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The Above-Ground Biomass Production and Distribution in White Willow Community During 11 Years of Primary Succession

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1. Introduction

In 1996 the water level in the studied area, the central lake of the Nove Mlyny Reservoir, was reduced by 85 cm. The reason was the implementation of a project with the aim to remedy the negative effect of the reservoir on the biological function of the river corridor. Within the project two islands across the reservoir were to be constructed. After the water level was reduced, seedlings of White Willow appeared immediately on the uncovered sediments. The area of the Nove Mlyny Reservoir thus became a unique natural laboratory of the succession of soft floodplain forest in several dozens of hectares (Buček et al., 2004). The initial stages of the White Willow community, originating from the primary succession (Bergmann, 1999; Matic et al., 1999), prove to be highly productive ecosystems.

The aim of research was to monitor the development of the successive community not only regarding the number and growth of individuals but also other production indicators, such as the biomass of stems, branches and leaves, the LAI or the stem volume, in order to create a natural model of community succession. A natural succession model can both bring some light into the principles of community growth and be a suitable source of knowledge concerning the cultivation of fast-growing woody plants on energetic plantations.

2. Material and methods

2.1 Study area

The permanent research plot was established in 2005 in Vlckuv ostrov Island, the construction of which was finished in 2001. The middle Nove Mlyny reservoir is located approximately 40 km to the south of Brno (the Czech Republic), 16O 37´ E and 48 O 55 N, at an altitude of 170 m a.s.l. In the stand, aged 5 at the time, a rectangular area of 20 x 50 m was set up. The initial succession stages until the age of five were studied in smaller areas because of the high population density (Konůpek, 1998; Kovářová, 2003).

The area is located in Northern Pannonian biogeographical subprovince (Culek et al., 1996); it is characterized by warm climate with low precipitation, therefore it belongs to a warm climatic region (Quitt, 1971). The soil in the research area has been artificially created. The sediments which had naturally sorted in the liquid environment were relocated from the

reservoir bottom to the middle of the artificially created island embankments by suction dredgers. The upper horizon contains loamy particles, after 15-20 cm these are sandy. With the reservoir water permanent storage quota of 170 m a.s.l. the surface of ground water is 20 cm deep.

2.2 Field and laboratory works

In 2005 all trees in the research plot were numbered and their biometric characteristics – the height and the girth of the stem at breast height (using the VERTEX III altimeter and a tape) – were measured. The measuring was repeated annually, always after the end of the growing season. In 2010 individual trees were surveyed by means of the FieldMap (IFER) technology; the obtained data were used for the creation of a 3D visualization of the research plot (Fig.1), using SVS application.
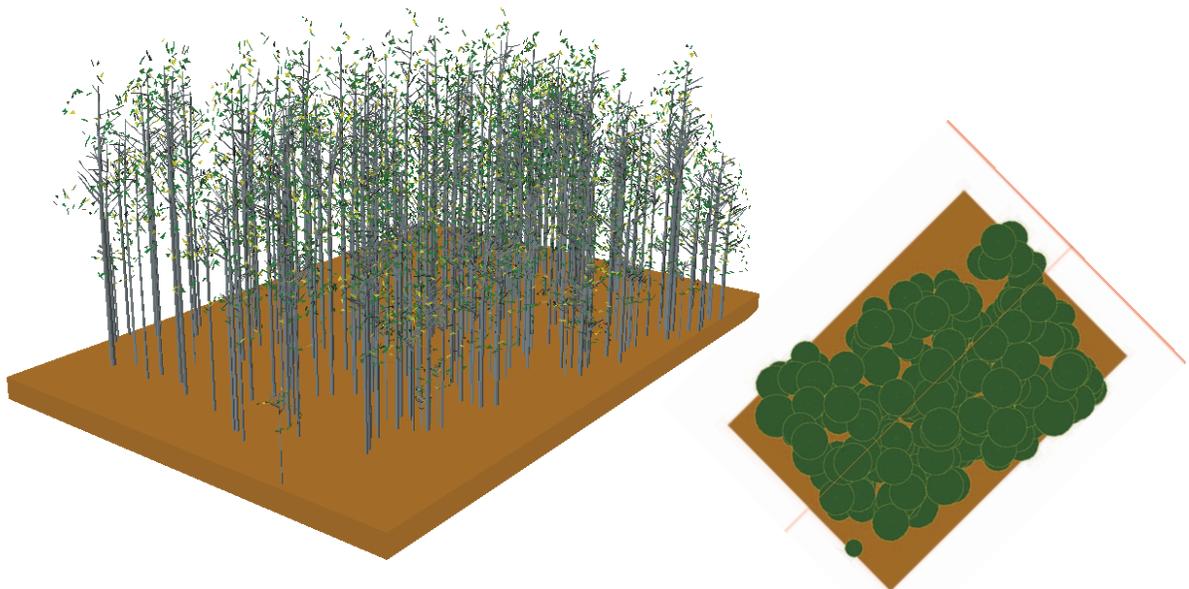
Fig. 1. 3D visualisation of research plot in age of 11 years

In order to gain production characteristic of the stand, the method published by Newbould (1967) was used in a form slightly modified by authors.

