* and *Deschampsia flexuosa* are the highly-transpiring species of the undergrowth. In the case of full covering of the forest floor with these species, the water requirement of these can be equal to the water requirement of a pine stand. Thus it can be acknowledged that these species are competitive towards the stand as for profiting from the resources of ground water, and for that reason should be eliminated from the stand, especially on the areas where water deficiency occurs. Whereas a species with minor water requirement is European blueberry, the presence of which, also as a significant addition in the undergrowth with the domination of *Calamagrostis epigejos* or *Deschampsia flexuosa* significantly decreases the total water requirement of the undergrowth.

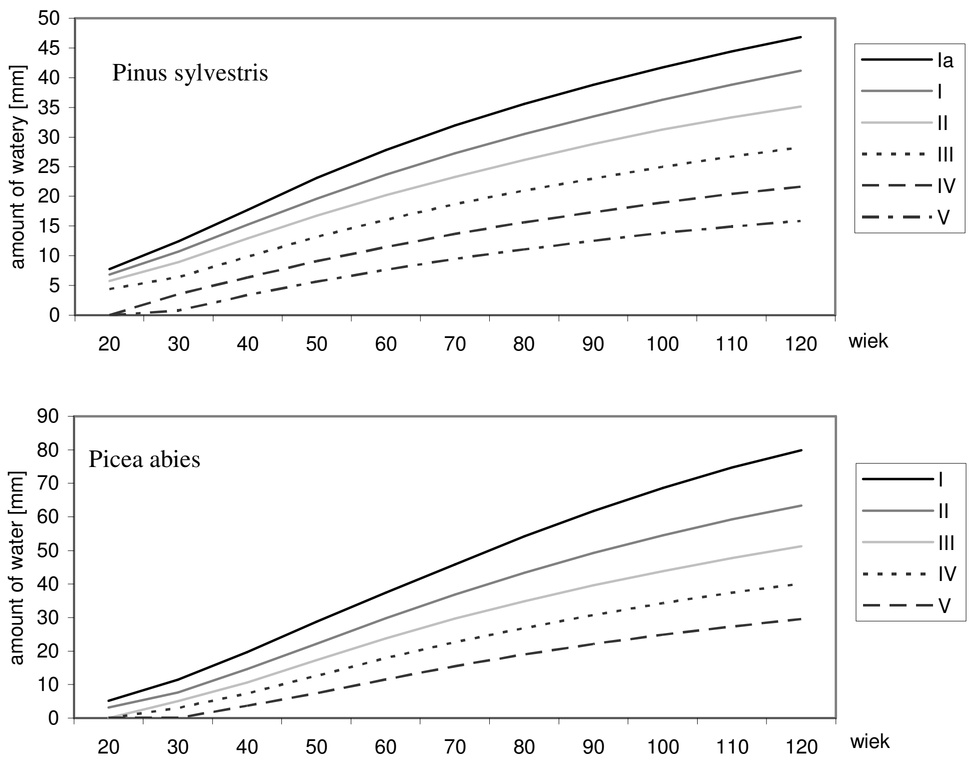
**Table 9.** LAI and transpiration of herb layer Scots pine stands with different stand structures (Lüttschwager et al.,1999)

| Location | Species (only covering >10%) | End of April | | End od May | | End od June | | End of July | |
|---|---|---|---|---|---|---|---|---|---|
| | | % LAI | % transpiration | % LAI | % transpiration | % LAI | % transpiration | % LAI | % transpiration |
| Rösa | Pinus sylvestris | ----- | 72 | ----- | 44 | ----- | 52 | ----- | 50 |
| | Calamagrostis epigejos | 54 | 20 | 45 | 41 | 49 | 31 | 25 | 18 |
| | Brachypodium sylvatiocum | 33 | 7 | 48 | 11 | 39 | 11 | 58 | 18 |
| | Rubus idaeus | 0 | 0 | 3 | 1 | 7 | 4 | 6 | 6 |
| | Rubus fabrimontanus | 13 | 1 | 3 | 2 | 5 | 3 | 4 | 5 |
| | Deschampsia flexuosa | 0 | 0 | 1 | 0 | 0 | 1 | 7 | 3 |
| Taura | Pinus sylvestris | ----- | 67 | ----- | 57 | ----- | 49 | ----- | 45 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Deschampsia flexuosa | 100 | 33 | 100 | 43 | 100 | 51 | 100 | 55 |
| Neuglobsow | Pinus sylvestris | ----- | 74 | ----- | 76 | ----- | 58 | ----- | 66 |
| | Deschampsia flexuosa | 88 | 17 | 91 | 21 | 79 | 29 | 77 | 28 |
| | Vaccinium myrtillus | 12 | 9 | 9 | 3 | 21 | 13 | 23 | 6 |

## 2. The Role of the Forest in the Hydrologic Cycle

The stand considered as a total number of trees only to a small extent influences directly the increase of water retention. The water amount retained in the timber of the main forest-formative species, determined on the basis of the tables of stands' resources (Szymkiewicz, 2001) and of the raw timber humidity (Krzysik, 1970) indicates, that trees older than hundred years contain in their tissues only several dozen millimeters of water (Fig.1.).



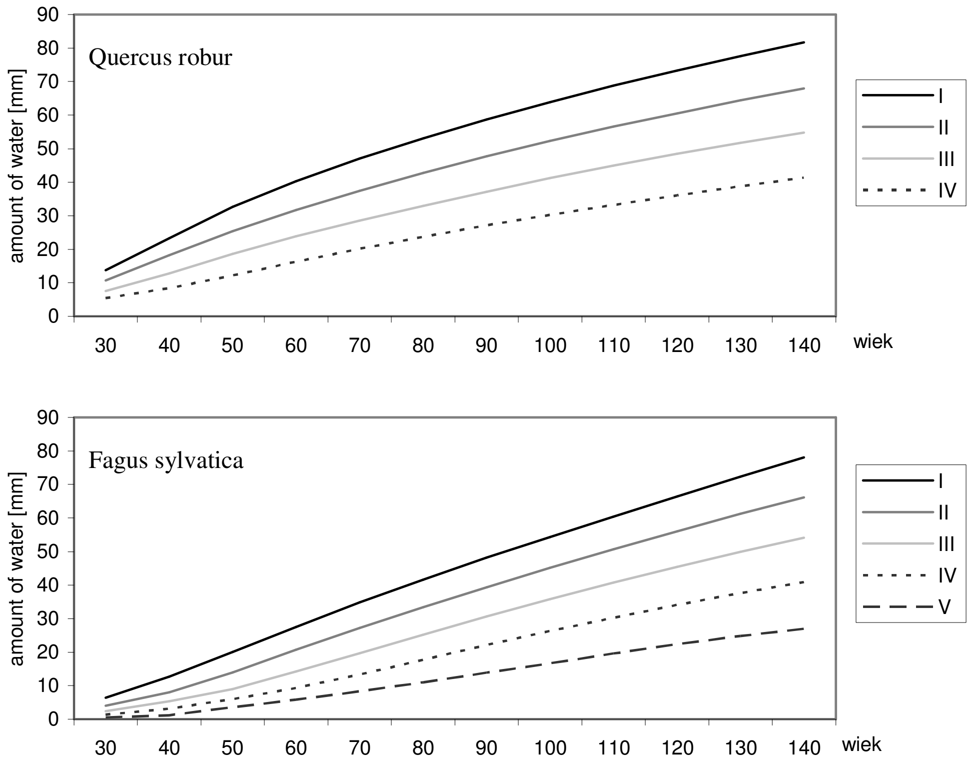



**Fig. 1.** Changes with age the amounts of water of the different evaluation stopped in the wood of trees

However the ecosystem of the forest, as a multi-layer system of a high three-dimensional complicatedness exerts a great influence on the water cycle, what manifests itself by the following :

- Ability to lower the water outflow through retention of the water in the forest soil, high water requirement of the stand, high interception rate (deforestation of the river basin leads to the immediate increase of water outflow by about 35% (Dubicki, Woźniak 1993).
- Reduction of the superficial flow by development of the organic layer of the soil land forest cover layer,
- Ability to balance the temperatures , what manifests itself among other things by persistence of low temperatures after winter, resulting in longer remaining of the snow cover and its flower melting, what causes belated and prolonged outflow of the water from the thawing snow, also flattening and elongation of the spate.

The forest ecosystems intensively alter the water circulation in early spring, when causing changing the superficial overflow of water into ground overflow, and also in the vegetation season when retaining practically the total precipitation water.

The compact layer of the forest vegetation make a barrier against the overflow of the precipitation water into the soil. The amount of retained precipitation (interception) is characterized by a large variability within the species and among different species as well (Ulrich et.al. 1995). During the vegetation season the water intake of the forest flora efficiently limits the overflow of water into the depth of the soil profile. In habitats supplied only with precipitation water the stand and the remaining vegetation layers collect the total available water contained in the soil.

The role of the stand in limitation of the superficial overflow has been presented among others by Adagiu and Arghiriade (after Bac, Ostrowski 1969): at level drop amounting to 33% the average superficial overflow from an area without vegetation has been measured out as the 43% of precipitation, whereas from a beech stand depending on its density from 0,6% to 1,2%. Also at larger ground level drop the overflow from the forested area is reaching values giving the evidence of high limitation of this process: at ground level drop of 48% from 55 year old beech and spruce stand averagely 0,8% of precipitation has flowed, from beech stand of the same age at ground level drop of 62% - 3,4% of precipitation has flowed down. In the forests of Vietnam only just 1-2% overflow of precipitation has been measured as superficial overflow (Podwojewski et al*.,* 2008), even dough the yearly precipitation reached up to 1800 mm.

The effect of forestation level on the overflow of water in water courses has been presented i.a. on the example of Białowieża Forest's region by Pierzgalski (Pierzgalski et al. 2002). It has been demonstrated that enlargement of forestation influences the delay of snow thawing spates. On an agricultural collecting area of Chwiszcza river with an 8% forestation level the culmination of snow thawing spate occurred two week earlier than on the collecting area of Orłówka river with a 100% forestation level. The outflow index of comparable collection areas during the period of 1985-1999 amounted to 0,063 in summer half-years and to 0,217 in winter half-years in the completely forested basin of Orłówka river and respectively 0,075 and 0,381 in the agricultural basin of Chwiszcza river.

The forest ecosystems constitute a compact cover of the ground, which one through its being multi-layered considerably influents the overflow of the precipitation water by limitation of its erosive abilities. Amongst the most important features connected with the anti-erosive protection of the forests can be numbered:

- decrease of the amount of water reaching the ground,
- decrease of the energy of the rain reaching the ground,

- limitation of the superficial outflow,
- decrease of the speed of the water that flows down the hillside (high roughness index of the ground surface),
- absorption of the water by the cover and the organic layer of the soil.

Detention of the precipitation in the treetops decreases the amount of the water that reaches the soil, what makes a contribution to limitation of the erosion. Coming of the precipitation across the canopy of the stand causes the breakup of the raindrops and decrease of their energy. The ability of stands to limit the superficial outflow has a fundamental meaning for the inhibition of the erosion. Adagiu and Arghiriade (after Bac, Ostrowski 1969) present exemplary differences in the amounts of eroded soil depending on the cover of the area :

- area without vegetation cover – the soil erosion rate 32 000 $m^3$/ha,
- area with above 100 year old beech stand with density of 0,8 - 0,068 $m^3$/ha, but with density of 0,7 – 0,152 $m^3$/ha,
- area with 55 year old beech and spruce mixed stand with density 0,8 – 0,120 $m^3$/ha
- area with 55 year old beech stand with density of 0,8 – 0,913 $m^3$/ha, and with density of 0,6 – 0,517 $m^3$/ha.

Deforestation of wide areas will lead to increase of the problem of erosion, especially in mountain regions. Presently this problem will occur and increase in the Beskides, where spruce stands die away in masses, leading to the uncover of the hillsides.

## 3. The influence of the forestry management on the hydrologic situation

Conducting a forestry practice that consists in total or partial removal of the stand strongly affects the respective elements of the environment that influence the circulation of water. The removal of the trees results in reduction of the evaporating surface leading to decrease of transpiration, and also to smaller interception (Breda et al., 1995). Consequently the humidity of the soil increases. Therefore in the case of stand thinning operations advantageous conditions are being created for the development of the left trees and of the lower layers of the stand also the natural restoration. Whereas in the case of clear-felling it comes to the increase of outflow and of superficial overflow. Oliinik and Chubatyi (1978) have measured that such operations lead to the increase of the river-outflow by 35%. Conducting of an operation of stand-thinning results also in decrease of the amount of organic matter cumulated in the soil land on its surface. In 30 year old spruce stands it has been measured that his decrease reaches 20 t/ha, what directly affects the water circulation (Podrazsky et al*.,* 2006). Particularly of great importance for the water circulation is the forestry management conducted on the areas with organic soils, e.g. areas drained earlier. Conducting of cutting young stands on such an area results in considerable increase of the outflow (Grace et al., 2006).

Appropriate selection of the species composition of the stand also exerts influence on the water circulation. In lisymetric studies conducted in Eberswalde it has been pointed out that the evapotranspiration of the forest, defined as the total amount of the transpiration of all layers of the stand and the evaporation of the soil amounts in the case of: pine stands (84 year old) – 76% of the yearly precipitation, pine stands (51 year old) undergrown with beech (11 year old) – 81%, pine stands (76 year old) with a second level of beech (33 year old) – 82%, and for beech stands - 83%. Contemporarily a decrease of interception appears amounting respectively: 29%, 23%, 24%, 22% (Muller, 2003). The species composition of the stands exerts an influence on the kind and the quality of the humus. The change of the composition from wild pine to beech has caused a change in the type of humus and has led to the loss of the volume of organic matter (by the reason of accelerated mineralization). On comparison to the stands composed of one species, the mixed stands demonstrate decrease of water retention capacity from 30-50% (Schäfer et al*.,* 2002).

IBL examinations (Białkiewicz F. and Babiński S., 1980) carried out in several small lowland catchments in the eastern part of the country demonstrate that the amount of retained water rose by 59 mm as a result of the reconstruction of tree stand and phytoremediation, while the evapotranspiration rose only by 9.5 mm. In consequence, the effective retention increased by 50 mm.

Not only the direct interference with the stand, but also making available the forest for different purposes, including conducting the cultivation by building of forest roads and working on the log skidding tracts, strongly influence the water circulation. The roads are barriers for the natural movement of the water in the forest. Intensive exploitation of the roads and skidding tracts in the mountains leads to formation of highly erosive areas (Vicha et al*.)*

## 4. Regulation of the hydrologic relations on the forested areas in Poland

### 4.1. Land drainage (temporary improvement)

From the beginning of the fifties to the end of 1991 on the areas of State Forests drainage installations have been realized on the territory of 850 000 ha. From 1992 the drainage installations have been realized only to a very small extent (Fig. 2). The and improvements have been carried out primarily on the areas recognized as excessively damp, what determined the draining character of these. The gravitational drainage systems perform a positive function (timber production) in the damp habitats during the initial period of working of the fittings, but later in rainy years, the lack of possibility of closing the outflow or its inhibition is the one of the reasons of water deficit increase during rainless periods, and also of disadvantageous transformations of the environment.

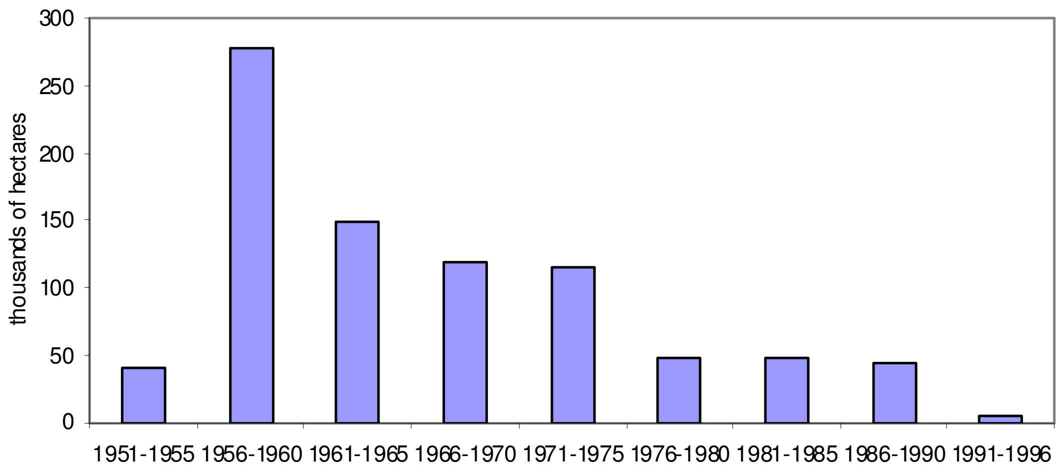



**Fig. 2.** Performing land reclamation on woodlands since 1951 (Wiśniewski 1996).

In the light of the present knowledge of the environment „*making the marshy wastelands in the forest productive”* is rated negatively, also the cases of wrongly accomplished or exploited hydrologic installations, especially in the local depressions of the terrain, where the improvement of the hydrologic situation in a small fragment of the forest could have cause habitat variations in its major environment. Currently occurring rainless periods of long duration indicate necessity of activation relating the restitution of retention capacity of hydrologic installations. Since many dam constructions had been a subject of decapitalization, and lack of their maintenance and of proper handling restricts their functionality.

Currently under the assumption that the drainage installations existing in the forests should be adapted for performing retention functions, by possibility of limitation or closing of the outflow. It demands, except for additional investments, also appropriate maintenance and exploitation of installations adjusted to the actual and predicted weather conditions. In the forests irrigation, except for regulated outflow, is used only in forest nurseries.

In 1997 the Director-General of the State Forests General Management approved initiation the elaboration *The principles of planning and realization of small retention in the State Forests*. In this elaboration the concept of small retention has been defined, as an ability of water collection in „*small natural and artificial water reservoirs and dam up of the water in the river and stream beds, channels and ditch”*. As the objectives of small retention the following have been recognized :

- improvement of irrigation of the forest habitats by elevation of the ground water level on the areas directly adjoining the reservoir or the dam installation,
- modification of the rapid outflow of the superficial water from the forest area to slow ground outflow,
- diversification and improvement of the forest environment,
- to provide the forest game, the birds and insects with water what consequently is conductive to increase of biological resistance of the stands,
- to provide water for fire protection,
- to provide water for farming purposes, for sprinkler irrigation and for fishery,
- formation of recreation areas.

In the amended in 2003 *The Principles of the Sylviculture* it is recommended for the forest inspectorates which desiderate water should work out a small retention development program with consideration of the following:

- conservation of the natural water reservoirs and water courses in approximately natural condition,
- conservation of the river valleys in natural conditions, including riparian forests, carrs, and other natural environmental formations,
- conservation of forest swamps , bogs, mosses and meadows,
- reconstruction and renaturation of the damaged and dry bog moors and restitution of the natural shape of the water courses and drainage ditches which were regulated in the past.

### 4.2. Small Retention Programs

***Territorial estimate of the needs of small retention***

For the requirement of Country Program for Retention Enhancement two analyses have been prepared which contain distinction of the country regarding the needs of small retention. In the analysis of the IMiGW in Poznań entitled: „ Hierarchy of the area needs of small retention in Poland" the requirements, planning principles and realization of the small retention on the territory of country regarding the environmental conditions. In this analysis the realization of the tasks of small retention in agricultural areas, and in forest areas, on which the deficit of water is the most noticeable. It has been underlined that the small retention had to be treated as activity that leads to:

- improvement of the hydrologic situation through retention of the maximal amounts of precipitation (dam up of the water courses, build-up of water reservoirs),
- improvement of the water quality,
- limitation of the transit of rubble.