Six sample trees of different DBH (diameter at breast height) classes were destructively sampled during the research. The sample trees were taken from adjacent stands; the research plot was left for solely natural succession.

After felling, the sample trees were divided into meter sections and their leaves and branches were gradually removed. Twenty leaves were sampled in each section at random. The girth of the stem was measured each 20 cm; a cross section was extracted from the stem basis for the tree-ring analysis; and a part of stem was extracted for the establishment of wood density.

The removed leaves and branches were dried at a temperature of 105° C until they reached constant weight. The series of 20 leaves from each section were scanned and their area was measured using the ImageTools application. Further, also these leaves were dried and their drymass was measured. The volume of wood samples was ascertained using a measuring cylinder, then the samples were dried again and their drymass was measured.

The energy content accumulated in leaves, branches and wood was found out calorimetrically (Bomb Calorimeter PARR 1281).

2.3 Data evaluation

The annual measurement of all trees in the research plot was used to calculate:
1. Population density
2. Mortality
3. Number of sample trees in DBH and height classes
4. Mean height and DBH of stem

The drymass of leaves and branches of sample trees were added up for individual sections to gain the total drymass. The volume of stem was calculated using the formula for the blunted cone volume as the sum of volume of the 20cm sections. The stem drymass was calculated from the wood density by multiplying the stem volume. Further, the average specific leaf area (SLA) for the leaves of individual sections was calculated as the quotient of a leaf drymass and its area. The SLA value was then used to calculate the area of leaves in individual sections from the total leaf drymass.

To derive the values of growth characteristics of sample trees non-linear Gompertz function was used:

$$Y = (a*exp\,(-\,b*exp\,(-\,c*x))) - d, (1) \tag{1}$$

where "Y" is the mean value of biomass of sample trees in each DBH class, "x" is the mean diameter at breast height in cm for the particular DBH class, and coefficients a, b, c, d are presented in Table 1.

Growth quantity	Coefficients				Regression coefficient	Mean error
	a	b	c	d		[%]
Stem volume	595	5.9	0.0925	3.0	0.992	8.56
Stem biomass	235	5.3	0.08	2.4	0.993	2.61
Branch biomass	98.8	10.15	0.095	0.0	0.999	0.35
Leaf biomass	5.5	8.8	0.16	0.008	0.993	0.13

Table 1. Regression coefficient, mean error and the coefficients of the non-linear Gompertz function used for the processing of the biomass of White Willow sample trees

The data valid for a stand area unit (1 ha) were obtained by multiplying the mean values by the number of trees in each class and their summarization. The non-linear Gompertz functions were used to process the data of the White Willow biomass as they express the data very well, which is proved by the high values of regression coefficients (Table 1).