The regional requirements within the range of small retention have been defined on the basis of analysis of spatial variation and differentiation of the following elements of the environment,

- distribution of precipitation,
- maximal total daily amounts of precipitation,
- duration of the meteorological dry periods,
- periodicity of occurrence of hydrologic dry periods,
- distribution of medium-low-, low-, and medium-high maximal outflow with p+1%,
- characterization of the spates,
- disposition of the forest and marshy areas,
- disposition of the water resources of the lakes,
- disposition of places with special natural attractions,
- water deficit of the croplands,
- climatic water balance.

The second analysis, concerned with the needs of small retention is the one realized In IMUZ Falenty entitled „ Small retention – the needs and capabilities of retention". In this paper the voivodships have been ordered according to their characteristic features, which indirectly evidence the needs and capabilities and legitimacy of the realization of tasks of small retention. There have been admitted 13 criterions, that characterize each voivodship, namely :

- the number of day sequences with duration of at least 15 days without precipitation in the vegetation season,
- yearly water resources characterized by adequate intensity for utilization in small energy production,
- proportion of reclaimed areas,
- proportion of irrigated areas,
- proportion of marshy areas,
- proportion of drained grounds,
- proportion of areas of fish ponds,
- deficits of water,
- agricultural and climatic deficit of the precipitation,
- outflow index,
- the index of the areas of national parks, nature reservations and landscape parks.

As the result of the above mentioned studies there has been created a collaborative valuation of the hierarchy of the small retention needs, in which within the territory of the country there have been distinguished four zones differentiated according to the needs of small retention :

*Zone I* – with the most urgent requirements of the development of small retention, as a consequence of disadvantageous climatic conditions and great needs of improvement of hydrologic situation on agricultural areas. To this zone the following voivodships have been qualified according to the former administrative division: siedleckie, bielsko - podlaskie, chełmskie, zielonogórskie, gorzowskie, pilskie, poznańskie, leszczyńskie, konińskie, bydgoskie and włocławskie.

*Zone II* – with great requirements of the development of small retention, having better climatic conditions than the zone I, having great needs of agriculture, industry, and municipal management. To this zone the following voivodships have been qualified: kaliskie, sieradzkie, piotrkowskie, łódzkie, radomskie, skierniewickie, warszawskie, płockie, toruńskie, ciechanowskie, ostrołęckie, łomżyńskie and białostockie.

*Zone III*- with intermediate requirements of small retention development, as a consequence of advantageous with relation to the general conditions of the country climatic conditions, but having great needs of water. To this zone the following former voivodships have been qualified: szczecińskie, koszalińskie, słupskie**,** gdańskie, elbląskie, olsztyńskie, suwalskie, legnickie, wałbrzyskie, opolskie, częstochowskie, katowickie, krakowskie, kieleckie, tarnowskie, lubelskie, zamojskie.

*Zone IV* – mountain-zone with the greatest superficial water resources , in which the problems of the small retention have to be treated in a special manner. It is a zone, where there are the most advantageous conditions for the build-up of the larger water reservoirs.

***The requirements and possibilities of enlargement of water retention in the forests***

The realization of the small retention program in the lowland forests can be conducted through the following:

- utilization of the water collecting potential of the existing drainage systems
- build-up of dam installations on the natural water-courses,
- realization of „dug" reservoirs.
- The existing drainage systems which provide great capabilities in the forests mostly consists of drainage ditches. It should be also noticed that these systems have originated on the areas formerly existing as water reservoirs that created areas of ground retention or areas of water collected in swamps and small ponds. The drainage systems have been made only for utilization on the permanently waterlogged areas, or periodically waterlogged areas with the object of reposition of the superficial water that stagnates for too long period in spring. And although the canons of land improvement indicated the necessity of application of outflow regulating system, after all the build-up of the dam-up installations had frequently been planned in the second stage of the investment, which usually had never been realized. The lack of possibility to close the water outflow caused persistent drawdown of the ground water, resulting in habitat changes and in disappearance of areas the environmental value of which is currently detected, since these areas increase the biological differentiation.

The drained grounds in the forested terrains take an area of non trifling size, since as Wiśniewski (1996) reports, to the end of 1991 the drainage installations have been realized on an area of 850 000 ha. In the next years the new investments have been realized in inconsiderable dimension, limiting the working to the areas which have been drained already. Therefore the area of 850 000 ha can be regarded as the size of area on which potentially the works aimed to increase the water retention or to renaturize the hydrogenic habitats, should be carried out. The total requirements within the range of regulation of the hydrologic relations have been estimated as 1050 000 ha. This fact indicates, that in the case of including in the small retention and renaturization program the wetland areas, the area size of the marshy habitats in the forests can significantly increase.

Utilization of the drains as retention reservoirs is beneficial also in regards to the long shoreline of the ditches, through this there is a intensive influence of the water collected in the ditch on the forest habitats. Transformation of the drainage system into retention system can lead to the increase of the amount of water in the soil, therefore in the vicinity of it should appear species characteristic for the wet- or marshy habitats. The increase of soil humidity can also benefit the forest management, especially on the areas with organic soils, where in consequence of drying up the process of rot is taking place, and in the case of unveiling of the rot it undergoes intensive erosion and blowing away. Transformation of the land improvement systems must take into account the actual condition and characteristics of the stands growing on these areas. However in many cases the drainage led to improvement of the water conditions and to improvement of the condition and productivity of the stands. In such cases it should be considered, whether restoration of the swampy conditions is well-founded, since working with the direction of heightening the ground-water level will lead to mass die-back of the trees and transformation of this areas into ones, which are unprofitable regarding the forest production.

The second group of objects, on which superficial retention increasing activities can be carried out, are the existing natural water courses. Although utilization of the drainage systems as retention reservoirs is a method, which can be recognized as safe regarding the high degree of transformation of natural environment through drainage, insomuch increase of retention through dam-up of the natural water-courses ties in with a variety of threats for the existing environmental system. In the valleys of water-courses occur habitats, often of great environmental value, which regarding their location often are substantially natural. In the case of such investments it is necessary to perform a particularly detailed recognition of environmental values and to forecast how will the heightening of the water level of the water-course influence the circumjacent forest environment and whether the main objective will be realized without a loss for the other components of the environment. For instance high water-level in a water-course that remains stable for a long time can cause die-back of trees growing in the valley of the water-course and in consequence leads to transformation of the marshy forest habitats into non forest habitats – bulrush or brushwood habitats. Therefore if the purpose of the retention increasing activities is the preservation of the forest habitats, the dam-up constructions ought to be projected with an extreme circumspection, and continuous monitoring of the water level and of the health of the trees should be maintained, in order to lower the dam-up level in the case of threats – what should be made possible by the dam-up construction. Particularly it is necessary to keep in mind preservation of the wetland habitats, which occur in Poland on a small area and the existence of these depends on the horizontal movement of the ground- and surface water. Stopping of the water that flows in the water-course and its dam-up leads to inhibition of the water movement what creates unfavorable conditions for the wetland habitats.

Building over of the water courses with dam-up constructions to start with should take place in the case of regulation of these formerly. It have led to the acceleration of the outflow what caused bottom erosion. An alternative for building of dam-up constructions is the possibility of replacement of the water-courses to their old riverbeds or make the water-course meandering, thanks to that a longer way of outflow and speed reduction is gained as results of the diversification of the course of the flow. However these methods are largely more expensive, though in regards to the greater influence of the water on the neighboring areas and to the reconstruction of the nearly natural conditions, are more beneficial. Particularly sensitive for the variations of the water conditions is the ash and alder wetland, which may diminish in cosequence of changes of hydrologic relations. As a result of greater humidity of the ground paludal and carr species may appear (the process of swamping and carring), in the case of drying process – species from lime-oak-hornbeam forest.

The third group of objects, that are able to retain water are the „dug" basins, which may be without outflow or with the overflow of water. In the case of the basins without overflow, the colleted water will be derived from the ground resources and from precipitation. Theoretically such basins can be made in any place. However the necessity, possibility and purposefulness of such an investment should be considered. Potentially the forest areas, where such objects may come into being are the wet and marshy habitats. In the fresh habitats in regards to the low ground water level and ground permeability the water retention is very difficult, and digging of a "wholes" of depth of a few meters in the ground is pointless. Whereas as to the habitats with high ground water level there appears a question „ whether the change of the ground retention into superficial retention is advisable?" In many cases it is not, and on the areas with organic soils buildup of such objects is simply harmful, because the rare habitats are damaged and the effects of retention seems to be doubtful.  In is particularly regarded to bogs, where attempts at forming of open water surface leads to decrease of the amount of collected water, since the bog retains extreme amounts of water and opening the water surface causes increase of the evaporation. Furthermore construction of dug basins on bogs is connected with degradation of existing unique habitats. It is also necessary to reflect on the aims and necessity of reconstruction of small forest reservoirs. In the cases , when the disappearance of a pond has been caused by human activity, the reconstruction of such an object seems to be advisable, however it should be remembered that the process of overgrowing of the reservoirs is a natural process of devolution. For that reason it is important to diagnose the situation before the startup of the reconstruction activities, so as not to waste the elements of the environment of great natural value.

However the build-up of overflow reservoirs through widening of the banks of a flow and heightening the water level by means of a dam-up construction is beneficial in many respects:

- enlarges the length of the contact of the shoreline with the circumjacent overland environment, and increases the influence of the water on the neighboring areas;
- changes the characteristic of the flow from drainage course into irrigative course;
- there are forming beneficial conditions for the development of aquatic plants and of many species of intervertebrates and vertebrates,
- the landscape is differentiating, especially in regions poor in natural reservoirs.

This kind of reservoirs which are formed through widening of the riverbed and build-up of a dam-up construction usually cumulate great amounts of water. Particularly beneficial for the circumjacent ecosystems are the basins, which are formed with diversified shoreline. Through that unique microhabitats are created, which significantly differentiate the ecotone zone between the basin and the land. Build-up of reservoirs on water-courses seems to be quite reasonable in the case of that have been regulated before.

***Realization and needs of activity within the range of small retention in the State Forests National Forest Holding***

The realization of small retention in the State Forests included the build-up of small water reservoirs and of dam-up and accompanying constructions on the water-courses situated in the forested areas. In the years 1998-2005 totally a number of 2216 constructions of this kind have been realized. These are very small reservoirs with the average capacity below 10 000 m3. The dam-up constructions are mostly water-gates, river bars and small dams. The costs of the realization of small retention in the forests amounted to about 38,6 million zloty, including mainly funds of State Forests with the support of WFOŚiGW, EkoFundusz, and of external funds.

In the years 2008-2013 it is planned to put into operation above 4000 objects of small retention, which make a contribution to collect totally about 40 million m3 of water. These undertakings will be realized within the frames of the program entitled : *Enhancement of retention capacities and prevention of floods and droughts in the forest ecosystems on the lowlands*.

With reference to the hierarchy of needs presented in the beginning within the range of small retention it should e noticed, that on the areas of Zone I the management of State Forests forecasts realization of many activities within the range of small retention, concerning in particular Regional Management of the State Forests (RDLP) in Poznań and in Toruń. In the regional managements which administrate the forests on the areas reckoned to the Zone III –also many undertakings are planned, however these are referred to improved areas primarily e.g. Regional Management of the State Forests (RDLP) in Szczecinek. In seems that in some regional managements both the needs and the possibilities of realization are greater than the declared proposal. For instance in the RDLP Łódź, the considerable area of which is situated in the zone „ with great requirements of development of the small retention", relatively little range of activities connected with the enhancement of the retention have been declared

The realization of the activities that make contribution to enhancement of small retention on the lowlands by the State Forests National Forest Holding, should be based generally on the areas which have been subjects to land improvements. The total surface of such areas is about 1 million ha. The existing drainage systems should be adapted for the storage of water. In contrast with the other methods of enhancement of superficial retention i.e. dam-up of the natural water-courses and digging of outflowless basins, utilization of the existing drainage system is beneficial also in regards to the little interfering with the natural environment, therefore the realization of the small retention program will not damage the wetland habitats. Furthermore the retention of the water in the drains will conductive to restoration of the condition of these areas from the period before the drainage , his means that these activities will lead to renaturation of the wetland areas. Also in the case of natural water-courses the activities that lead to enhancement of retention should be situated on the regulated water-courses.

Despite the great range of activities that have been declared by the units of State Forests Management it may be ascertained that in comparison to the needs existing in the country, and which get out of the great area transformed by the man, these activities should be treated as the beginning of the pursuits of improvement of the hydrological conditions.

## 5. Conclusion

Presented issues of the influence of forests on the water cycle point out to great possibilities of water retention in woodlands. Forests by the size of their territory can play major part in the water management. Properties of forests enable to achieve this objective in three ways:

- increasing small water retention assisted with reservoirs storing the excess of spring thaw,
- increasing the soil retention,
- shaping the structure of tree stands.

Improvement of the soil water retention can be achieved by disseminating activities aimed at control the loss of soil organic matter and even its restoration, preventing further drying of the soil cover and the restoration of the proper structure of the soil. The increase of soil organic matter improves the soil structure by rising the share of medium size pores that are of great importance for the amount of water availability for plants, and hence soil retention capacity rises and prevents drying.

These date show that when the area of forests amounts to 9.1 million hectares in Poland, at properly formed structure of the tree stands and phytoremediation it is possible to retain over 5 billion $m^3$ of water in forest ecosystems. This is a huge amount considering that in Poland there are 150 large and medium reservoirs. Their total capacity is about 3.5 $km^3$.

# Game abundance and hunting bag in Polish forests (numerical data, regional variation, changes in the last decade, available sources with the commentary)

*Dr Jakub Gryz*

## 1. Introduction

Currently there are 13 birds and 18 mammals on the list of game species (the Regulation of the Minister of the Environment of 16 March 2005, Official Journal of the Laws 2005, No 48, Item 459). In the last decade three new species entered the list: racoon dog (*Nyctereutes procyonoides*) and American mink (*Neovison vison*) in 2001 (the Regulation of the Minister of the Environment, Official Journal of the Laws 2001, No 43, Item 488, with later changes), and racoon (*Procyon lotor*) in 2004 (the Regulation of the Minister of the Environment of 16 April 2004, Official Journal of the Laws 2004, No 76, Item 729). One species, grey heron (*Ardea cinerea*) has been deleted from the list.

In many cases it is difficult to explicitly classify game species as typically forest or otherwise related to other ecosystems. Roe deer may serve as an examples as there are two ecotypes (field and forest) of the species. Also, wild boars may spend a few months annually outside woodland, inhabiting vast corn fields. Moreover, population of red fox successfully inhabit forest, agricultural land as well as build-up areas. Having the aforementioned facts in mind, species of the highest significance for the economy (i.e. big game) are characterized at first. Among small game abundance trends for fox, badger and two typically forest birds were analyzed. Remaining 20 species: stone marten (*Martes foina*), pine marten (*Martes martes*), raccoon dog, raccoon, American mink, Western polecat (*Mustela putorius*), muskrat (*Ondatra zibethicus*), brown hare (*Lepus europaeus*), rabbit (*Oryctolagus cuniculus*), coot (*Fulica atra*), woodpigeon (*Columba palumbus*), mallard (*Anas platyrhynchos*), pohard (*Aythya ferina*), tufted duck (*Aythia fuligula*), teal (*Anas crecca*), white-fronted goos (*Anser albifrons*), bean goos (*Anser fabalis*), greylag goos (*Anser anser*), partridge (*Perdix perdix*), pheasant (*Phasianus colhicus*), were omitted as they are not strictly connected with forest areas or their economical significance is marginal.

The information presented in this study is grounded mainly on the Statistical Yearbooks of the Central Statistical Office (GUS) that base on the hunting reporting. If it is not the case, the alternate source is given. Hunting statistics in Poland are drawn up on the base of annual hunting plans prepared by managers and leaseholders of hunting districts. It needs to be noted though that error of such data may be considerable and difficult to estimate. It is mainly due to the lack of willingness of hunters to do the game inventory, which is because of numerous economical, sociological and technical factors. Most of the annual plans are grounded on so-called "all-year-round observations". Yet, the activities and procedures are not methodologically defined, which in practice means that the obligatory forms are filled with not quite reliable data. The credibility of such data, being the result of "all-year-round observations" was questioned by researchers many times (i.e. Nasiadka 1998, Bobek et al. 2006, Bobek et al. 2007, Bobek et al. 2009). Only in a fraction of hunting districts and game breeding centers annual inventory is conducted according to acknowledged methods (i.e. Ciepluch 2005). The hunting bag data, especially this referring to big game, is much more credible.

## 2. Species review

### 2.1. Elk (*Alces alces*)

Among ungulates elk is the largest species, spread mainly throughout taiga and tundra. West border of the species range lays in Poland. In the second half of 1940s remnant population of elk in our country survived only in Biebrza marshes. Thanks to natural expansion from the area of former USSR and reintroduction in 1951 to Kampinoska Forest, elk's Polish population grew both in number as well as in the occupied territory. Harvesting of the species began in 1970. In the 1980s and 1990s due to overexploitation (being the result of abundance overestimation), national population of elk was in severe decrease (Gębczyńska & Raczyński 2001, Okarma & Tomek 2008). As a result, in 2001 all-year round closed season for the species was introduced (Regulations of the Ministry of Environment of 10 April 2001 and 16 March 2005). Moratorium on elk culling is still in power. In the last season before the moratorium was introduced (2000/2001) ca. 300 individuals had been harvested.

As elk's cooling stopped, the decreasing trend reversed and during the last decade a systematic growth in the species number was observed. In Spring 2009 7,515 individuals were recorded (fig. 1).

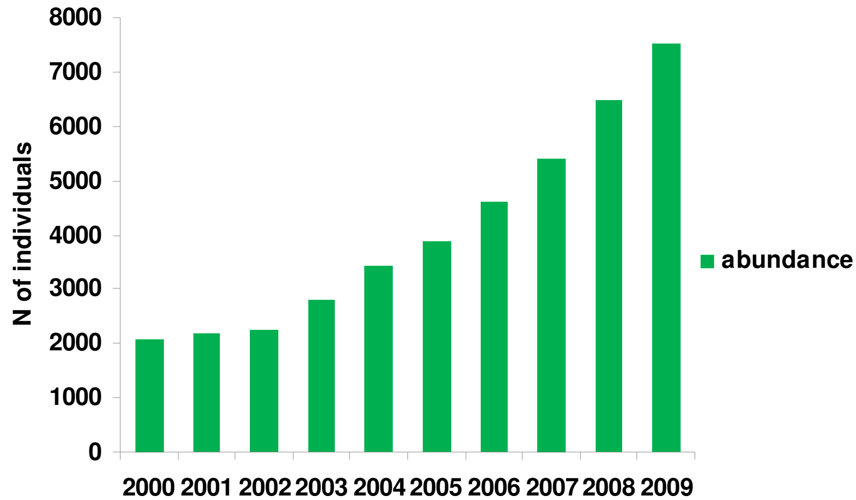



**Figure 1**. Changes in the number of elk in Poland in the last decade

Comparing the above-mentioned result with other data, referring to the same year but derived from other sources, reveals some discrepancy. According to figure 1 in 2007 5,414 elks were inventoried. Yet, data delivered by Nasiadka (2008) indicates abundance on the level of 3,500 individuals. Nowadays, similarly to previous decades, elks are most numerous in the Voivodeships: Podlaskie, Warmian-Masurian, Lublin, and Masovian (Budny et al. 2010).

### 2.2. Red deer (*Cervus elaphus*)

The species occurs in the whole country, the most numerously in West Pomeranian and Warmian-Masurian Voivodeships. The lowest densities are noted in central Poland, in the areas with low wood coverage (Masovian and Łódź Voivodeships). In the last decade a growth in number from 117.5 thousands in 2000 to 176 thousands in 2009 was recorded (fig. 2). The hunting bag varied slightly between years (39 to 46 thousands, fig. 3).