3. Results

3.1 Population density development

The community of the White Willow sprang up as a cohort on the island – all trees are of the same age and the same species. In such a community the predominating relationship is intraspecific competition, which leads to high mortality related to the growth of individuals. This process is referred to as self-thinning and it follows the 3/2 rule (Slavíková, 1985). The development of the population density in the research plot (Fig. 2) complies with this ecological law.
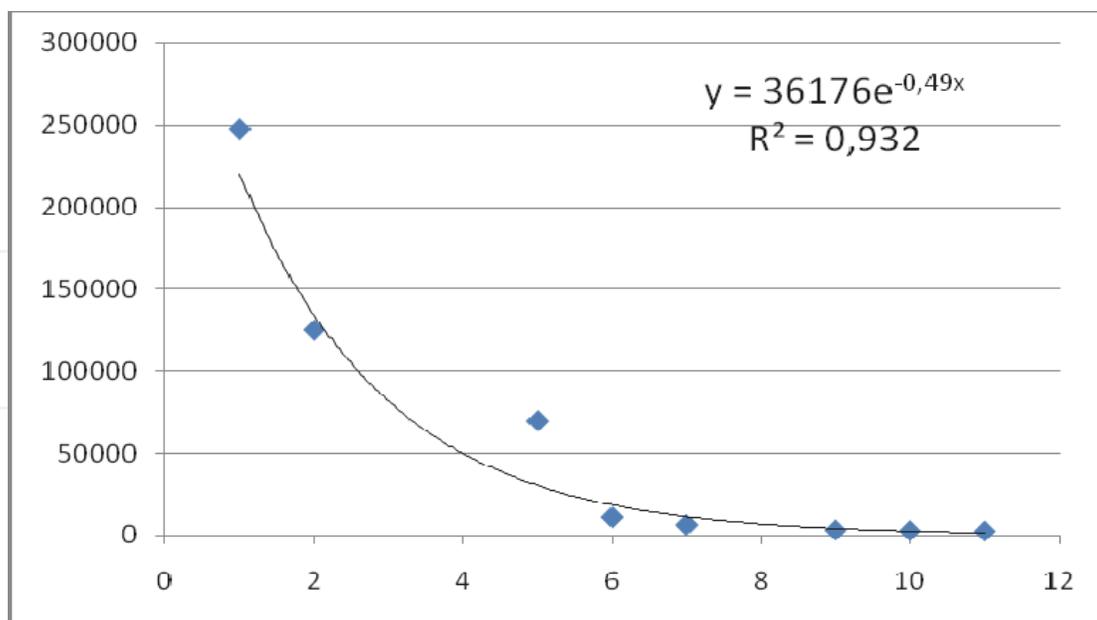
$$y = 36176e^{-0,49x}$$
$$R^2 = 0,932$$

Fig. 2. Population density (No. of trees per hectar). development during succession

The gradual transition of trees from lower DBH classes to higher ones is expressed in Table 2. We can see the diversification of DBH values and the considerable mortality of trees in the lowest DBH classes which is caused by the lack of radiation in the lowest stand layers. With the succession of the community, the canopy closure expressed by LAI (see chapter 3.3) increases and for a light-demanding species, such as the White Willow, the amount of radiation soon drops under the value of the photosynthesis compensation point.

The mortality in the second year of succession rose to 50%, then it dropped to about a third. The key moment came in the sixth year of succession when the intra-annual mortality reached 85%, which was reflected in the productivity stagnation. Since this year, the intra-annual mortality decreased gradually to 51%, 12%, and 9%. The total mortality after 11 years reached 99%!

3.2 Tree size development

The gradual development of the mean DBH and the mean height is presented in Figures 3 and 4. At the age of 11, the average annual height increment was 1.4 m and the average annual diameter increment was 1.2 cm. However, the maximum height of dominant trees is up to 22.6 m and the maximum DBH is 28.6 cm. The stand now manifests a clear division into height layers. The height increment started to slow down from the age of 9, in contrast to the diameter increment, which continues with approximately the same speed. Moreover, the increase in the mean DBH is more noticeable thanks to the mortality of the trees from the lowest DBH classes.

3.3 Leaf area development

The difference in the SLA between the leaves in the shade and the leaves in the sun was considerable. The lowest SLA value of the leaves at the crown base of subdominant trees was 0.00433 g*cm^{-1}; on the other hand, the highest SLA value measured in the sunny leaves at the crown top of dominant trees was 0.12748 g*cm^{-1}. Therefore, the same drymass of sunny leaves takes a thirty times smaller area.

DBH class	Succession age							
[cm]	1	2	5	6	7	9	10	11
I (0.00–1.00)	247600	46880	8533	200	10	0	0	0
II (1.00–2.00)		78160	27733	1260	450	70	10	20
III (2.0–3.00)			20667	1670	490	70	10	10
IV (3.00–4.00)			6800	1740	480	60	50	0
V (4.00–5.00)			2400	1340	610	60	40	10
VI (5.00–6.00)			2133	1060	670	100	60	50
VII (6.00–7.00)			800	710	680	230	120	120
VIII (7.00–8.00)			400	680	470	230	230	70
IX (8.00–9.00)			267	380	410	250	180	140
X (9.00–10.00)				400	380	210	170	170
XI (10.00–11.00)				530	360	280	220	190
XII (11.00–12.00)				330	380	240	230	220
XIII (12.00–13.00)				220	310	210	190	230
XIV (13.00–14.00)				200	230	300	240	240
XV (14.00–15.00)				70	170	120	160	130
XVI (15.00–16.00)				100	120	230	150	100
XVII (16.00–17.00)				30	50	120	200	120
XVIII (17.00–18.00)				30	60	110	110	200
XIX (18.00–19.00)					30	80	90	60
XX (19.00–20.00)						80	130	100
XXI (20.00–21.00)						40	50	130
XXII (21.00–22.00)						10	70	80
XXIII (22.00–23.00)						10	20	40
XXIV (23.00–24.00)							10	30
XXV (24.00–25.00)								0
XXVI (25.00–26.00)								10
XXVII (26.00–27.00)								0
XXVIII (27.00–28.00)								10
XXIX (28.00–29.00)								10
Total	247600	125040	69733	10950	6360	3110	2740	2490

Table 2. The numbers of trees in DBH classes during succession

$$y = -0.027x^3 + 0.569x^2 - 1.905x + 1.722$$
$$R^2 = 0.993$$
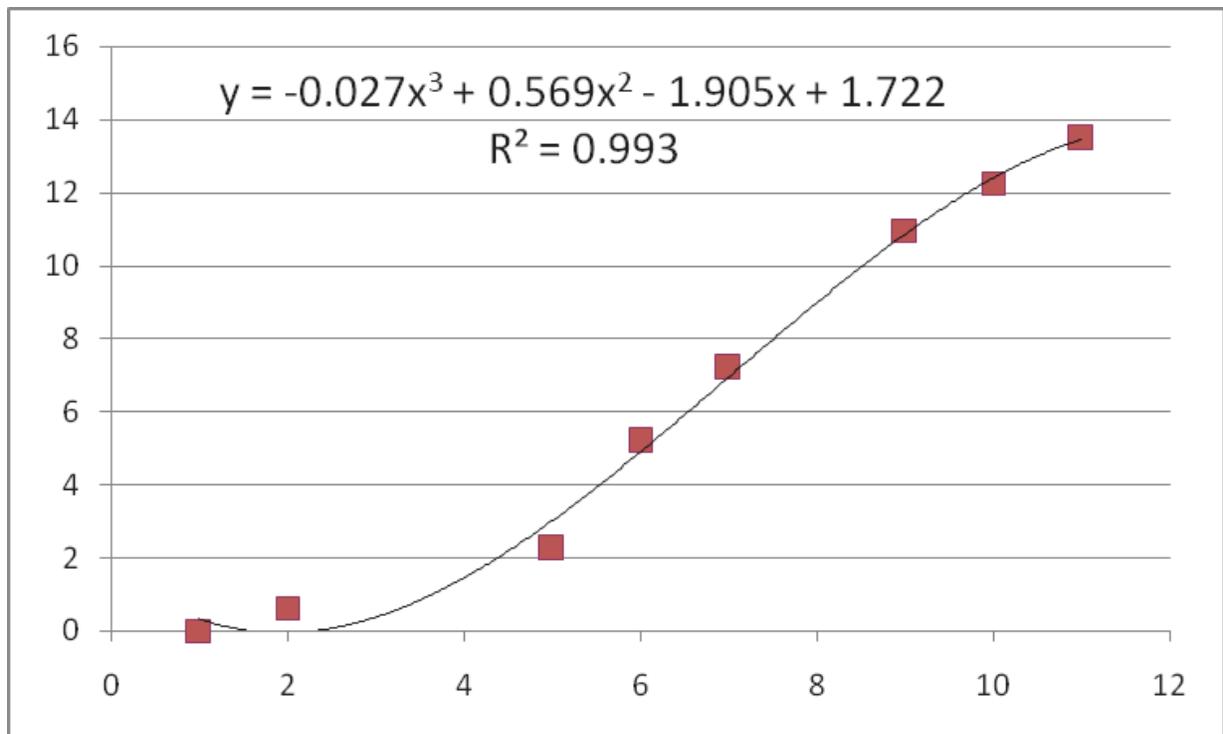
Fig. 3. The development of the stand mean diameter at breast height [cm] during 11 years of succession