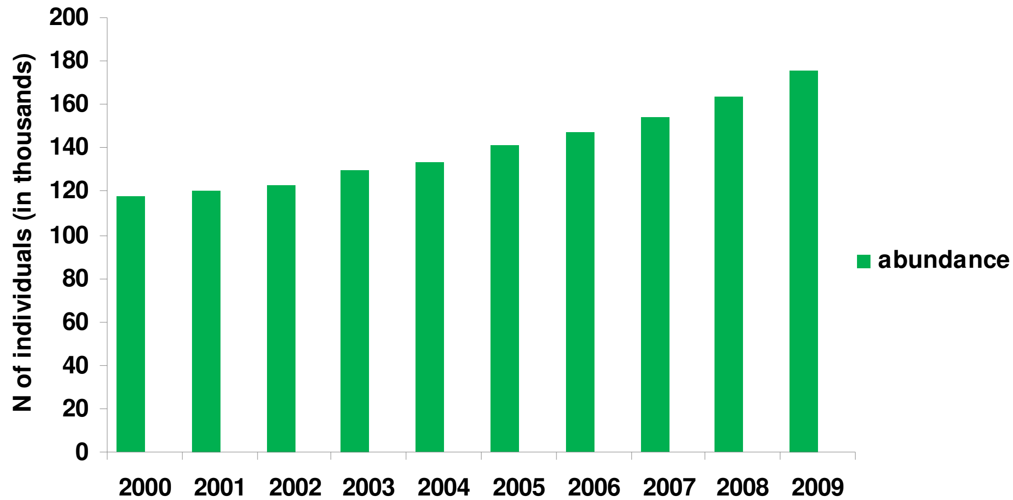



**Figure 2.** Changes in the number of red deer in Poland in the last decade

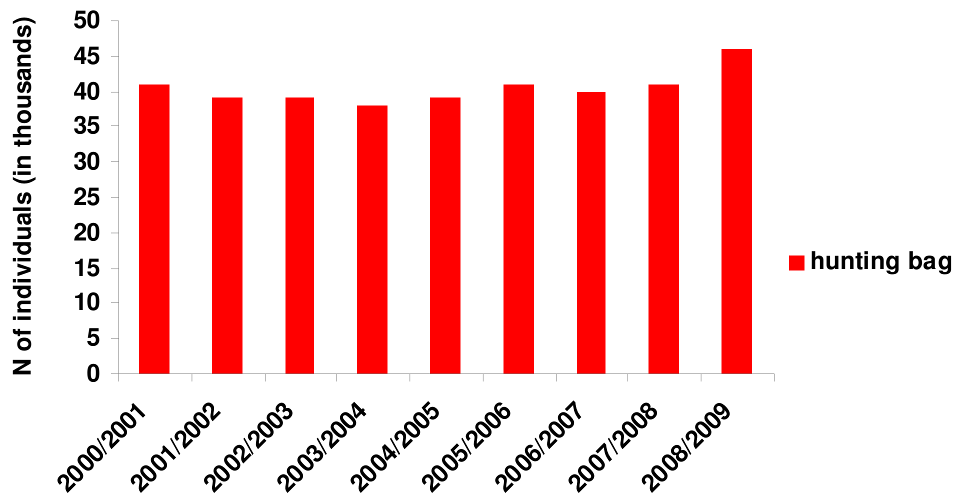



**Figure 3**. Changes in the hunting bag of red deer in the subsequent hunting seasons

## 2.3. Fallow deer (*Dama dama*)

Fallow deer is an alien species to Polish theriofauna. The area of its natural occurrence encompasses the Middle East, mainly Turkey (Dzięciołowski 1994). The species was introduced to Poland in the 13$^{th}$ or 17$^{th}$ century. Yet, on a large scale the process took place in the second half of 19$^{th}$ century (Włodek 1979, Łabudzki 1993, Okarma & Tomek 2008).

Nowadays, fallow deer exist in whole Poland, with an exception of Podlaskie and Świętokrzyskie Voivodeships. The most numerously they inhabit Wielkopolska region as well as Kuyavian-Pomeranian and Silesian Voivodeships.

As a result of reintroduction and to smaller extent natural expansion, the area of occurrence of fallow deer increases systematically. In the last decade its number in Poland doubled, from 9,050 in 2000 to 20,667 individuals in 2009 (fig. 4).

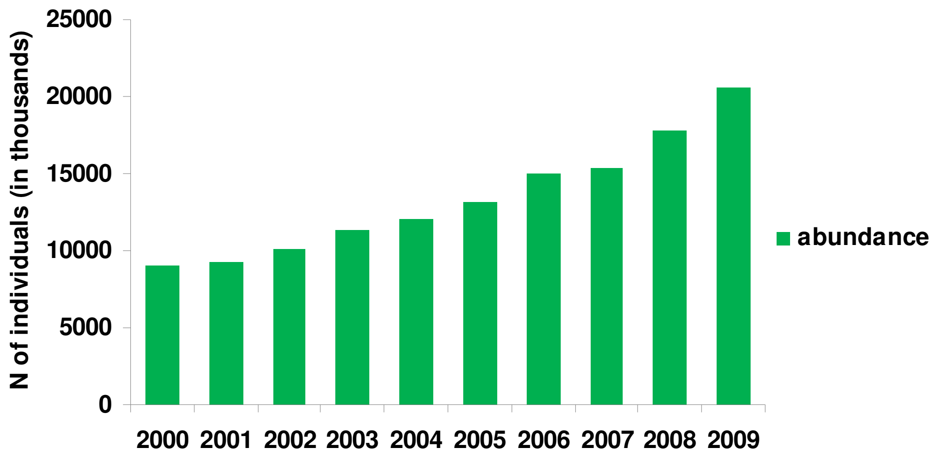



**Figure 4.** Changes in the number of fallow deer in Poland in the last decade

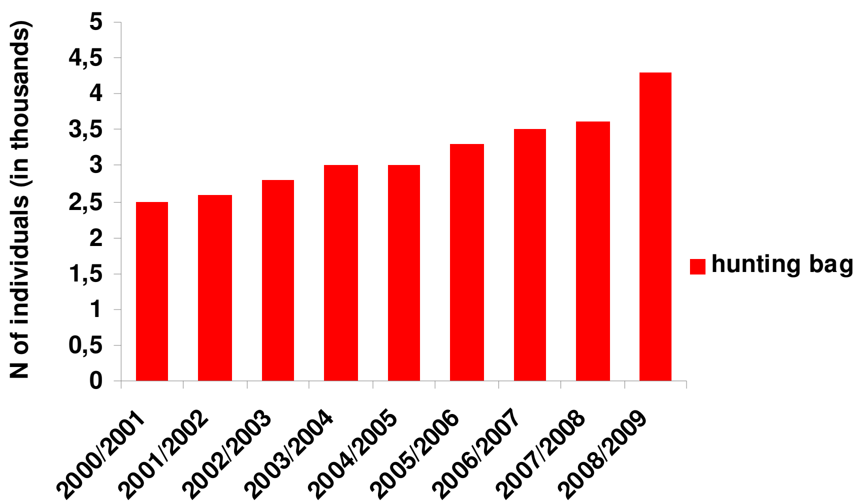



**Figure 5.** Changes in the hunting bag of fallow deer in the subsequent hunting seasons

Similar trend was observed in the case of hunting bag. In the hunting season 2000/2001 ca. 2,500 individuals were cooled, while at the end of the decade (2008/2009) it was more than 4,300 ind. (fig. 5). Most fallow deer were harvested in the Wielkopolska region and in Kuyvian-Pomeranian and Silesian Voivodeships.

### 2.4. Sika deer (*Cervus nippon*)

Natural distribution range of this representative of ungulate (Cervidae) family is East Asia. In Poland, there are two populations of the species that are the result of purposeful introduction. In 1895 sika deer were brought to the vicinity of the Vistula Lagoon (Kadyny). The other population came into existence in 1911 in the Upper Silesia (Pszczyna).

Despite fluctuations in number, for at least half the century no considerable changes in the distribution range in Poland were noted (Kamieniarz & Panek 2008).

In 2000, in the vicinity of the Vistula Lagoon 200 individuals were recorded by the members of local hunters' associations. The maximum number was reported from 2005 when almost 440 individuals were counted. In the subsequent years a steady decrease of the population was registered so in 2009 the abundance was assessed for 310 individuals (Budny et al. 2010).

The hunting bag reflected changes in the population abundance. In the season 2000/2001 64 animals were culled. Then, the hunting bag grew steadily, reaching the maximum in the season 2002/2003 (131 individuals) and afterwards it started to drop up to 33 ind. in the season 2008/2009 (Budny et al. 2010).

The other population, inhabiting the area of the Game Breeding Centre at the Kobiór (former Pszczyna) Forest District was not numerous, in 2008 it was 25 ind. (Budny et al. 2010). In the season 2007/2008 no harvesting was done (Kamieniarz & Panek 2008).

### 2.5. Roe deer (*Capreolus capreolus*)

Roe deer is the most numerous among big game in Poland and is spread throughout the whole country. The biggest number of these animals occupy the area of Greater Poland, West Pomeranian and Lower Silesia Voivodeships.

According to the statistics, the abundance of roe deer presented an uprising trend in the last decade: its population grew from 600 thousands in 2007 to 827.5 thousands in 2009 (fig. 6). It must be taken into consideration that this numbers may be significantly underestimated (Pielowski 1999, data of the Department of Forest Zoology and Wildlife Management WULS-SGGW). The hunting bag was quite stable, only in the seasons 2006/2007 and 2007/2008 a drop in the harvest rate was noted (134 and 141 individuals were culled, respectively) (fig. 7). This decrease in the harvest rate could have resulted from sparing the population after severe winter 2005/2006.

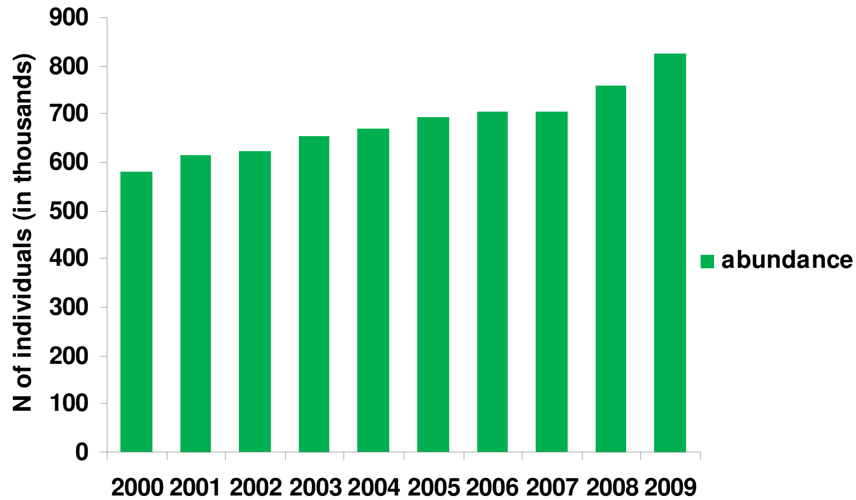



**Figure 6.** Changes in the number of roe deer in Poland in the last decade

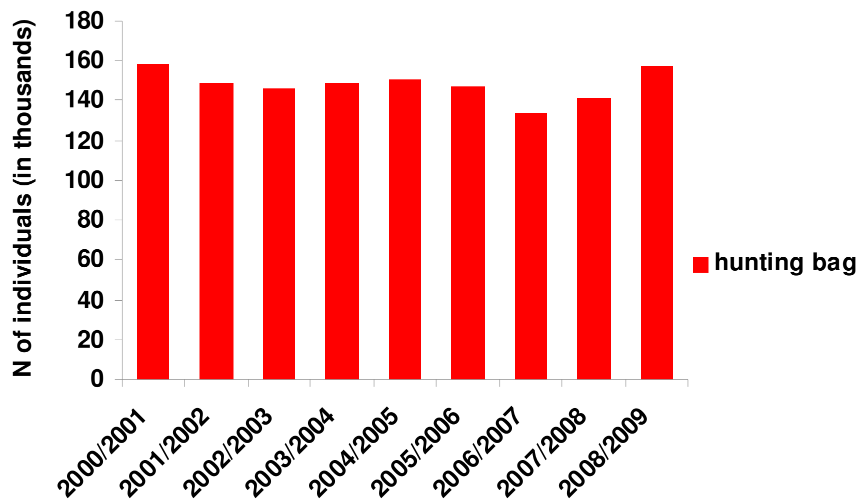



**Figure 7.** Changes in the hunting bag of roe deer in the subsequent hunting seasons

### 2.6. Mouflon (*Ovis orientalis* f. *aries*)

It is the only bovid (Bovidae) listed as a game species in Poland. Mouflon is not indigenous to Polish fauna. European populations of this species are the descendants of feral domestic sheep inhabiting Sardynia and Corsica (review in Lasota-Moskalewska 2005). Populations of mouflon in our country are the result of planned introductions. The animals were brought to Lower Silesia (Sowie Mountains) in 1901, the area that holds the strongest Polish population nowadays. The species can be numerously met in the Jawor Hunting District (Lower Silesia Voivodeship), where it was introduced in 1970s. The two populations are isolated (Okarma & Tomek 2008). Apart from Lower Silesia, mouflons were also introduced to the other 10 Voivodeships. Yet, their abundance in most of them is very low.

In the whole country the abundance of mouflon, thanks to restocking and restricted exploitation of existing populations, keeps growing. In the last decade the lowest number was recorded in 2002 (1,514 ind.) and the highest in 2009 (2,595 ind.) (fig. 8). However, data presented in the figure 8 is not in line with the other sources. According to Solarz (2008) the whole Polish population of mouflon did not exceed 1,000 animals at that time.

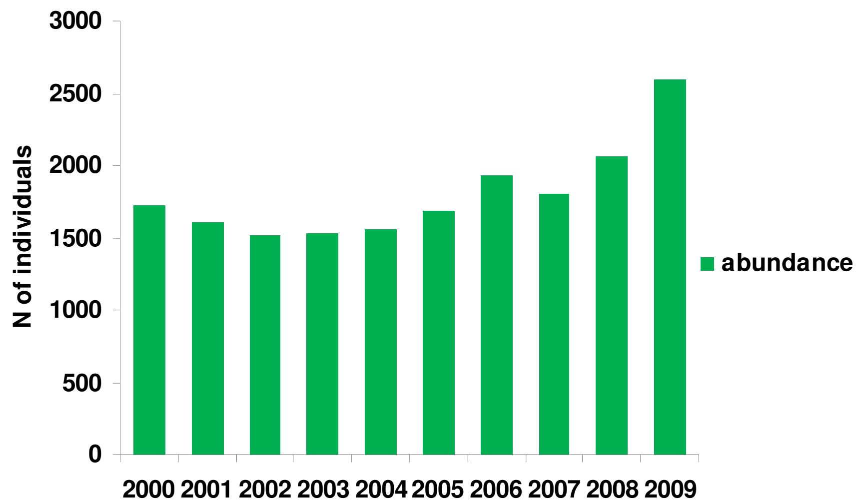



**Figure 8**. Changes in the number of mouflon in Poland in the last decade

Mouflons were harvested almost exclusively in Lower Silesia Voivodeship. During the last ten years the hunting bad was between less than 60 to 140 individuals per season (Okarma & Tomek 2008).

## 2.7. Wild boar (*Sus scrofa*)

Wild boar (Suidae) is distributed numerously in the whole country. Having in mind incomes from sales of wild boar carcasses and, on the other hand, costs incurred by managers and leasers of hunting districts as a compensation for the damages in agrocenoses, it is the game species of the main economical importance.

A systematic increase in wild boar population was recorded: from 118 thousands individuals in 2000 to over 250 thousands in 2009 (fig. 9). A combination of factors may have influenced that situation: high adaptability of the species, favorable changes in crop structure, high reproduction rate, supplemental feeding delivered during the whole year, large carnivores extermination, and abundance underestimation.

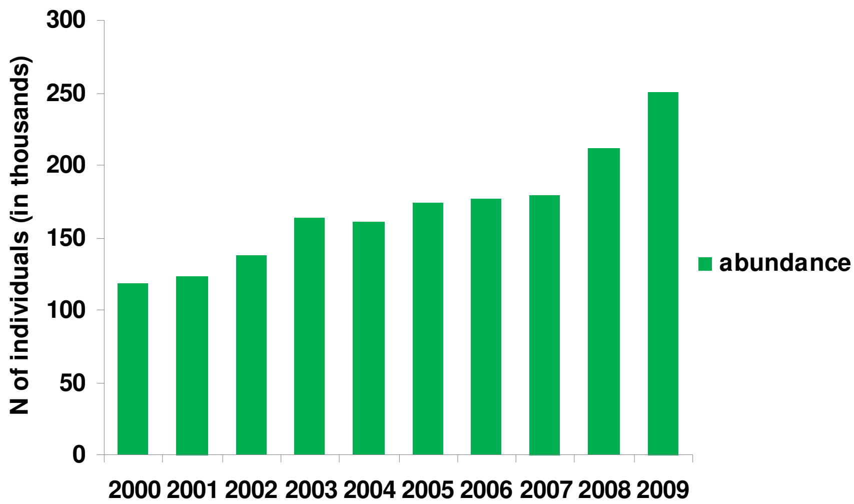



**Figure 9.** Changes in the number of wild boar in Poland in the last decade

The highest harvest rate of wild boar was reported from west Poland (Greater Poland, West Pomeranian and Lower Silesia Voivodeships). Total harvest rate grew in the last decade reaching its peak in 2009 when 251 individuals were culled (fig. 10). Yet, this trend was not as clear as in the case of abundance.

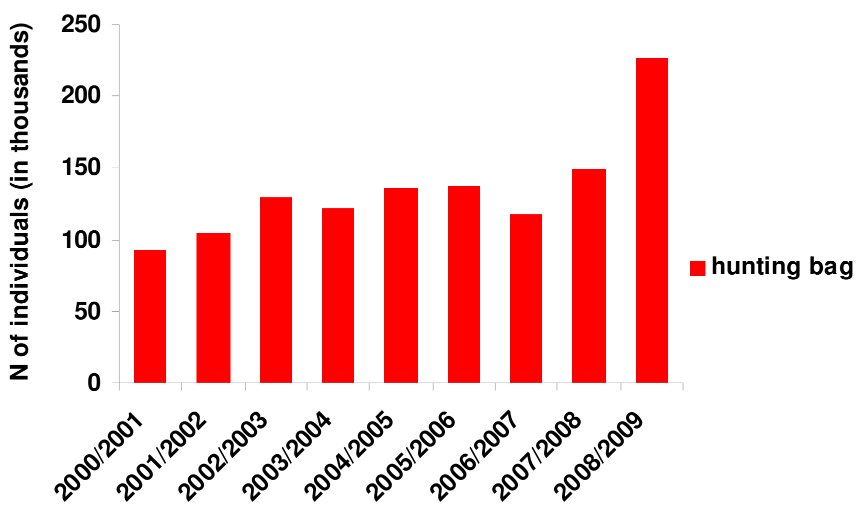



**Figure 10.** Changes in the hunting bag of wild boar in the subsequent hunting seasons

## 2.8. Red fox (*Vulpes vulpes*)

The species is common in the whole country and is currently the small game species hunted most often. Both abundance and harvest rate grew steadily until 2006, next a slight decreasing trend was registered (fig. 10 and 11).