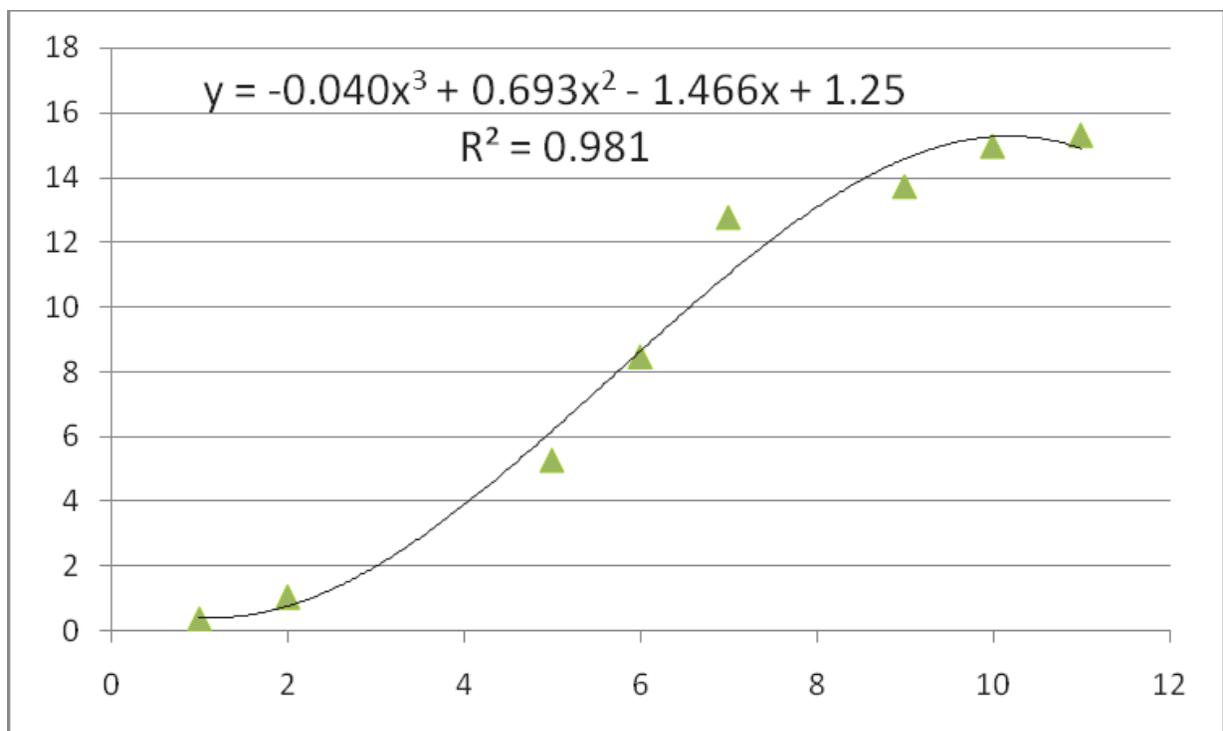$$y = -0.040x^3 + 0.693x^2 - 1.466x + 1.25$$
$$R^2 = 0.981$$

Fig. 4. The development of the stand mean height [m] during 11 years of succession

The distribution of leaf area in the stand at different ages is visualized in Fig. 5 – there is an obvious shift of the crown space to higher layers or higher DBH classes and from the age of 9 the stand started to create particular layers; at the age of 11 there are three obvious layers and there are a few dominant trees.
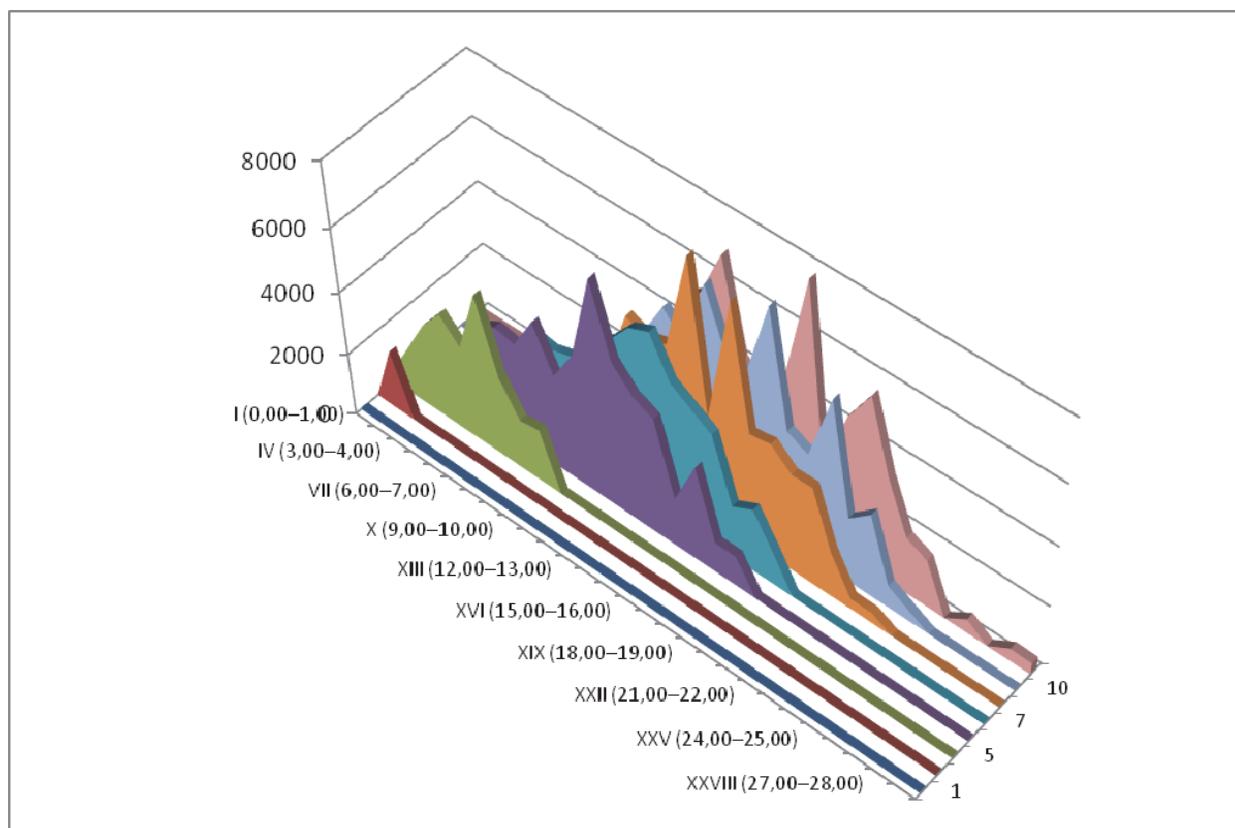
Fig. 5. The distribution of leaf area [m2] in DBH classes in the White Willow stand during the succession