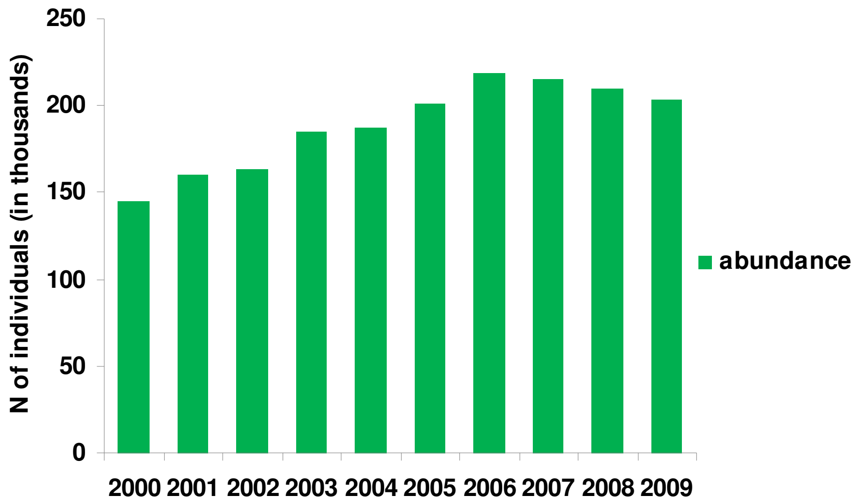



**Fig. 11.** Changes in the number of red fox in Poland in the last decade

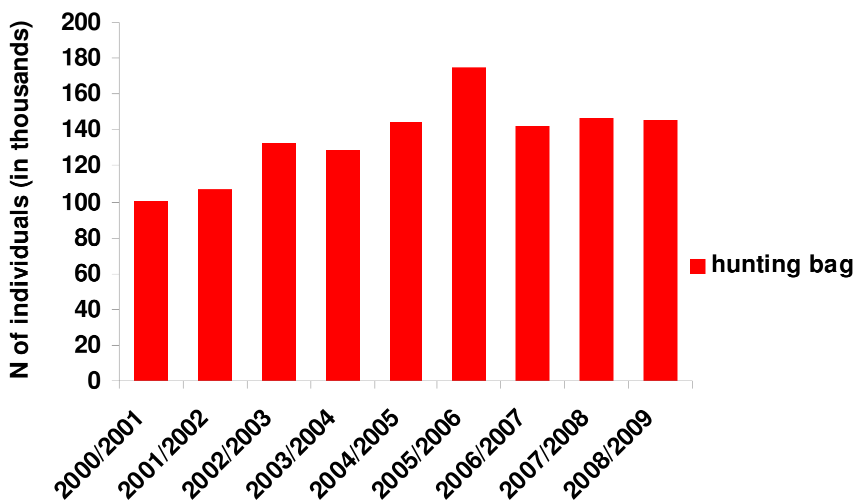



**Fig. 12.** Changes in the hunting bag of red fox in subsequent hunting seasons

One of the main factors that influenced the number growth was rabies vaccination (Goszczyński et al. 2008). This illness used to be the natural factor that limited red fox abundance. Also, ability of the species to inhabit new habitats (agrocenoses, build-up areas) was important. Additionally, lower demand for red foxes' fur led to lower hunting pressure (review in Okarma & Tomek 2008).

### 2.9. Badger (*Meles meles*)

The species is met in the whole Poland, yet its importance from the point of view of game management is negligible. In the first half of 1990s ca. 350 individuals were harvested each season. Starting from the season 1996/1997 hunting bag started to grow (Kamieniarz & Panek 2008). In the season 2008/2009 over 3,700 badgers were culled (Budny et al. 2010). This means that in the last 15 years the harvest rate of the species grew more than ten times. The trend can either reflect the abundance increase or greater interest of the hunters in the species (for example because of valuable fat).

### 2.10. Hazel grouse (*Bonasia bonasia*)

The species nests in south and north-east Poland. Its spring abundance is estimated at ca. 7,000 individuals (Bonczar 2004). No data on the abundance trend in the whole Poland are available. Yet, in some areas hazel grouse has become more numerous (Keller et al. 2007).

Harvest rate of the species in the last decade was very low and leveled at around 100 individuals per season, with the maximum value of 132 ind. per season 2007/2008 (data from the leased hunting districts). The hazel grouse's shooting concentrated mainly in the Carpathian Mountains and in north-east Poland (Kamieniarz & Panek 2008, Budny et al. 2010).

### 2.11. Eurasian woodcock (*Scolopax rusticola*)

This bird is present in the whole area of Poland, including mountains. Data on its abundance are very scarce and refer to study areas, i.e. in the Bialowieza Primeval Forest 500-600 pairs were registered (Pugacewicz 1997), and in Wigry National Park, in the years 1989-1993, population abundance was estimated for 50-60 pairs (Zawadzka & Zawadzki 1995). No data on the total Polish population abundance or its trends are available (Tomiałojć & Stawarczyk 2003).

The hunting bag of Eurasian woodcock varied considerably in the last decade. Before Polish accession to the European Union more than 4,000 birds were shot annually (the most - 4.9 thousands in the season 2002/2003, data from 93% of all hunting districts). Hunting took place in spring (15 April to 15 May) during mating flights. When Poland joined the EU and in consequence implemented regulations of the Bird Directive, resulting in a ban on spring hunting, the number of birds harvested plummeted. In the leased hunting districts in the season 2008/2009 ca. 800 Eurasian woodcocks were culled (Budny et al. 2010). Along with EU regulations the shooting season of the Eurasian woodcocks in Poland was moved to autumn (1 September to 21 December). However, this change did not get the acceptation of most of the hunters which led to drop in the hunting bag.

## 3. Summary

Abundance of most of the species discussed in this review increased during the last ten years. These trends can be assumed as reliable. Yet, as it was mentioned in the introduction, concrete figures may differ from the actual state. Also, the hunting bag of the aforementioned species grew in general.

# Non-wood forest products in Poland: abundance and use (bark, resin, fruits, mushrooms, tourism and recreation)

*Michał Kalinowski*
*Forest Research Institute*
*Department of Forest Management*
*Sękocin Stary, ul. Braci Leśnej nr 3*
*05-090 Raszyn*

*Paweł Staniszewski*
*Warsaw University of Life Sciences - SGGW*
*Faculty of Forestry*
*ul. Nowoursynowska 159*
*02-776 Warszawa*

## 1. Introduction

Utilisation of non-wood forest products has its particularly rich tradition as a branch of forestry in Poland. The so called Polish concept of forest minor production, being the effect of work and experience of generations of foresters, was developed in the 40s of the 20th century under the supervision of professor Wiesław Grochowski. The concept's basic assumption has been the idea that the whole of forestry production process: both the production of wood and the production of all other forest uses (non-wood forest products – NWFPs), are oneness. The year 1989 was crucial for the use of NWFPs. The organisation of harvesting and processing of goods was taken over by private sector.

## 2. Historical development of non-wood production and services in the country

### 2.1. Resin tapping

In the after World War II period, the leading branch of forest utilisation was - till the end of the 70-s, collection of Scots pine (Pinus sylvestris) resin. Beginning with the early 80-s however, the process of continuous decrease and finally the end of resin harvest has been observed (Fig. 1). Nowadays, domestic production of resin was totally supplanted by the imported raw material, first of all from China, Belarus, the Ukraine, and Brazil (Głowacki 1999). The raw material resources, estimated in the after war period for some 30 thousand tons a year, are currently assessed to be approximately 15 thousand tons a year (Głowacki, Staniszewski 2003). Theoretically it is possible to reactivate resin collection even at this level (in compare to the maximum one from the year 1961: 24,5 thousand tons (Central Statistical Office, Forestry 1997-2008) without any negative influence on the natural environment; in order to accomplish this, an analysis of economic efficiency would be however needed and besides, the world market prices level would also be very influential. Moreover, there is no study of the assessment of the possibility to use environment friendly stimulators of resin and the analysis of the market of resin and resin products.

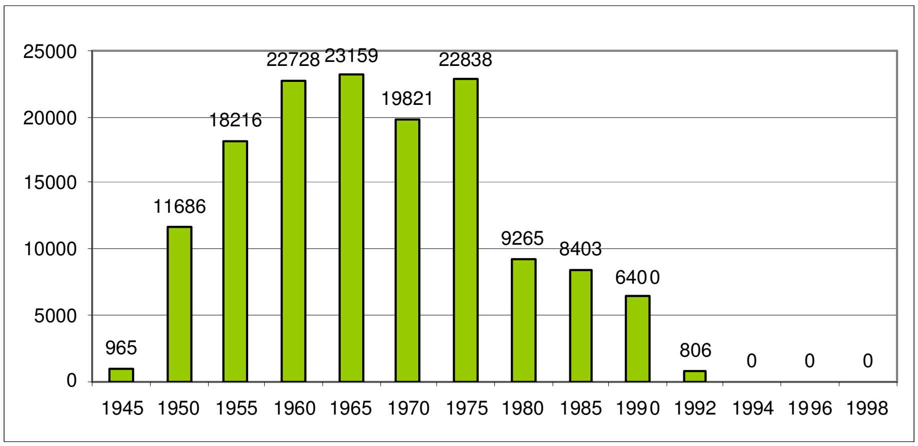



**Figure 1.** Scots pine resin tapping in Poland (in tones)

## 2.2. Use of bark of forest trees

The problem of utilization of forest trees bark should be perceived in two aspects. First, we encounter utilization of bark obtained for its high chemical value. In Polish conditions this applies mainly to pharmaceutical bark: mostly oak (Ouercus sp.) and alder buckthorn (Frangula alnus); with demand exceeding largely the supply. These are however merely hundreds of tons (Antkowiak 1998).

Norway spruce bark (Picea abies) was commonly used in Poland in the tanning industry in the fifties and sixties of XX century (reaching the maximum level of more than 16 thousand tons in the year 1952 – Table 1). However, its utilisation has been decreased as a result of the import of high quality tannin raw materials and the common use of synthetic tanning agents.

| 1945 | 1950 | 1955 | 1960 | 1965 | 1970 | 1975 | 1980 | 1985 | 1990 |
|---|---|---|---|---|---|---|---|---|---|
| 150 | 11200 | 13200 | 7100 | 1800 | 1300 | 100 | 0 | 0 | 0 |

**Table 1.** Spruce bark utilisation in Poland (1945 – 1990) in tons (Grochowski 1990).

The important aspect of bark use is utilization of barking refuse. On the basis of yearly timber production and average percentage of bark in timber one can estimate that every year we have to utilize over 2 million m³ of bark refuse, that is ca. 900 000 tons of dry bark mass (Głowacki, Staniszewski, Ruszczyńska 2004).

The main two directions of bark refuse utilisation is composting and using as a fuel. The large amounts of pine bark are used in the production of fertilizers - using it as an ingredient of peat-bark gardening bed or as an independent bed. Bark can be also used as soil conditioner or organic fertilizer.

Energetic use of bark refuse is one of the main methods of recycling. In the past the process of bark burning was considered unprofitable, often with negative balance and harmful for environment. This is due to the fact that the majority of bark refuse comes from wet barking and so its humidity can be as high as 60%. Another inconvenient characteristic of bark is its high content of ash: 2.14-3.14%, while in timber only 0.3%. Thanks to modern technology these problems are solved by using fluid boilers in which bark is submitted to the burner via air current. In fluid boiler bark is dried and only afterwards it is burned.

The problems connected with utilisation of forest floor goods are currently becoming especially important in Poland. The concept of minor forest production assumed that the harvest of forest floor economic plants and mushrooms be organized or, at least, supervised by the administration of the State Forests. This idea had found its practical expression in the large network of purchase spots, those were run in the close cooperation with local foresters. On the other hand, the gathering of plants and mushrooms for the collectors' own use and other than protected species and carried outside the protected areas was unlimited and, actually, out of control.

### 2.3. Recreational function of forests

Among non-wood forest services, the greatest emphasis in Poland is being drawn to the utilisation of recreational function of forests. A broad adjustment of forests for recreation was started at the early seventies of the 20th century. The dense network of recreation and tourist facilities was then constructed such as camping sites, forest bivouacs, parking areas. The construction and maintenance costs of these facilities were covered by the State Forests. Nowadays, recreation and tourism are a permanent and constantly growing social phenomenon. The urbanisation and industrialisation processes and, as the result, rise in population of the cities, have created increasing demand for recreation, whose natural form is a regular contact with natural environment. Forests are broadly accessible to the public and the access is free of charge. The tourist pressure on forests increases particularly around large industrial centres and agglomerations. According to Głuch and Łonkiewicz (1991) nearly 50% out of 300 thousand respondents declare forests as the most attractive form of recreation. The growing general concern of society for recreation with special regard to forest areas points to the need of forest areas accessible for recreation.

## 3. Non-wood Forest Products and Services in Europe.

The very useful and unique source of information related to NWFP&S are country reports – part of COST Action E30 Economic integration of urban consumers' demand and rural forestry production (http://www.joensuu.fi/coste30/). Generally, comparing to south, middle-east and eastern Europe, in western and north European countries non-wood sector is rather poor developed. In some countries decrease in wood production resulted with activity of forest owners and entrepreneurs looking for new opportunities to increase income in non-wood sector (Helles, Thorsen 2005). In particular the opportunities of future development is in non-wood services, like forest tourism and recreation (Aarne et al. 2005).

The indicators of selected products and services in fife European countries are shown in table 2. Countries were selected as representative for “NWP&S model”, based on COST Action E30 country reports: Finland (Aarne et. al. 2005) - “Scandinavian”, with high developed forestry and rich traditions of use NWFP&S; United Kingdom (Slee et al. 2005) and Denmark (Helles, Thorsen 2005) – “Anglo-Saxon” – with poor forest cover of country, where modernisation resulted with complete decline of traditions of non-wood use of forest; Lithuania (Mizaras 2005) - middle and east part of Europe – the rich tradition of non-wood resources use accompanies transition of economy, Italy – south of Europe - the rich tradition of non-wood resources use and large diversity of products (Kalinowski, Staniszewski 2007).

| Indicators → Products and services ↓ | Economical importance and financial benefits | Conflicts between users | Workplace creation |
|---|---|---|---|
| Fruits | FIN, GB, LT | LT | FIN, LT |
| Mushrooms | FIN, LT, I | LT | FIN, LT, I |
| Nuts | I | | I |
| Bee products | | | |
| Other food products | | | |
| Herbs | LT | | LT |
| Resin | | | |
| Bark | I | | I |
| Foliage, needless (incl. ornamental) | FIN, GB | | FIN |
| Other plants (incl. Christmas trees) | DK | | DK |
| Grazing | | | |
| Hunting | FIN, LT, I | | LT |
| Tourism and recreation | FIN, DK, GB, LT, I | GB | FIN, DK, GB, LT, I |
| Education | FIN, DK, I | | |
| Nature preservation | FIN, LT, I | | |
| Source of energy | | | |

**Table 2.** The indicators of selected products and services in selected European countries (Fin – Finland, GB - Great Britain, DK – Denmark, LT – Lithuania, I – Italy)

## 4. The importance of Non-Wood Forest Products and Services for forest sector and rural development

There are very few studies dealing with contribution of non-wood forest production to rural development in Europe. Non-wood sector contributes to forestry and rural development in many aspects. One of the most important is source of additional income and livelihoods for low educated part of people living in rural areas. The detailed study on those focus conducted Emery (1998). Sisak (1998) surveyed 1500 households in the Czech Republic, asking people on their activity by berries gathering. Similar study conducted Markkula and Rantavaara (1997). The results on those researches are shown in the table 3.

| | 1994 | 1995 | 1996 |
|---|---|---|---|
| Czech Republic | | | |
| Berries | 6,0 | 7,5 | 4,3 |
| Mushrooms | 6,1 | 7,8 | 4,8 |
| Finland | | | |
| Berries | - | 8,3 | - |
| Mushrooms | - | 1,5 | - |

**Table 3.** The amount of bilberry fruits (Vaccinium myrtillus) in kg/household gathered (Czech Republic) and consumed (Finland) in average household (Sisak 1998, Markkula, Rantavaara 1997, Kalinowski 2000).

In the 60-s and 70-s, minor forest utilisation in the State Forests had participated in up to 25% to the total value of forestry production. In special conditions the income from non-wood products may exceed revenue of wood production. It seems to be important, taking into account, that forest entrepreneurs and owners look for new income possibilities in non-wood sector (Helles, Thorsen 2005).

At present, the actual value of minor forest production is estimated at 2%. The most substantial problem is the fact that the importance of minor forestry production has been nowadays underestimated by the forestry administration in Poland. The status an relevance of selected non-wood forest products is shown in the table 4.

| **Products** | **Status** | **Economic relevance for rural economies** |
| --- | --- | --- |
| Fruits | heavily harvested, available data are not complete (considerable extent of harvest volume is unrecorded) | high |
| Mushrooms | as above | |
| herbs | heavily harvested; mainly outside forest sector – increasing importance of plantations; | poorly recognised |
| Parts of plants for ornamental purposes (i.e. mosses) | locally heavily harvested – harvest volume difficult to be estimated | considerable share of harvest is unrecorded. |
| Resin | not harvested since 1993 | |
| Bark | waste: utilised outside forestry sector, for horticulture; tanning: not harvested since 1975; pharmaceutical: utilised – several species. | poorly recognised |
| Forest grazing, fodder and litter | historical importance | |

**Table 4.** Selected non-wood forest products harvested in Poland and their actual relevance (Zając and authors 2005, changed).

The problems related to assessment and use of non-wood forest products resources, described in next part of report, are as follows:

- large variability of yield ,
- little of statistical data,
- little developed legal and organizational framework.

## 5. Non-wood forest resources in Poland

### 5.1. Recording of statistical data by Central Statistical Office

The assessment of total non-wood production in Poland is not possible. First of all, because of the statistical data is not complete - doe's not cover the real harvesting of non-wood goods. The amounts of forest fruits, mushrooms and other goods gathered by people for their own needs is not recorded and very difficult to assess. The commercial harvesting of non-wood goods is partly unrecorded by Central Statistical Office (unofficial-road selling). Although, data on total, official buying of forest floor goods recorded by CSO is more and more complete. The result of decrease of harvest in 1960', 1970' and 1980' was economical, but the increase in 1990' and 2000' was partly because of increase of harvesting, but partly – more complete data recording by CSO (Fig. 2).

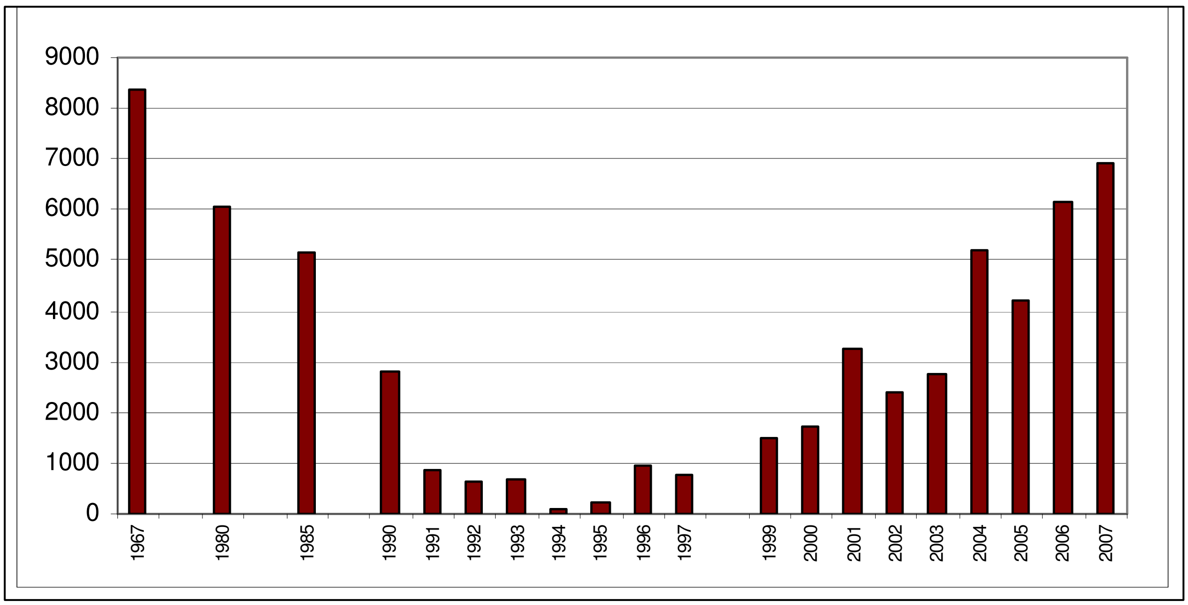



**Figure 2.** Total collecting of forest mushrooms at buying points (t)

**Figure 2**. Mushrooms commercial harvesting (in buying points) (Central Statistical Office)

The structure of statistical data published by CSO in forestry yearbook is more and more detailed. Now the data: volume and value of forest fruits and mushrooms commercial harvesting (recording in buying points) is published in structure of species and regions.

## 5.2. The assessment of non-wood forest products resources in Poland

Resource assessment is one of the first steps to develop the sustainable use of non-wood products, providing data necessary for all those dealing with NWFP: users, forest owners, managers and scientists. The aim of inventories conducted was to get information about spatial distribution of resources, its qualitative and quantitative characteristics, and to develop yield-tables, which would show the availability of raw-material.

### 5.2.1. Inventory of resources

Inventory methods applied in the resources assessment in the 1950s and 1960s were similar for all species. Employees of State Forest Service estimated the area covered by the plants under investigation and recorded field observations. First, the occurrence was definitely described in classes, like: massive, abundant, rather abundant, and rare. This was replaced by more objective assessment in percentage intervals (less than 5%, 6-30%, 31-60%, and above 60% in inventory of alder buckthorn (Frangula alnus) – Grochowski, Zdanowski 1963; less than 20%, 20-40%, 41-60% and above 60% in inventory of bilberry (Vaccinium myrtillus).
The most of inventories of forest floor resources were conducted by Forest Research Institute. In 1950's and 1960's in 6 projects were assessed the resources of 25 species of plants. In bilberry inventory (Vaccinium myrtillus), fields of plant were grouped in into four categories, according to their quality. Lowland sites formed the first three categories whereas the fourth category was reserved for sites on mountains. In lowland sites the first category formed bilberry fields with very good potential, high plant density and plant height more than 40 cm. The second category consisted of plants with various densities and heights 20-40 cm. Finally, category three reflected low plant density and highs 10-20 cm.
The results of inventory of the most important species of forest floor – bilberry (Vaccinium myrtillus) are shown in the table 5.

| | Ground cover class (%) | | | | | |
|---|---|---|---|---|---|---|
| | 1- 20 | 21-40 | 41-60 | 60- | Total | Resources available for commercial use |
| lowlands | 244 895 | 217 434 | 126 857 | 64 902 | 654 088 | 432 489 |
| mountains | 15 805 | 6 309 | 1 986 | 892 | 24 992 | 24 992 |
| Total | 260 700 | 223 743 | 128 843 | 65 794 | 679 080 | 457 481 |

**Table 5.** The area (ha) of bilberry resources in the State Forests in Poland (Zdanowski, Grochowski 1965).

The last assessment of resources of forest floor species was the inventory of four herb species, which are under partial conservation: alder buckthorn (Frangula alnus), lily of the valley (Convallaria maialis), asarabacca (Asarum europaeum) and common bearberry (Arctostaphylos uva-ursi). The method used in the inventory was similar to that used in earlier inventories. The results of the inventory revealed that the resources of the first two species are large, while the resource of asarabacca (Asarum europaeum) and common bearberry (Arctostaphylos uva-ursi) are little and it might be necessary to put these species under total conservation (Kalinowski 2001). The comparison of results of the two inventories of alder buckthorn conducted in 1963 and 1998 are shown in table 6.

| Year | Ground cover class (%) | | | Total |
|---|---|---|---|---|
| | 1-30 | 31-60 | above 60 | |
| | Hectares | | | |
| 1963 | 148147 | 12286 | 3179 | 163612 |
| 1998 | 279573 | 88315 | 25824 | 393712 |

**Table 6.** The area of alder buckthorn (Frangula alnus) (Rzadkowski, Kalinowski 2001).

### 5.2.2. Yield assessment

Yield research is the second step to assess forest floor resources. It is realized using a net of sample plots, on which the raw-material (fruits, parts of herbs) was gathered and recorded (weight and other characteristics). Grochowski (1990) introduced two important terms: theoretical yield – everything that could be harvested, and practical yield – the amount of row-material that can be harvested with economical benefits and without losses in environment. The example of relation between theoretical and practical yield are shown in the figure 3.

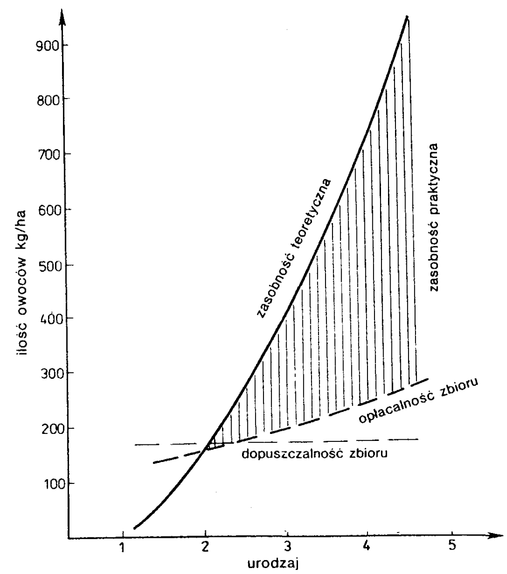



**Figure 3.** Theoretical and practical yield of bilberry in mountains (Grochowski 1990)*

The yield-tables were estimated for the most important forest floor species – bilberry (Vaccinium myrtillus). The research was conducted on sample plots 25 $m^2$ (5×5m). 2145 observations were recorded in yield-scale: 1. very low, 2. low, 3. average, 4. good, 5. very good yield. The relation between the yield of berry field and yield in 5- level scale is as follows:

$$\bar{y} = 27{,}17x_i^2 - 0{,}14x_i + 0{,}02$$

* Translation: “ilość owoców kg/ha” – the amount of fruits kg/ha, “urodzaj” – yield, “zasobność teoretyczna” – theoretical yield, “zasobność praktyczna” - practical yield, “opłacalność zbioru” – profitability of collecting, “dopuszczalność zbioru” – environmental limits of collecting.

$x_i$ - yield in 5-level scale,

$\bar{y}$ - the yield of berry field (kg/ha).

The assessment of forest floor resources is very difficult and problematic. The reasons of difficulties are as follows:

- large and unpredictable variation of yield (in time – seasonal, and space) (Grochowski 1990, Lintu 1998, Mizaras et al. 2005),
- large time-consuming research,
- large scale of resource.

### 5.2.3. Harvesting of forest fruits and mushrooms

In years 2000-2008 value of total collection of forest fruits and mushrooms generally grew up and amounted from 52,98 mln zł in 2002 up to 106,81 mln zł in 2006 (Fig. 4). Generally, it is difficult to estimate and delimit between the real growth and changes in data recording (CSO covers more and more of forest fruits and mushrooms harvesting every year).

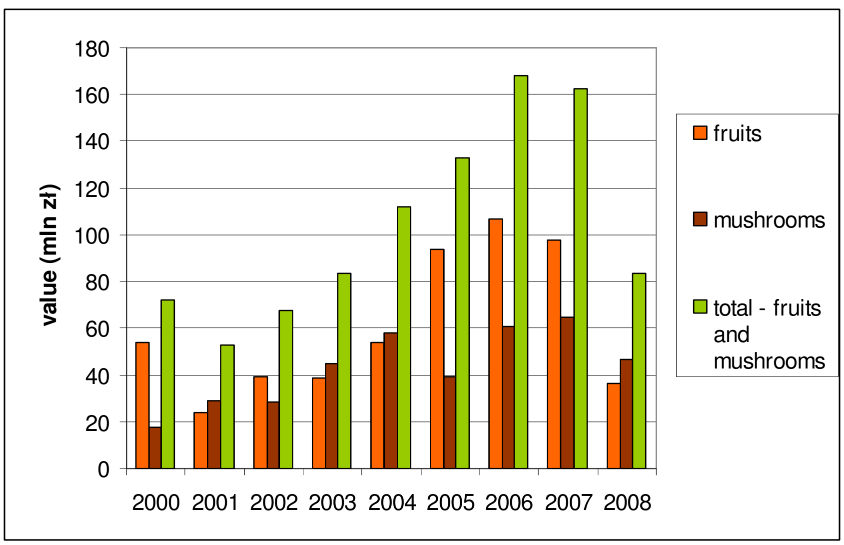



**Figure 4.** Value of fruits and mushrooms collected on buying points (Central Statistical Office, Forestry 2005, 2009).*

* The average exchange rate for conversion of national currency to Euro in 2008-2009 is about 3,9.

The share of total value of forest fruits and mushrooms collected on buying points in total value of wood sold by the State Forests amounts 1,8 up to 4,1% (Fig. 5). The forests managed by State Forests cover about 80% of total forest area, so on one hand the total value of sold wood is larger. However, on the other hand, fruits and mushrooms collected on buying points are not the total harvest and value of the total value of non-wood production in Poland is much bigger.

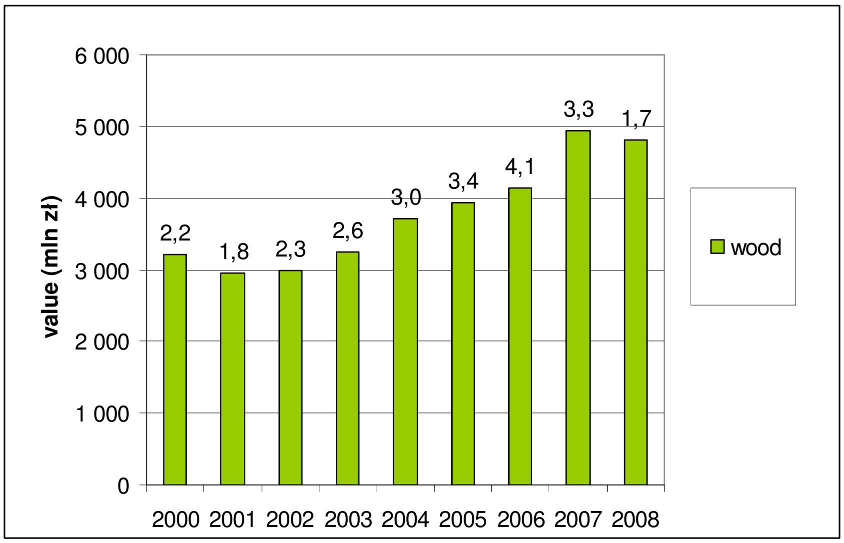



**Figure 5.** Value of wood sold by the State Forests (and percentage of total value of forest fruits and mushrooms collected on buying points in total value of wood sold by the State Forests) (Central Statistical Office, Forestry 2005, 2009).

### 5.3. Forest tourism and recreation

The best illustration in terms of utilization of recreational functions of forests is the research on the assessment of conditions for the development of recreational functions of forests of the Mazowiecki Landscape Park (MPK) (Janeczko 2002). Evaluation studies on scenic beauty of forests that are carried out in Poland are occasional. However the need to launch such studies is emphasized by many researchers (for example Janeczko 2000, Stępień et al. 2000). It is by no means a new trend in the recreational management of Polish forests. It has to be thought that the fast development of research methods and studies on scenic values of forests proceed along with the growing demand for forest social functions.

Currently, a spatial approach to forest natural environment is being emphasized in a majority of analyses. This is a result of the advancement and, first of all, wide availability of modern techniques of space management. Digital databases that most forest districts in Poland have at their disposal contain detailed information about forests. Studies on recreational needs and preferences of tourists play a particular role in recreational management of forests. In Poland studies in this area have been conducted for over twenty years (Łonkiewicz et al. 1982; Krauz 1989; Gołos 2002; Janeczko 2002). They allowed to establish preferences of tourists as regards forms and sites for recreation, recreational management of forest, time and frequency of recreational activities, as well as preferable elements of the scenic beauty of forests.

A broader approach to the issue of social preferences has been presented in the studies concerning the assessment of the conditions for the development of recreational functions of forests of the Mazowiecki Landscape Park (Janeczko 2002). These studies permitted to determine not only recreational preferences of a tourist, but also to establish relationships between such preferences and individual characteristics (sex, age, education) family status and place of residence. So far, no studies has taken account of recreational needs of handicapped persons. Only recently, have been undertaken studies aimed at defining principles concerning access to forests for the needs of the handicapped persons especially those using wheelchairs (Woźnicka 2002, 2003). Such studies are presently carried out in the communal forests of Warsaw.

The development of studies on the assessment of the non-wood forest services may cause that in the future these services will subject these services to the market economy rules. Today, the costs of recreational management of forests are mainly covered by the State Forests hile benefits go to the business entities providing tourist services. Studies

## 6. Summary

The good summary of report is SWOT analyze of factors affecting development of Non-Wood Products and Services in Poland:

| **Strengths** | **Weaknesses** |
|---|---|
| - sector is based on small and middle, modern enterprises<br>- large potential of innovations and development<br>- tradition of use of non-wood resources (especially as food products) | - the large variation of the resource (supply) in time and space (especially fruits and mushrooms),<br>- products are no long fresh (short durability) and difficult in transport and storage,<br>- creation of value added is limited in parts of product chain close to a forest |
| **Opportunities** | **Threats** |
| - new trends of health and wellness (natural products) | - the resources management is not sustainable (intensive use of small number of species, lack of resources assessment and legal/organizational framework)<br>- the statistical data is not complete<br>- some natural products are replaced by artificial equivalents (bilberry and bilberry, wine natural cork – plastic corks and caps, recreation in forest and fitness clubs)<br>- the sector is not well organized and has not representation body (association) |

# Climate Change – Forest Relationships. Global and Polish aspects

*Kazimierz Rykowski*
*Forest Ecology Department*
*Forest Research Institute*
*Warsaw*

## 1. Introduction

**1.1.** Climate change has become a fact. The question concerns the pace and nature of this change, as well as the decisions and measures to be taken in order to limit its effect on humans and the economy. The interrelationships between climate, forest and economic activity, based on wild nature's biological production, are equally apparent, though not always sufficiently recognized, as they are multi-faceted and sometimes go in opposite directions. It is impossible to exhaust, in a synthetic study like this, this complex, interdisciplinary subject undergoing continuous development. Therefore, the focus should be on the most important, selected issues and the Polish economy's share in addressing them.

The mechanisms of carbon absorption and emission are at the core of the mutual relationships between forest, forestry and climate change whose causes are looked for in the growing concentrations in the atmosphere of glasshouse gasses, like $CO_2$. Let us not forget that life on our planet is made up of carbon compounds. Carbon cycling in the biosphere has shaped and will continue to shape carbon resources in the atmosphere, in living and dead organic matter (biomass) and in fossil deposits. In each case, the binding of carbon dioxide with water and solar energy in the process of photosynthesis of autotrophic plants is the primary process initiating its absorption, accumulation and emission. All the rest of the world feeds only on what is produced by plants absorbing carbon from the atmosphere. Organic matter not only accumulates, but also releases carbon in the combustion (oxidation) processes. The processes shaping natural environment, nature as a whole and the living conditions, including humans', are involved in and accompany biomass production.

It is through the production of biomass that forests have shaped and continue to shape climate and air composition, regulate precipitation, temperature and air movements, create conditions necessary for the existence of a large number of plant and animal species, accumulate gene resources and organisms being biomass producers and consumers, as well as those restoring biomass to its original usefulness state in the ecological energy-matter transformation processes. Climate changes affect nature's functioning with all these phenomena and processes. Some have a damaging effect on them, others favours them, either instantly or in the near or far perspective of the evolution process.

Forests participate in these transformations more than other nature's structures. Covering about 30 per cent of landmass, they are the most important carbon absorbers on land. Therefore, their protection, management method, reduction or increases of forest area, improvement or degradation of their condition are the principal issues related to the preservation of the global climate equilibrium.

**1.2.** Forests occur in a quadruple role in the climate change process, and these roles set the directions of mutual impact of climate, forest and economy:

1) as the "cause", that is as a source of greenhouse gasses (GHGs), mainly $CO_2$, but also methane, due to the growth of emissions as a result of deforestations (change of land use forms), incorrect forest uses (intensive soil cultivation, lack of regenerations or late regenerations, forest fires or retaining standing trees until stand disintegration);
2) as the "victim" of climate change causing increased vulnerability to pests and deceases, increased forest flammability, changes in species composition, changes in the natural ranges of tree species;
3) as the "beneficiary" of climate changes, benefiting from the " greenhouse effect" and the "fertilization effect"(eutrophicating compound deposit) stimulating biomass growth, which is manifested in the growth of standing stock, growth in the increment growth rate, and beneficial conditions for growth and regeneration;
4) as the "remedy" for global changes and the poor condition of the environment on account of: a) ability to absorb and relatively permanently accumulate carbon in forest ecosystems' structures (wood, soil), b) wood's substitutive properties for materials whose production damages the environment and contributes to climate change (construction materials, such as steel, aluminium, cement, brick, packages – plastic), c) wood's substitutive properties for fossil fuels, d) ability to regenerate to the benefit of the environment;

Therefore, the role of forests and forest management depends on the methods and targets of forest management and the ways by which their produce, particularly wood, is used. The above mentioned roles which forests can play in climate shaping, and the ensuing forest management's impacting possibilities, reveal a significant lack of knowledge, particularly because the extent of response of large nature's systems to the environmental conditions existing before the change has been unknown, the knowledge of the structure and functions of forest ecosystems has only been fragmentary and the object of study has changed throughout the research process. There may appear a situation where practical actions will be largely based on the results of extrapolation of historical knowledge, rather than parameterized for the new conditions, with forecasting possibilities being simultaneously limited.

**1.3.** The Framework Convention on Climate Change (UN FCCC 1992) and the Kyoto Protocol set by the Parties to the Convention (1997) point to forests as one of the most effective terrestrial absorbers of atmospheric carbon. The simplest forestry's participation method in $CO_2$ reduction and climate change containment is augmentation of forest cover that is the area of carbon absorption and biomass production. Other forms of land use like agriculture, industrial and transport infrastructure, urbanization or new settlements, where emission surpasses absorption, are certainly a constraint here.

Wood is the main element of forest biomass used by man on which forest management may have the greatest impact and shape it to its purpose in terms of quantity and quality. The essence of climate protection in this case consists in retaining carbon assimilated in wood not longer than its production cycle (e.g. rotation). Thus, the concentration of $CO_2$ is effectively reduced slowing down climate changes.

An equally positive effect can be achieved using wood in substitution for fossil fuels (the largest source of carbon emissions to the atmosphere) or materials whose production is energy consuming or based on "dirty" technologies (steel, concrete, plastic).

In addition to wood, also forest soil is the place of a relatively steady carbon accumulation. However, forest management's impacting possibilities are here strongly limited by habitat quality and soil capacity.

All the above gives forests and forestry a historical chance to play a key role in managing the Earth's natural, terrestrial resources and alleviating climate change. This can be accomplished through:

- forest cover growth and land use rationalization,
- forest management based on the sustainable development principle (species composition regulation, stand conversion, rationalization of tending cuts, augmentation and protection of organic matter in soil, etc.),
- rationalization of timber use, increase of its durability and utilization of its substitutive properties (construction timber, fuel timber, other).