As regards the total leaf area, its development can be clearly shown using the leaf area index (LAI) (Fig. 6). In eleven years the initial negligible LAI values at the beginning of the succession grew up to a relatively high value of 6.6.

3.4 Biomass production development
3.4.1 Stem volume
The stem volume is a basic production characteristic of forest stands. The development of the wood volume storage during the succession is presented in Fig. 7.

There is a clear fast increase in hectare storage during the first years of succession; from the age of 6 it decreases. The age of 6 is of key significance from the point of view of potential effectiveness of harvest. The stand had already achieved very high storage – 244.6 $m^3.ha^{-1}$ – with the mean DBH 5.2 cm and height 8.5 m. Moreover, the six-year-old stand reached the highest average annual increment – 40.75 [$m^3*ha^{-1}*a^{-1}$].

Fig. 8 shows that in the first two years of succession the entire storage was concentrated in the low DBH classes (up to 2 cm); at the age of 5, the core of the storage is still in the lowest DBH class but a considerable part is transferred to DBH classes up to 9 cm. In the sixth and seventh year of the succession the storage is quite evenly distributed in DBH classes 2–19 cm
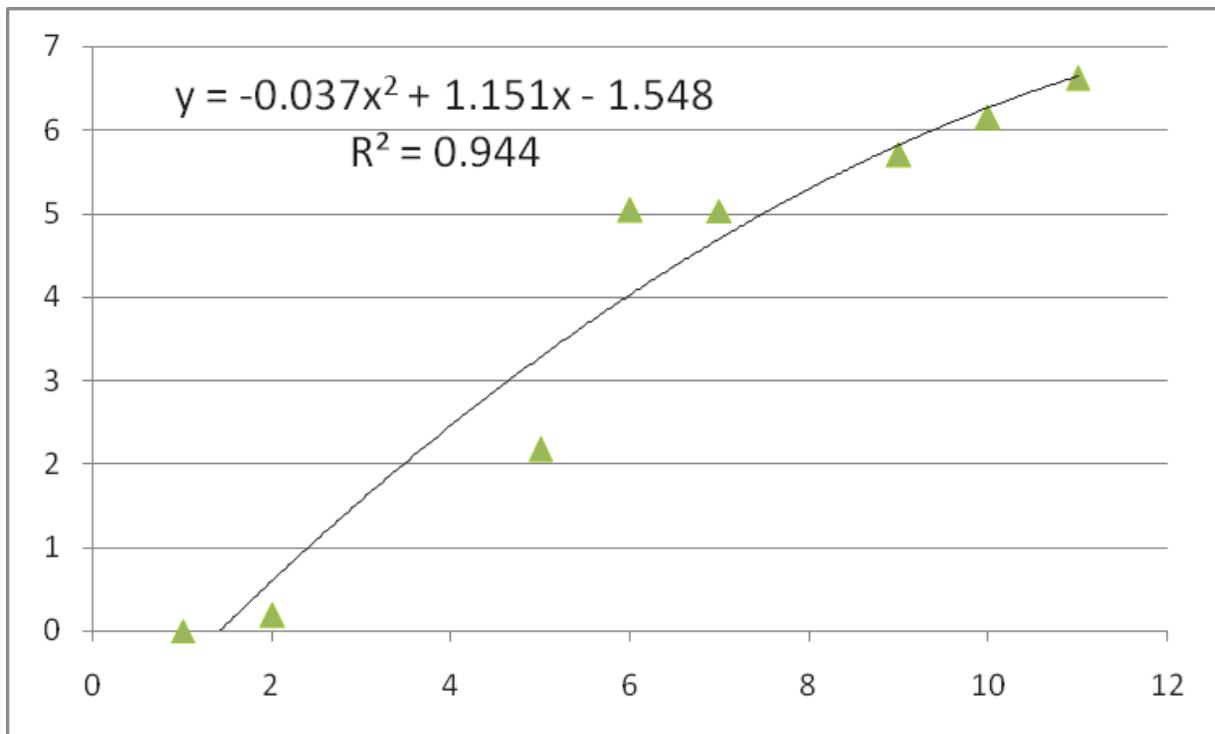
Fig. 6. The development of the leaf area index of the White Willow stand during 11 years of succession
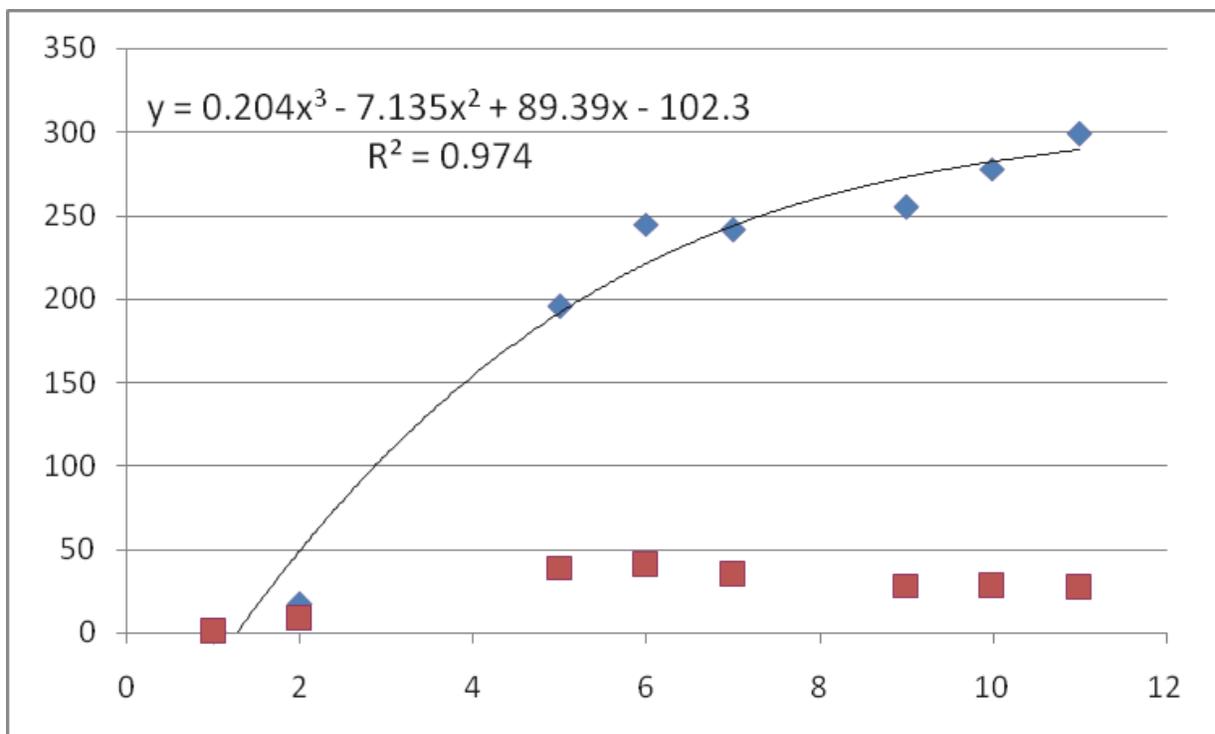