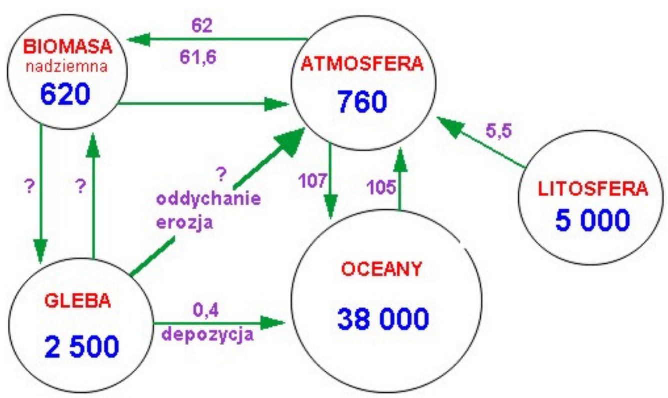
It is estimated that the above actions may contribute to a global reduction of the pace of climate change by about one fifth.

Forest management was for the first time referred to as a tool mitigating climate changes already in the 1970s (DYSON 1977). However, it was not until the Kyoto Protocol that such a possibility was considered at global level.

The Kyoto Protocol is in fact the first global "environmental" tool regulating the world economy. In a move to protect the planet's sustainability, it deals with the mechanisms governing development, setting technological barriers to energy consumption, regulating its forms and sources. The conservative approach of some states to the reduction of greenhouse emissions (as this means reduced economic growth and increased unemployment, e.g. in the USA) is accompanied by a distrust of other states feeling that their sovereignty in the use of their own natural resources is limited (limitation of deforestations in the poor countries of the South by the rich countries of the North). The greatest controversies concern the methods of involving forest and forestry in the fulfilment of their obligations and in making use of absorption in the emission balance.

## 2. The role of forests in the global carbon resources

**2.1.** The main global carbon pools and annual flows between them are illustrated in the following drawing:




Ryc. 1. Główne, globalne pule węgla oraz roczne przepływy między nimi (w Pg) ; (wg LAL, 1999)

**Fig. 1**. The main global carbon pools and annual flows between them (in Pg), (according to LAL, 1999).

Picture description: BIOMASA nadziemmna – aboveground biomass, ATMOSFERA - atmosphere, GLEBA – soil, OCEANY – oceans, LITOSFERA – lithosphere.

The Earth's active area plays the principal role in the accumulation and cycling of carbon in the biosphere. Approximately 125 gigatones (Gt)[1] of carbon is exchanged between vegetation, soil and atmosphere, or two fifth of the total carbon exchange between the earth and the atmosphere; forests which globally accumulate more than half of the planet's carbon participate in about 80% of this exchange (Fig. 2).

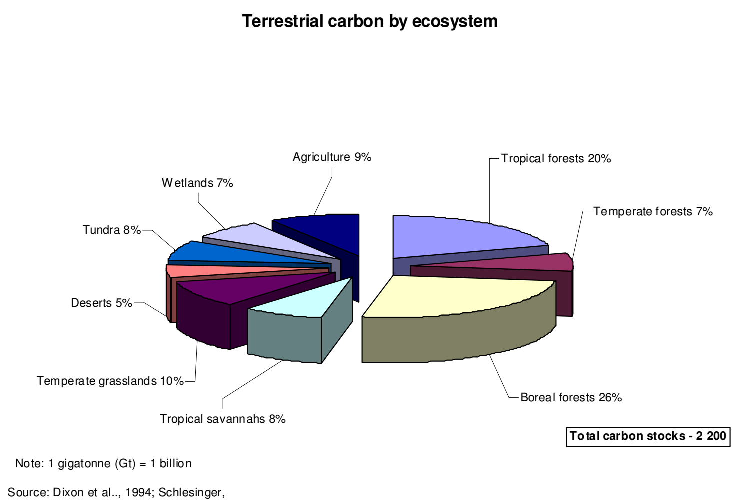



**Fig. 2.** Carbon distribution by terrestrial ecosystem (DIXON et al. 1994)

Carbon exchange means not only its absorption but, but also its release. The main source of carbon emissions is, apart from fossil fuel combustion, forest felling. There are proves that stump extraction in the 1980s is responsible for about one fourth of all anthropogenic carbon emissions to the atmosphere (HOUGHTON 1999). Nevertheless, there are sufficient conditions for the biosphere to absorb or accumulate during the next 50 years 60 to 87 Gt of carbon in forest resources, and 23 to 44 Gt of carbon in agricultural soils (BROWN *et a*l. 1996).

Information on the size of carbon pools accumulated in forest ecosystems is divergent and cannot be compared due to different measurement techniques which change over time and space as a result of geographic-climate differences (also microclimate differences) and forest development phases (OLLINGER, SMITH 2005; BERT, DANJON 2006; OSTROWSKA 1999, 2006; LAMERS et al. 2006; LAL 2005; BERGH et al. 1999). The main "reservoirs",

[1] One Gt equals to one billion tonnes.

.

where carbon is accumulated and stored in forest ecosystems, and the average share of carbon pools in the global balance can be presented as follows (RYKOWSKI 2006 on the basis of literature):

- assimilatory apparatus (crown) – approx. 7.0% C;
- stem/trunk– about 19.0% C (the trunk contains approx. 66.0% of whole tree biomass, of which 58.0% is in wood and 8.0% is in bark);
- stumps and roots– approx. 7.0% C (about 14.0% of wood biomass);
- wood residues (twigs, slash) – approx. 5% C;
- litter – approx. 11% C;
- organic matter in soil – approx. 46% C;
- shrub layer – approx. 5% C.

In general, forests contain more than half of the carbon deposited in terrestrial vegetation and soil, estimated at approximately 1200 Gt. Boreal forests accumulate much more carbon than any other terrestrial ecosystems (26% of all terrestrial carbon resources),while tropical and temperate zone forests – 20% and 7%, respectively (DIXON et al. 1994), (Fig. 2).

**2.2.** Soil is one of the most important carbon pools in forest ecosystems featuring high accumulation permanence, yet arousing much controversy and doubt as to its quantity and sequestration mechanisms. As a result of the humification process, consisting of a number of complicated, enzymatic hydrolysis, oxidation and polymerization processes, organic carbon transforms into dark-coloured, cyclic, colloidal compounds, called humus substances. These substances are very resistant to decomposition and therefore they bind carbon in a very permanent way causing soil to become a $CO_2$ absorber. This applies first of all to that part of the humus which enters into reaction with the mineral fraction of soil, particularly with clay minerals (RICHARDSON, EDMONDS 1987; THENG et al. 1989).

It is estimated that global resources of carbon compounds in soil are nearly 2.5 times larger than in the atmosphere and nearly 4.5 times larger than in the aboveground biomass of terrestrial ecosystems. A detailed assessment of the possibility of permanent carbon bonding by forest soils is very difficult. Also, a precise measurement of organic carbon resources in soils is hindered due to a great variety of chemical compounds containing this element, as well as due to a temporal and spatial variability of soils (STEVENS et al. 2006). At the same time, these data are urgently needed for reliable reporting on Convention implementation and for building a strategy to reduce greenhouse emissions, as well as models and forecasts of carbon accumulation in forests.

In forest soils, organic carbon can be accumulated even down to a considerable depth; at a level of 20 to 80 cm below ground, there still is 40 to 50 % of the total carbon pool. This fact should be taken into consideration while estimating carbon deposits in forest soils.

Habitat features characterizing a habitat-type of forest have a large impact on carbon accumulation in raw humus and endohumus.

It should be emphasized that organic carbon resources in mineral soil layers undergo high fluctuation over time and space. In the case of homogenous, tropical forests, the total carbon resource may differ by 600%, oscillating between 50 and 300 tones per hectare (SOMBROEK et al. 1999). In the temperate zone, differences in carbon deposits are of course much bigger due to a high heterogeneity of forest soils.

Therefore, the carbon deposited in forest ecosystems' soil and litter constitutes a considerable part of its whole resource. On a global scale, the amount of carbon in soil accounts for more than half of the carbon resources in forests. There are however differences depending on climate zone. About 80-90% of carbon in boreal ecosystems is accumulated in the form of organic matter in soil, while in tropical forests, carbon is evenly split between soil and vegetation (Fig.3).

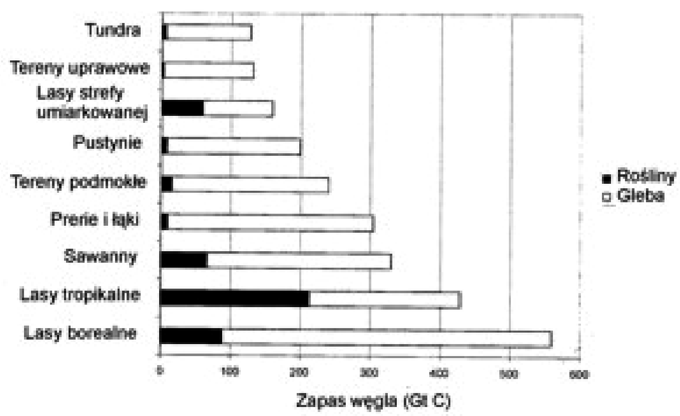



**Fig. 3.** Carbon store above ground level and in soil by vegetation formation type (according to IPCC LULUCF 2000).

Picture description: Tundra – Tundra, Tereny uprawowe – Cropland, Lasy strefy umiarkowanej – Temperate zone forests, Pustynie – Deserts, Tereny podmokłe – Wetlands, Prerie i łąki – Prairies and meadows, Sawanny – Savannas, Lasy tropikalne – Tropical forests, Lasy borealne – Boreal forests, Zapas wegla – Carbon stock, Rosliny – Vegetation, Gleba – Soil

The main cause of this difference is the impact of temperature on the production and decomposition of organic matter. In the boreal forest zone, organic matter accumulates in soil as its decomposition pace is slower than its growth pace as a result of production. In the sub-tropical zone, higher temperatures initiate a fast organic matter decomposition process and its fast cycling in the form of nutrients.

## 3. Carbon emissions from forest ecosystems

Until the 19th century, people had had a small impact on terrestrial carbon resources, however since the industrial revolution, man has marked its activity in global carbon cycling by using fossil fuels and cutting forests.

Between 1850 and 1980, over 100 Gt of carbon was emitted to the atmosphere which accounted for one third of the total amount of carbon emitted by people over that period (HOUGHTON 1996).

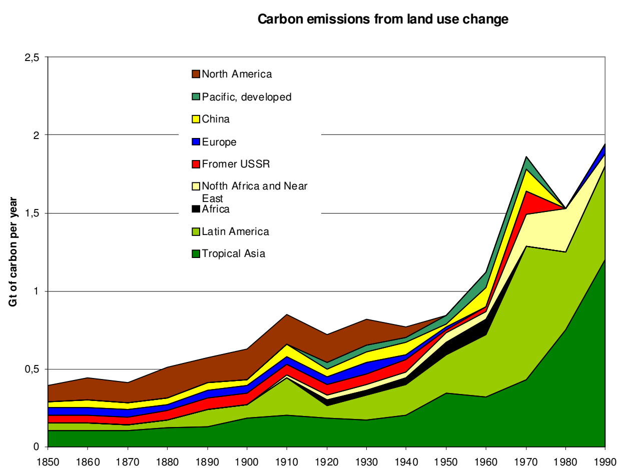



**Fig. 4.** Carbon emissions related to land use change in different parts of the world

The 19th century saw the highest degradation of forests in the temperate climate zone (North America, Europe). In the 20th century, the area of temperate climate forests stabilized, and the tropical primeval forests became the main source of carbon emissions (HOUGHTON 1996), (Fig. 4). Today, forest area in the developed countries slightly increases; between 1980 and 1995, its average growth amounted to 1.3 million hectares per year (FAO 1999). In recent years, many forests in the temperate climate zone (e.g. in Europe and east of North America) have become carbon reservoirs as a result of established plantations and afforestation of the abandoned agricultural land, while tropical forests have become the main area emitting carbon. The rate of cutting tropical forests between 1980 and 1995 was estimated at 15.5 million hectares per annum (FAO 1999).

The net emission of carbon resulting from land use in the 1980s is estimated at about 2–2.4 Gt per annum (Fig. 4), or nearly 23–27% of total $CO_2$ emissions caused by humans (HOUGHTON 1999). The largest impact on the emission of carbon to the atmosphere due to land use change is from the conversion of tropical forests to other forms of use (*slash & burn*), including forest cutting, burning, and crop farming or livestock breeding. Biomass burning also releases other greenhouse gasses to the atmosphere, like methane and nitrogen oxides. Burning forest biomass gives 10% of the global emission of methane. Forest degradation is also reflected in carbon losses. It is estimated that in the 1980s, the annual net emission of carbon stood at 0.6 Gt (HOUGHTON 1996). In the tropical part of Asia, carbon losses caused by forest degradation nearly equal the losses caused by deforestation.

There are proofs that changes in the concentration of atmospheric gasses caused by human activity affect the carbon cycle in forests. Global concentration of atmospheric $CO_2$ increased from 280 ppm before the industrial revolution to 370 ppm in 2000; also, deposition of nitrogen compounds has increased. Both phenomena lead to a so called “fertilization effect”, or plant productivity growth.

Recent years have seen a significant biomass growth on permanent observation plots established in the old-growth, natural forests of North and South America. Other proofs of increased carbon assimilation in forestland come from micrometeorological measurements of the $CO_2$ flowing across the primeval forest, as well as estimations of atmospheric $CO_2$ distributions at the continents scale. Also, findings of European studies indicate growth of growing stock and increment rate in the temperate climate forests (SPIECKER *et a*l. 1996; KARJALAINEN et al. 1999). It means that through a combined effect of afforestation, regeneration and rehabilitation of degraded forests, as well as support of the existing forests’ growth, carbon absorption by those forests is approx. 1–3 Gt per annum (MALHI, BALDOCCHI and JARVIS 1999).

**4. Climate change versus forest occurrence and structure**

If temperature on the Earth’s surface increases during the 21st century, as forecasted, all ecosystems will experience the most violent and fastest changes since the glacial era. Forest distribution on our planet and its composition will undergo deep changes, and the forest administration and management strategies will have to adapt to the new situations. The scenarios for the 21st century developed by the IPCC XXI are usually unanimous as concerns global warming, but less unanimous as concerns the level of precipitation (a “dry” variant and a “wet” variant is foreseen). The most essential changes predicted for the end of the 21st century can be summarized as follows:

- concentration of atmospheric $CO_2$ is likely to double,
- mean temperature will rise by approx. 1.5–4.5$^0$C,
- precipitation will increase globally by approx. 3–5%,
- sea level will rise by 45 cm.

As global forecasts are not very precise, and frequently contradictory, in-depth analyses are needed for making strategic, let alone operating decisions at different organization levels, as well as temporal and spatial scales. It is expected that climate change altering the recent system of temperatures, humidity, precipitations, etc. will be accompanied first of all by changes in plant occurrence. The hypothesis is confirmed by paleobotanical and ecophysiological studies, as well as the wide-ranging observations of ecosystems and computer simulations.

Climate changes over the past 10,000 years resemble those changes which are anticipated should the atmospheric $CO_2$ concentrations double. The contemporary Quaternary Period can be divided into the Holocene (approx. 10 thousand years) and Pleistocene (approx. 10 thousand to nearly 2 million years back). The Holocene followed the periods of Pleistocene glaciations, after the Glacial Epoch; this is the climate warming period which has lasted till the present. During that time, mean temperature has increased by approx. 2$^0$C. This temperature is also shown in the GCMs model explaining the circulation of greenhouse gasses (SHUGART et al. 2003). The Holocene decided about the structure of contemporary forests by shaping the current ranges of occurrence of plant species, including forest trees.

Paleobotanical studies have shown a natural northward shift of tree species ranges in North America by some hundred kilometres (DAVIS 1981; WEBB 1988). This concerns species such as pine (*Pinus strobus*), oak (*Quercus* spp.), maple (*Acer* spp.), spruce (*Picea* spp.). Those shifts have turned to be significant only at certain locations, e.g. the Eastern Coast of North America. A characteristic feature of these changes is the retreat of all studied species northwards.

**5. Probable changes of forest-forming tree species in Europe.**

The results of model simulations show dramatic changes in the occurrence ranges of contemporary forest-forming tree species in Europe, at the assumption that atmospheric $CO_2$ concentrations will double (SYKES, PRENTICE 1995). It is of special significance for Poland where the majority of analyzed species are nature-valuable and economically valid forest-forming species whose natural ranges cross Poland's territory (Fig. 5).

**Fig. 5.** Changes in the natural occurrence ranges of Scots pine (*Pinus sylvestris*) in Europe. A – current status, B – climate $2xCO_2$

Fig. 5 cont'd. Changes in the natural occurrence ranges of Norway spruce (*Picea abies*) in Europe. A – current status, B – climate $2xCO_2$

Fig. 5 cont'd. Changes in the natural occurrence ranges of pedunculate oak (*Quercus robur*) in Europe. A – current status, B – climate $2xCO_2$

Fig. 5 cont'd. Changes in the natural occurrence ranges of European beech (*Fagus sylvatica*) in Europe. A – current status, B – climate $2xCO_2$

Fig. 5 cont'd. Changes in the natural occurrence ranges of sessile oak (*Quercus petrea*) in Europe. A – current status, B – climate $2xCO_2$

Fig. 5 cont'd. Changes in the natural occurrence ranges of small-leaved lime (*Tilia cordata*) in Europe. A – current status, B – climate $2xCO_2$

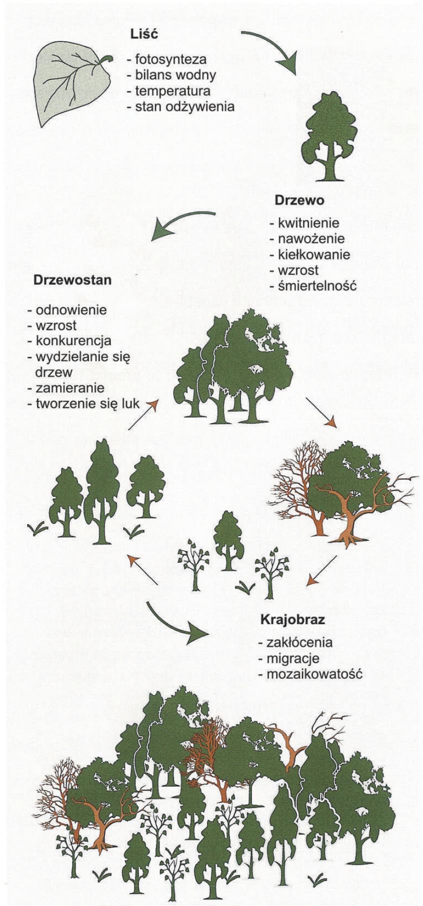
The anticipated changes concern the main forest-forming species which lose their recent ecological optima and will be exposed to all ensuing consequences, starting from biochemical and physiological changes which reveal themselves first in phenology and then in productivity, and which will have an impact on their health condition, susceptibility to known and unknown biotic threats, as well as resistance to abiotic environment factors. It is difficult to predict now all possible consequences to forest management and forest status, particularly so, because changes will not confine to species level only, but will also affect the ecosystem and landscape.

Potential forest ecosystem responses to climate change can be grouped as follows:

- changes in forest location,
- changes in forest structure,
- changes in forest productivity.

Understanding the impact of climate change on forest ecosystems requires knowledge of the ways of forest's functioning in different biological and ecological, as well as spatial and temporal scales (SHUGART 1998; WOOWARD 1987).

The forest ecosystem functions in structures at different biological complexity levels (Fig. 6).




Możliwe reakcje ekosystemu leśnego na zmiany klimatyczne na różnych poziomach organizacji (według: SHUGART et al. 2003)

**Fig. 6.** Responses of natural systems to climate change at different organizational levels in a hierarchic structure

Picture description: Possible responses of forest systems to climate change at different organizational levels (according to SHUGART et al. 2003).

**Liść – leave**, Fotosynteza – photosynthesis, Bilans wodny – water balance, Temperatura – temperature, Stan odżywienia- nutrition status. **Drzewo – tree,** Kwitnienie – blooming, Nawożenie – fertilization, Kielkowanie – germination, Wzrost – growth, Śmiertelność - mortality. **Drzewostan – stand,** Odnowienie – regeneration, Wzrost – growth, Konkurencja – competition, Wydzielanie sie drzew – self-thinning of trees, Zamieranie – dieback, Tworzenie luk - gap formation. **Krajobraz – landscape,** Zakłocenia – disturbances, Migracje – migrations, Mozaikowatość – mosaic structure.

Ecosystem response to environmental changes takes place at producer's level – in a tree leave and "spreads around", being strengthened or reduced by regulatory and compensation mechanisms, spreading the effect in multiple directions across the entire tree, stand and father on – to phytocoenosis, and through the energy used – onto consumers, reducers, whole biocoenosis, and from the ecosystem – onto the landscape. The response in a leave lasts as long as the photosynthesis reaction, yet changes in the occurrence of particular plant groups and changes in their ranges take much more time. To change their geographical location, species in late succession stages require a longer duration of the impact than pioneer species, even whole ages. However, even the tiny daily or monthly alterations have influence on flowering , European spruce bark beetle, germination, and consequently on species distribution. By reducing the time scale to hours, minutes or seconds, we can speak about disturbances in the physiological reactions of cells and tissues at the level of photosynthesis, respiration, closing and opening of stomatal pores, etc. Even small climate changes deeply alter the functioning of the organic world, penetrate into its mechanisms and modify its processes; their damage or disfunction is not manifested at once and can remain unnoticed, while the observed changes are attributed to other, unknown factors whose effects we have known before and which we know how to interpret.

This is a probable cause of recent increase of insects, so called "secondary pests", in coniferous stands. It would be by all means interesting to investigate the ecophysiological status of spruce stands attacked by the European spruce bark beetle from this point of view. According to the forecasts concerning changes in the occurrence ranges of Poland's species (Fig.6 – model simulation) in the light of climate change (temperature and precipitation), Norway spruce (*Picea abies*) changes its ecological optimum moving northwards and eastwards. Trees exposed to such changes show a reduced resistance to biotic threats, increased susceptibility to pathogenic factors, and are naturally exposed to intensified attacks of their natural enemies. The biological structures which do not follow up with environmental changes or have lost such skills are thus eliminated. If the above hypothesis is true, then the persistent combat against bark beetles is erroneous and one-sided, regardless whether the protected stand is a commercially managed forest or a forest reserve.

Similar observations have been made in the mountains, where climate warming alters the recent vegetation zonation system (Fig. 7). The northward and upward shift (to upper locations in the mountains) of the current tree species ranges seems to set the direction of change of forest locations associated with climate change.

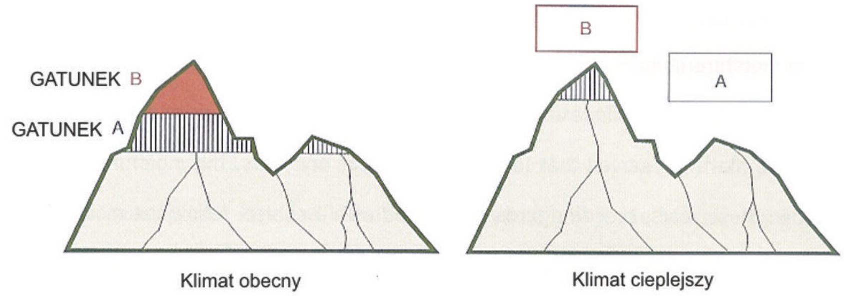



**Fig. 7.** Changes in vegetation zones in the mountains as a result of climate warming. Climate warming has caused retreat of species "B", while the favourable conditions have caused its replacement by species "A" (according to MALCOLM, PITELKA 2000).
Picture description: Gatunek A – Species A, Gatunek B – Species B, Klimat obecny – Current climate, Klimat cieplejszy – Warmer climate.

There are also other grounds for this interpretation. Working Group II of the Intergovernmental Panel on Climate Change (IPCC) of the Framework Convention on Climate Change (FCCC) noted in 2001 that boreal forests that is Northern Hemisphere forests, as well as upper montane forests, with predominant coniferous species, are affected by climate changes in the first place and that their condition deteriorates (GITAY et al. 2001). Earlier, in the first report of the IPCC (1995), it was stated (WATSON et al. 1995) that nearly one third of global forest vegetation on average (and sometimes one seventh to two thirds, depending on the region) changed from coniferous to broadleaved forests due to increased temperature, water availability and increased concentration of atmospheric $CO_2$. Similar observations were also made in Poland (KOWALSKI 1993).

Of course, these interpretations assume that plant responses to the changing growth factors have not changed, only the growth factors have changed.

Climate change and the shift of climate zones can be faster than the changes taking place in plant communities. This is of key significance for the location of natural forests. However, this issue is less valid for plantations and managed forests where foresters can plant trees and saw seeds commensurate to the climatic requirements of species, however on condition that recognition of these requirements, done in the past, reflects the current status (DAVIS, SHAW 2001).

Phenomena such as tree seed migration, changes in the spread of pests and diseases and fires also have an impact on forest location changes. Allowing such spontaneous changes, that is not preventing them through silviculural treatments, may save many species from extinction – they simple have a chance to find a new, suitable place for themselves.

## 6. Climate change versus forest productivity

Changes at photosynthesis and species composition levels are certainly reflected in ecosystem productivity, that is timber growth. $CO_2$ is the main factor of photosynthesis and its concentration affects plant productivity. Yet the correct assessment must be based on the interrelationships between $CO_2$ concentrations, temperature and water availability. These relationships are not fully recognized and improvement of one of the factors need not necessarily result in productivity growth (SHUGART et al. 2003). The transpiration mechanism steering the opening and closing of leaf stoma and regulating water economy in plants plays a big role here.

Research under controlled conditions has shown that for plants growing in the atmosphere with a double concentration of $CO_2$, that is approx. 660 ppm (with the other growth parameters remaining the same), the young plants produce approx. 40% more biomass, and the older and mature plants produce nearly 26% biomass. In the case of woody species, the combined effect of warming and $CO_2$ concentration increase may give a positive result. This relatively positive result of biomass production may however cause big changes in other elements of the forest ecosystem, such as species composition, biological diversity of other trophic levels, sustainability and resistance to health-threatening factors, etc. As the experiment under controlled conditions proceeded, the positive effect diminished.

The positive response of a tree leave to $CO_2$ concentration and its biomass growth do not immediately translate to biomass increment of a tree or whole stand. The higher organizational level, the more doubtful is the effect which spreads onto many substructures in the ecosystem's hierarchical structure. The observed response of a leave tissue and whole plant, as well as the interactive response of the ecosystem, demonstrating the positive effect of increased $CO_2$ concentration, is being reduced with the passage of time and organization level growth in natural systems (KORNER 1993), (Fig. 8). There are many causes of this, and usually they are inherent in the regulatory mechanisms whose recognition is still insufficient. One thing seems to be doubtless – the application of laboratory results to field conditions requires much prudence. And, secondly, the role of forests in accumulating more carbon amounts due to increased photosynthesis effectiveness requires further detailed analyses.

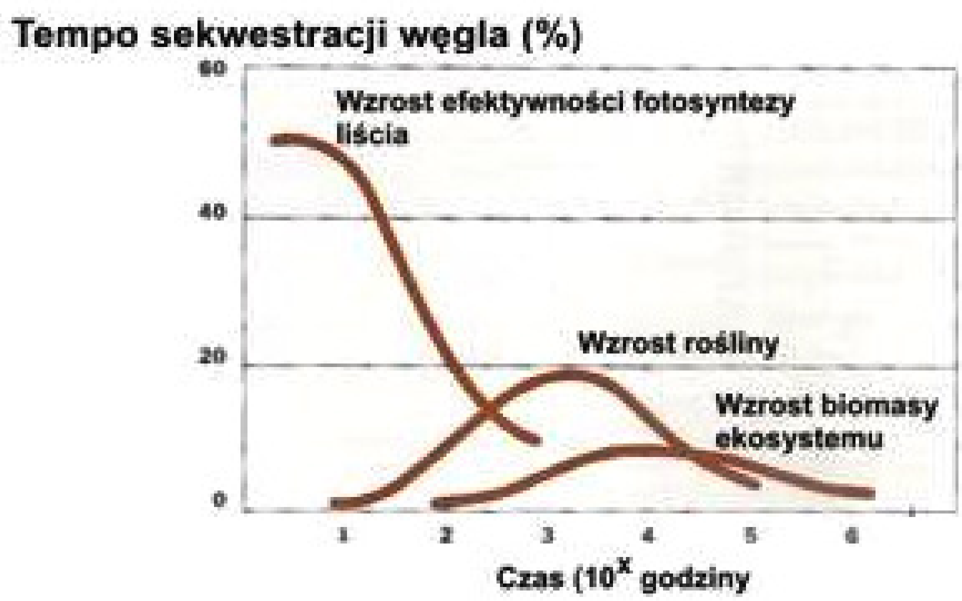



**Fig. 8.** Reduction of the productivity growth effect induced by increased $CO_2$ concentrations with the organizational level growth and passage of time (according to KORNER 1993) The time scale in Fig. 8 is expressed in hours to the power of *x*: if x = 1, the period is 10 hours, if x = 6, the period is 114 years.

Picture description: Tempo sekwestracji wegla (%) – Carbon sequestration pace (%), Wzrost efektywności fotosyntezy liscia – Photosynthesis effectiveness growth in a leaf, Wzrost rosliny – plant growth, Wzrost biomasy ekosystemu –Ecosystem biomass growth, Czas ($10^x$ godziny ) – Time ($10^x$ hour).

Recent studies (SCHLESINGER, LICHTER 2001) show that carbon growth in forest litter is also limited. An increase of carbon content in forests due to CO2 growth in the atmosphere is limited by nutrient content in soil (OREN et al. 2001). To achieve a better result, forests should be fertilized and irrigated, which is irrational. The effect should also be limited.

As the response of plants to carbon dioxide concentrations in the atmosphere is uncertain, there is growing demand for physiological and autoecological research *in situ* on a representative network of permanent observation-measurement plots, designed for long-term interdisciplinary observations.

Few studies of this type (http://www.face.bnl.gov; http://www.esd.ornl.gov/facilities/ornlface/pce1999.htm; http://cdiac.esd.ornl.gov/programs/FACE/face.html), carried out both under greenhouse conditions and in the field, provide more details. After the first years, it was confirmed that additional carbon in the atmosphere caused by concentration growth is located in fine roots and leaves, rather than in trunks or stems, and that Net Primary Production (PPN) growth cannot be a plant productivity indicator. A new edition of BIOME-BGC program takes into consideration forest fires and extreme climate states, such as draughts and winds (http://www.forestry.umt.edu/ntsg/).

Other reports (2005) confirm the scepticism as to the possibilities of accumulation of additional amounts of $CO_2$ by forest trees and acceleration of their growth due to increased carbon dioxide concentration in the atmosphere (Scientific American, August 26, 2005; http://www.sciencedaily.com/releases/2005/08/050809064251.htm). Researchers from the Duke University in Canada stated that if an increase in the concentration of $CO_2$ in the atmosphere is accompanied by simultaneous climate warming and drying, no increased carbon retention in forests should be anticipated; on the contrary, its resources will diminish. In his studies, KÖRNER (2005) from the University in Bazylea (Switzerland) did not observe any increased wood and leave biomass production after increased concentration of $CO_2$ in the atmosphere. What he observed was an increased exchange rate of carbon with the atmosphere. At the same time, he observed the possibility of increased root production and location of additional carbon amounts in the belowground biomass.

Recent years have seen extensive comparative studies in the USA on the existing climate models under the VEMAP Project (*Vegetation/Ecosystem Modelling and Analysis Project*). (VEMAP 1995; MALCOLM, PITELKA 2000). Six ecological models differing in parametric requirements, yet sharing the advantage of dynamic forecast, were compared. The results appeared to be extremely divergent.

This strong diversity concerned first of all the structure of forest formations at landscape level, degree of forest cover, northward shift of forest formations, increase of areas with predominant savannas, decline of boreal mixed forests, etc. The multiple of mutually excluding changes makes such simulations of little usefulness for planning forest management behaviour strategies. However, it documents the significant lack of knowledge of large vegetation formations' responses to the changes of vegetation conditions.

There are many uncertainties in forecasting forest statuses in a span of e.g. one hundred years (e.g. rotation). The models based on biogeochemical cycles (e.g. BIOME-BGC, TEM, CENTURY (AUCLAIR 2003) predict the Net Primary Production (PPN) value. However, the relationship between the PPN and stand productivity is not straight-lined. It is clear that a 20% growth in the PPN does not mean a 20% growth in timber production. An increase in primary production entails an increase in the losses due to consumers' activity, particularly insects, as well as diseases and competitors, fires, winds or hardly predictable events. Those events are generally not taken into consideration in contemporary models. Neither are the effects of selection, fertilization, conservation, etc. included in the model. As we know, young trees respond more intensely to climate change, and their share in biomass growth is marginal.

Uncertainty of vegetation changes entails even higher uncertainty in determining the impact of climate change on the productivity of forest ecosystems. According to the analysis of photosynthesis effectiveness and its impact on tree and ecosystem biomass, expectations of productivity growth must be limited by the periodicity and transitionality of this process. Moreover, another important factor may appear to be growth in the frequency and extent of natural distortions, like fires, strong winds, low or high temperatures occurring in atypical periods, draughts, floods, etc. As distortions occur on a spatial scale exceeding the scale of any ecosystem studies, and their time intervals are much longer than the longest ecological studies, it is very difficult to assess their impact on forest ecosystems. These phenomena have not been sufficiently taken into consideration in the existing models dealing with the impact of climate change on forests.

## 7. Carbon management strategies in forests

The total amount of accumulated carbon in forests depends on:

1) species composition in a stand,
2) habitat conditions,
3) management (tending cuts, felling age or rotation cycle),
4) climate conditions (temperature, moisture).

Forest management can efficiently influence the first three factors through different management methods.

The impact of different management methods is illustrated in Fig 9.

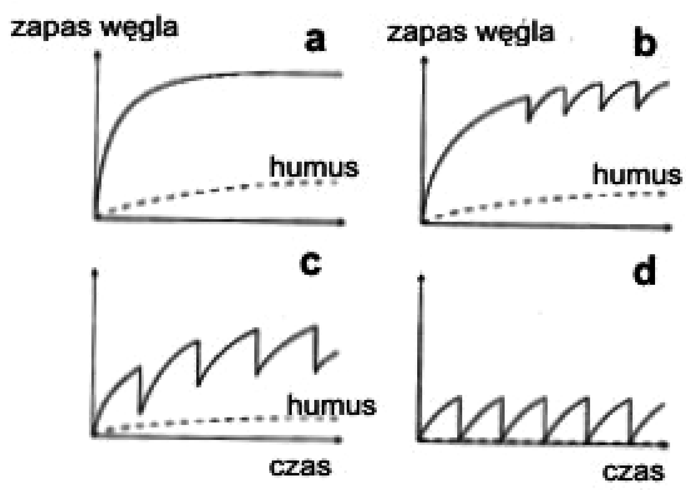



**Fig. 9.** Carbon stock and increment in (a) natural forests, (b) in selectively managed natural forests (c) in managed forests, (d) in plantations (according to (wg WBGU 1998). Czas – time

Natural forests show maximum growing stock and zero (0) increment; selectively utilized natural forests show reduced growing stock which is set off by small increment. Commercially managed forests feature a 40% lower growing stock compared to natural forests, however despite their utilization, they have a greater growing stock than increment, as the harvest does not exceed the increment. In plantations, there is about 10-15% of natural forests' carbon stock and the stock does not grow, for all the increment is used.

The applied management methods, or rather forest management's possibilities of impacting carbon accumulation, may serve for drawing the main carbon management strategies in forests (Table 1).

**Table 1.** Strategies, proposed measures and possibilities of forest management to reduce greenhouse gas concentration (according to CANNELL 1995; IPCC 1996)

| **Strategy** | **Proposed measure** | **Carbon concentration reduction potential to 2100 Gt** |
|---|---|---|

| | | |
|---|---|---|
| Protection and consolidation of existing carbon resources (reduction of indirect negative effect of forest management on forests) | Protection of forests on threatened areas | 40–80 |
| | Reduction of socio-economic pressure and deforestation prevention | |
| | Improvement of forest management through appropriate management: protection against pests, fires, boosting incremental growth , etc. | |
| Accumulation of carbon in new forests | Reconstruction of degraded forests | 20–30 |
| | Establishment of new semi-natural forests (afforestations) | |
| Substitution of fossil fuels and materials requiring large amounts of energy | Establishment of forest energy plantations | 50–200 |
| | Development of agro-forest farms | |
| | Application of biofuels generating electricity and heating | |
| | Substitution of cement, metals and plastics with wood | |

It should be emphasized that the current assessments of potential carbon sequestration are burdened with many doubts. First, the uncertainty derives from the socio-economic and technical barriers, second, many indirect effects on carbon accumulation in forests resulting from forest management are still unknown, and third, it is difficult to compare the economic and energetic effectiveness of substituting fossil energy sources with wood.

Nevertheless, three principal lines of procedure can be defined:

1) protection of the existing carbon resources and their consolidation; this concerns both the protected natural forests and managed forests based on the principle of Sustainable Forest Management (SFM)
2) creation of new carbon sinks through afforestation, plantation management, farmland afforestation management and rehabilitation of degraded forests;

3) use of wood in substitution for fossil fuels and materials whose production requires huge amounts of energy (metal structures, cement, plastic), establishment of energy plantations with short production cycles, use of biofuels, etc.

Certainly, these strategies are not mutually exclusive. The initiatives to increase carbon absorption and extend the time of carbon retention have already been taken, like for example the FCCC and Land Use Change and Forestry (LUCF) projects under the name Activities Implemented Joitly (AIJ).

**Ad 1.** In natural, unutilized forests, the carbon cycle is in fact closed (Fig. 10). For the strategy of managing this terrestrial carbon pool, the most essential thing is to preserve the achieved equilibrium status. At the same time, it should be remembered that the possibility to increase carbon content or increment in those forests is in fact nonexistent. Similarly small impacting possibilities occur in the case of moderate, selective use of natural forests. It can be said that the existing carbon management tools for this type of management are sufficient to preserve the stock and control its use at the required level. The largest number of management tools are provided by sustainable forest management (Fig. 10, Option C) which enables stock growth, sustainable wood utilization and carbon pool preservation in products as a result of substitution of other materials. Like in natural forests, closing the carbon cycling in managed forests, where carbon is recycled in the form of wood and wood products (Fig. 10C) should be a theoretically possible target solution.

**Fig. 10.** (A) Closed carbon cycles in natural forests, (C) in managed forests, (B) carbon emission as a result of deforestations; a – utilization of wood and wood products (carbon recycling)

The largest potential counteracting rapid climate changes is in the preservation of the existing carbon resources in forests. The majority of carbon emissions caused by deforestation appear relatively soon after felling. Reduced felling will bring a beneficial change in the level of atmospheric $CO_2$ sooner than afforestation or forest regeneration. The latter operations may cause accumulation of similar amounts of carbon, yet in a much longer time.

It is estimated that should deforestation be totally stopped, 1.2 – 2.2 Gt of carbon more could be accumulated (DIXON 1993). BROWN (1996) estimates that reduced felling in tropical forests might probably save 10–20 Gt of carbon (0.2–0.4 Gt per annum) by 2050.

However, as long as revenues from deforestations and incorrect forest use are one of the major drivers of economic development in the developing countries, their policy must take into consideration the causes of poverty and seek other ways of satisfying needs, if forests are to be protected.

Retention of carbon resources in the existing forests can be achieved by improving the existing management techniques. Reduction of carbon losses in the logging processes, that is the use of technologies reducing the impact of logging operations (*Reduced Impact Logging)* on carbon release, might be the most important factor. The conventionally performed logging generally cause a high amount of damage, particularly in the tropics (KURPICK, KURPICK, HUTH 1997). The new technical achievements (RIL) may reduce the degree of stand damage after felling by 50% (SIST et al. 1998) thus reducing the level of carbon emission associated with logging. NABUURS and MOHREN (1993) calculated that the long-term retention of carbon resulting from the RIL can, in tropical forests, reach 73–97 tones per hectare. Knowing those data and estimating that 15 million hectares of tropical forests, the majority of which are considered poorly managed forests (POORE et al. 1987), are cut every year (SINGH 1993), the potential growth of carbon resources in forests is tremendous. Additional carbon, saved thanks to the RIL techniques, depends on the conviction that conventional felling techniques could be continued, and that the problem is how to calculate these additional amounts of accumulated carbon left in the forest due to the introduction of new logging techniques (IPCC 2000).

**Ad 2.** 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 (DOWYDENKO 2003). The carbon accumulation process in afforested, post-agricultural soils proceeds in two stages: (1) in the first stage carbon is emitted to the atmosphere (2) in the second stage carbon is accumulated in soil during the further processes of stand growth.

The carbon emission stage, that is the negative carbon balance status caused by afforestations, is associated with soil preparation operations preceding afforestation, which affect its structure, like furrowing, deep ploughing, subsoiling, contributing to carbon oxidation and emission.

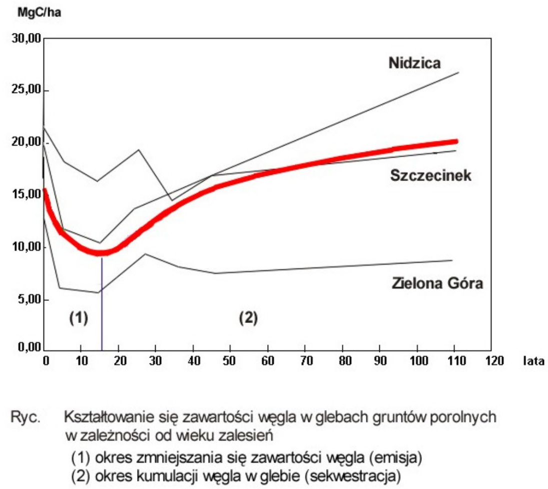



**Fig. 11.** Contents of carbon in soil in post-agricultural areas by afforestation age (DOWYDENKO 2003)

1) period of carbon content decline (emission)
2) period of carbon accumulation in soil (sequestration)

The period of carbon reduction in soil is followed by its growth and accumulation (Fig. 11). When a tree (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 afforestations (regenerations) is diverse and depends on the species, habitat or management method. The average annual afforestation output, expressed in tones per hectare, ranges from 0.8 to 2.4 tones in boreal forests, from 0.7 to 7.5 tones in temperate climate zone forests, and from 3.2 to 10 tones in the tropics (BROWN et al. 1996). Potential accumulation of carbon in agro-forest plantations is even more diversified depending on the nature and targets of production.

Assuming that the global area available for afforestation and agro-forest activities is 345 million hectares, BROWN (1996) estimated that about 38 Gt of carbon could be accumulated over the next 50 years – 30.7 Gt through afforestation and 7 Gt through the adaptation of agro-forest practices. A close look at the tropical regions allows concluding that additional 11.5–28.7 Gt of carbon can be obtained as a result of regeneration of 217 million hectares of degraded land (FAO 2001).

The land currently available for forestry will turn to be much smaller after taking into consideration all the social and economic aspects, as no more than one third of ecologically suitable land can if fact be utilized (HOUGHTON, UNRUH and LEFEBRVE 1991).

According to this scenario, afforestation and agro-forest activity will absorb approx. 0.25 Gt of carbon, and the restoration of damaged land – the next 0.13 Gt of carbon per annum.

**Ad 3.** The global consumption of wood has increased over the past 25 year by approx. 40%, reaching 3.4 billion $m^3$ in 1994. The value of this wood was nearly USD 400 billion; approx. 75% of wood was industrially processed (FAO 1994). More than half of the wood is used as fuel; for two fifths of the people in the world, charcoal is the main source of energy (FAO 1997).

Biofuels currently supply 14% of the total energy requirement. In the developing countries, these satisfy one third of the energy requirement. If the current biofuel consumption is substituted by fossil fuels, the additional amounts of carbon emitted to the atmosphere would be 1.1 Gt per annum (IPCC 2000). Unlike fossil fuels, the use of biofuels does not produce $CO_2$ emissions (net) to the atmosphere ($CO_2$ released to the atmosphere from burning biofuels is used by the regrowing biomass). The replacement of fossil fuels by sustainable biofuels reduce $CO_2$ emissions proportionally to the value of substituted fossil fuels. The anticipated future share of biofuels in satisfying the demand for energy should oscillate from 59 to 145 x $10^{18}$ J in 2025 and from 94 to 280 x $10^{18}$ J in 2050 (BASS 2000). The future consumption will depend on technology development which will enable effective use of biofuels, such as use of the gas generated from wood products.

The new “biofuel plantations” will bring long-term positive results, if they substitute the current plantations featuring a lower pace of carbon accumulation. In the long term, the mean carbon density (carbon content per unit area) in plantations oriented on biofuel production (this particularly concerns plantations with short production cycles) will of course be higher than in the majority of unforested areas. The situation will be opposite when natural forests are substituted by biofuel-oriented short-rotation plantations: the positive substitutive effect will disappear due to the change in the land-use form – *i.e.* emissions caused by deforestations.

Utilization of wood and wood products as substitutes, that is in place of the materials whose production entails large emissions of carbon dioxide (like cement, steel, aluminium, or plastic), may also lead to a significant net reduction of $CO_2$ emissions. A good illustration of that is the comparison of energy and contamination potential both in wood and steel when building a 3 m high and 30 m long wall of identical thickness, using those two materials (MEIL 1995). By using wood, approx. 3.5 times less energy is used and nearly 3 times less $CO_2$ is emitted to the atmosphere, not to mention other gasses whose emissions are multiple times smaller. In this way we reduce the greenhouse effect by about two thirds, consume about 20 times less water, without contaminating it, but contributing to its biological filtration. Such is the climatic and environmental sense of wood promotion.

## 8. Some economic aspects

Of 3.5 million hectares of land under the Activities Implemented Jointly programs developed according to the principles presented by the Land Use Change and Forestry, *(LUCF*), (FCCC 2000), 83% is oriented at carbon accumulation in the existing forests through their protection (by withholding cuts) or sustainable forest management (SFM). According to those projects, the long-term carbon accumulation oscillates between 0.2 and 85 tones per hectare for managed forests, or 4 – 252 tones per hectare for totally protected forests. The estimated accumulation effect over the entire project duration (100 years assumed) is 5.7 million tones of carbon in the case of sustainable forest management and 40–108 million tones in the case of their protection. The further 180 000 hectares is destined for the regeneration and afforestation of new areas giving growth of about 21.7 million tones of carbon in the adopted time scale. It is expected that two projects covering 200,000 hectares associated with agro-forestry will additionally accumulate 10.8 million tones of carbon.

The cost of accumulation of one tone of carbon in these projects is estimated at USD 0.1 – 15. It should however be remembered that there are different approaches to the methods of calculating carbon accumulation costs, and the issue requires special attention and research. Profitability of carbon accumulation in forests depends on the costs of emission reduction by industries (e.g. the power industry). Some studies show that additional accumulation of only approx. 1 Gt of carbon by forest management will be profitable.

All Scandinavian countries introduced a so called carbon tax for fossil fuels in order to obligate users to reduce the emissions of CO2 to the atmosphere and financially strengthen forest management which contributed to carbon absorption. In Norway, the tax is NOK 0.82 (or about USD 0.12) per litre of gasoline which equals NOK 343 (or USD 49) per tone of $CO_2$. The tax corresponds to the cost of emission offsetting the economic value of atmospheric $CO_2$ absorbed by forest biomass. The thus generated revenues correspond to the economic value of carbon sequestration in forest biomass and are 20–30 times higher than the economic value of wood as an industrial raw material in Norway. The price of wood is commonly known to be one of the highest wood prices in the world. It is declared (SOLBERG 1997), that this will precipitate some far-reaching changes in the forest-use policy, both in the poor and rich countries. The projects aimed at the restoration and preservation of sustainable forest ecosystems will be very profitable and at the same time may provide other significant environmental benefits, such as biodiversity increase, soil stability growth or water economy improvement.

## 9. Polish forestry's participation in climate protection

**9.1.** Poland's forests represent approx. 0.002% of the global forest resources, so their impact on global climate from this perspective is irrelevant. However, the sense of responsibility and participation in the common effort aimed at the improvement of human activity, including forest management, in order to restrain climate change and mitigate its effects is significant. The participation of forests in the regional and local land use structure and local topoclimate shaping is of great, measurable importance.

Polish forestry faces an extraordinary effort towards continuous augmentation of forest cover and maintaining forest utilization at a level below wood increment. These are the simplest and most measurable forest management activities in favour of timber growth. Since 1946, forest area has increased by about 2.5 million hectares (in some years, even 60 thousand hectares of forest were added per year), while usage has never reached the increment level, oscillating between 55% and 70% of increment.

The indications included in the IPCC guidelines are considered while defining the carbon resources in the timber biomass for Poland, for the purposdes of FRA assessment (Global ForestResources Assessment. On the basis of available date (Forest in Poland, 2005, 2006, 2007, 2008, 2009, CILP) regarding timber resources the carbon volume included inm timber biomass in Poland was estimated to reach 736 mln tonnes, of which 562 mln tonnes falls to over-ground mass, 158 mln tonnes – to underground mass, and 6 mln tonnes – to deadwood. The current share of Polish forests in the country's compensation of carbon dioxide emission is estimated on the level of approx. 8,8 %.

Changes in the nature of forest management in Poland and the evolution of forestry based on raw-materials towards sustainable forest management (The State Policy on Forests, 1997), foster climate protection activities and activate efforts increasing carbon accumulation in forest ecosystems. The appropriate silvicultural activities under the SFM program, which improve productivity, may to some extent increase the accumulative abilities of forest ecosystems (BERNADZKI 1993; RYKOWSKI 1999, 2000), (the possible range of absorption increase is given below in parentheses):

- stand conversion towards species compositions better adapted to habitats (approx. 20–25 tC/ha);

- introduction of underwood (improvement of growing stock – appox. 1.1 $m^3$/ha/year and carbon accumulation e.g. beech underwood – approx. 0.4 tC/ha/year);

- change of the management system from clear-cutting to shelterwood and from artificial to natural regeneration (clear cuts cause release of about 24 tC/ha, on poor soils approx. 15 tC/ha; abandonment of the clear-cutting method of management may cause accumulation of an additional amount of approx. 0.4 tC/ha/year);

- efficient tending cuts, particularly thinning, in the way enabling use of timber from increment thinnings (hard to assess in terms of volume);

- afforestation of post-agricultural land (approx. 80 tC/ha , 60 years of age).

Under Polish forest conditions, we can assume that forest management practices may cause an increase of carbon accumulation as a result of stand conversion by about 200–215x$10^6$ tC; as a result of the introduction of underwood – by 16–20x$10^6$ tC, and due to afforestation– by about 80–240x$10^6$ tC.

The problem however is that this growth is very difficult to document and separate from carbon accumulation growth caused by natural processes, independent from human activity. This might be possible only through steady monitoring and comparison of relevant data from managed forests with those from reference forests without economic intervention. There is urgent need that the State Forests NFH calls into being a network of such forests (RYKOWSKI 2003).

**9.2.** Recently, the State Forests NFH, the main administrator of Polish forests owned by the State Treasury, has started a series of research-application programs aimed to fulfil the obligations resulting from the Framework Committee on Climate Change and the possibilities of using the agreements laid down in the Kyoto Protocol.

A legislative proposal has been prepared specifying the legal-financial instruments to support the reduction of greenhouse gasses and other emissions.

A broad spectrum of analytical work has been commenced 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 patterns 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 the forest and the atmosphere is a new approach to explaining the interreactions between climate change and forest ecosystems (OLEJNIK 2008). To this end, a 34 m high measurement station has been erected (Tuczno Forest District, central-western part of Poland – 53°11'N, 16º05'E) in an about 20 m high pine stand, where specialist equipment has been installed. An eddy covariance technique is used for measuring $CO_2$ flows. The main instruments used in this method include a spectrometric gas analyzer and ultrasonic anemometer for measuring wind velocity and direction. The equipment required by the eddy covariance technique has to measure the concentrations of water vapour, carbon dioxide and the vertical wind velocity component at a pace of 20 times per second. Due to such measurements, a huge database is created which requires specialist analytical procedures.

In addition to the need for content measurements and estimation techniques for carbon sequestration in forests, there is another issue be dealt with- forest management adaptation to climate change. This is the task of another research program financed by the State Forests NFH. 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.

## 10. Conclusions

**10.1**. Climate changes affect the condition, development and distribution of forests through temperature increase in high latitude regions and precipitation changes around the Equator. All the regions with raised temperature and unchanged or reduced precipitation will suffer draughts which will affect vegetation growth and increase fire hazard. Fires are those factors which may become the highest threat to forests in those regions.

The existing forests may for some time sustain under the changed conditions. Their duration will depend on the adaptive skills of trees. However, changes in their natural occurrence ranges should rather be anticipated. The adaptive skills of trees, organisms with long development cycles will clash, over the period of one generation, with changes of temperature, $CO_2$, concentrations, soil moisture, habitat eutrophication (deposition of N compounds). Their ecophysiological responses will depend on the intra- and inter-species variability. They will also depend on interspecies relationships and ecosystem processes of: spread and preservation of pollinating species, plant consumers, insects, pathogens, other pathogenic factors, etc. Also, properties unknown so far can come into play, and the whole system may respond in the way that today is hard to predict. Mountains will probably be important refuges for many species. Changes in species distribution may lead to new species compositions in forest communities and to their extinction. Changes in the quantity and quality of forests will affect, as a feedback, the acceleration of the occurring changes.

Uncertainty as to how biosystems will behave and unpredictability of nature seem to be the main defects of all scenarios describing nature's future states resulting from climate change.

**10.2**. Forests occur in a quadruple role in the climate change process:

5) as the "cause", that is as a source of greenhouse gasses, mainly $CO_2$, as a result of deforestations,
6) as the "victim" of climate change causing increased vulnerability to pests and deceases, increased forest flammability, changes in species composition, changes in the natural ranges of tree species,
7) as the "beneficiary" of climate changes, that is benefiting from the " greenhouse effect" stimulating biomass growth,
8) As the "remedy" for global changes and poor condition of the environment on account of: ability to absorb and accumulate carbon in forest ecosystems' structures (wood, soil), wood's substitutive properties for construction materials and raw materials, as well as fossil fuels, and the ability to regenerate for the benefit of the environment.

Thus the role of forests and forest management depends on the forest management methods and targets, as well as on the ways of utilizing forest produce, particularly timber.

**10.3.** The likely changes of climate characteristics will cause, in the longer perspective, deep distortions in the directions and pace of ecological succession which will shape forest ecosystems, commensurately to the ecophysiological sensitivity of tree species to the "greenhouse conditions". Many of the created change models anticipate disappearance of some and promotion of other tree species, as well as shrinking of forestland with its current structure and functions, at least on a regional scale. Forest communities will undergo radical changes. Elimination of some autotrophic species and development of others will cause fundamental changes in the trophic change structure, entailing hardly predictable quantitative and qualitative changes in forest biodiversity at all organizational level. If these changes proceed in accordance with the predictions (the "wet variant" and the "dry variant" should be taken into consideration), we will have to do with structurally and functionally new forest ecosystems. This may radically alter the concepts and recent strategies of forest management development.

**10.4.** On the basis of the available knowledge, it is possible to predict the likely changes in forests as nature's structures, and forest management as a human activity in forests, in connection with climate change. Future studies will certainly verify these statements.

1. Natural species occurrence ranges will change, and these changes will be quasi-natural: with the rising temperature, the main forest tree species will migrate northwards, and towards higher altitudes in the mountains. This will entail changes in the structure of entire forest ecosystems and forest types.
2. Changes in ecosystem productivity are anticipated; these changes will be positive and negative as well. Forests may become more productive depending on the scale of temperature and precipitation changes, tree responses to higher $CO_2$ concentrations in the atmosphere, or mortality level. Many of these factors may vary depending on the region, forest type, species, etc.
3. The effect of increased CO2 concentrations is particular significant, complex and at the same time largely uncertain. Many assessments indicate an increased biomass increment and productivity growth, should the "fertilization effect" occur, at least periodically. The "carbon fertilization" effect at ecosystem level will be reduced by competition, insufficient level of other nutrients, or distortions (insects, diseases, fires, winds, etc.).
4. An increase should be assumed in the frequency and level of distortions in forest development, such as winds, fires, draughts, pests, diseases, etc. Adjustments should be introduced to the strategy of forest protection against biotic threats (particularly against secondary pests, noxious species, weakness diseases, etc.), as well as against abiotic factors (fires, winds, draughts, floods, extreme temperatures, season shifts, etc.).
5. We should anticipate the growing timber production and relatively falling prices on the timber market. However, this depends to a large extent on the degree of timber utilization as energy biomass, which may contribute to timber price growth.

**10.5.** Poland lacks a governmental program or a national strategy (or a document of a similar rank) encouraging scientific, economic and political circles to initiate undertakings aimed at counteracting or adapting to climate changes. Actions mitigating the effects of such changes or adapting forest management to them have recently been undertaken by the State Forests NFH.

The medium- and long-term forest planning foresees actions consisting in moderate reconstruction of stand structures, from coniferous to mixed or broadleaved forests, maintaining rational forest utilization (stock-increment-yield) and promotion of wood as a product protecting climate. The commenced works aim to formulate a climate change adaptation strategy for forest management which foresees the following silvicultural - protective measures: introduction of a second storey, introduction of underwood, adaptation of tending cuts, increase of carbon retention in soil and protection of organic matter, reduction of soil structure disturbances, preferences to natural regenerations, multidirectional timber promotion, particularly long-term wood and wood product management, afforestation of new areas and promotion of landscape afforestation, etc.

Retaining the representative forest areas, free from economic intervention and exposed to spontaneous adaptation processes, and transferring the knowledge acquired there to other managed areas (reference forests) should be important elements of the strategy.

The above tasks to be undertaken by forest management require scientific support, particularly determination of their effects on other forest management goals and forest functions.

**10.6.** In spite of some major doubts and concerns about the future of forests, the completed analyses and assessments justify formulation of the following assumptions for the forest management strategy to mitigate the effects of the anticipated climate changes.

1. Afforestation of post-agricultural land and wasteland; change of afforestation techniques by avoiding intensive soil preparation (ploughing), promotion of natural forest succession and seeding; optionally*:* use of suitable land in the afforestation process and introduction on a larger scale of “plantation forestry” with a shortened production cycle, at the same time ensuring sustainable timber utilization or its substitutive use (see: timber promotion).
2. Widespread introduction of the sustainable forest management principle:
   - Promotion of natural regenerations;
   - Limitation of clear cuts and reduction of their unit area;
   - Limitation of tending interventions, particularly mechanical soil preparation;
   - Increased intensity of tending cuts – on condition of sustainable timber utilization (see: timber promotion);

- Soil protection and increase of organic matter retention in forest ecosystems (introduction of underwood, stand reconstruction, introduction of second storey);
- Application of environmentally friendly forest utilization technologies, particularly those not causing damage to soil and stand:
- Abandonment of burning post slash;
- Use of bio-oils in forest equipment and machinery.

3. 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.
4. Extension of wood products' life cycle– their period of use should equal or exceed the production period.
5. Optional: increase of utilization to 70–75% of increment.

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