Fig. 7. The development of the wood volume storage in stems [m³.ha⁻¹] during succession connected by a trend curve and the development of the average annual volume increment [m³*ha⁻¹*a⁻¹]

with the maximum in 10–16 cm. In the last four years of succession, the wood storage in stems is gradually moved to the higher DBH classes and divided into three groups, with the concurrent decrease in significance of the trees in the lower DBH classes, which die out due to the intraspecific competition for light. The trees with diameters from 10 to 23 cm become the bearers of production. This fact is important for the selection of the optimum harvesting and transport technology.
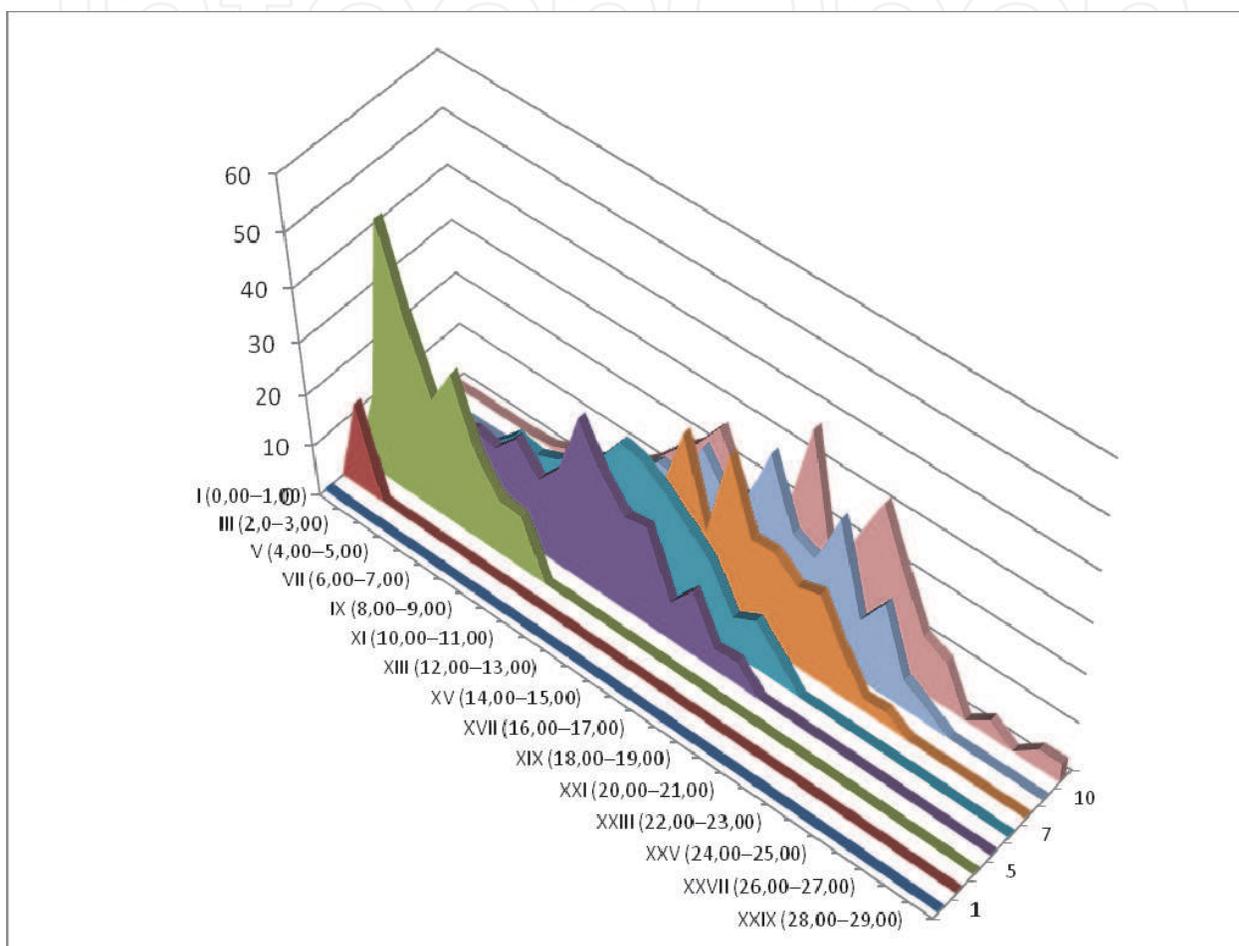
Fig. 8. The distribution of the stem volume storage [$m^3 \ast ha^{-1}$] in DBH classes during succession

3.4.2 Stem drymass

The drymass stored in stems expresses the production of the community better as the wood of fast-growing woody species has a relatively low density. The density we calculated for the White Willow (as the quotient of the volume of a fresh sample and drymass) was 337 kg*m^{-3}.

The drymass accumulated in the stems is expressed in the following graph (Fig. 9). At the age of 11, the community reached 102 t*ha^{-1}, but similarly to the values of stem volume, we can see the decrease in intra-annual growth starting at the age of 6. The average annual increment at the age of 6 was 14.38 t*ha^{-1}*a^{-1}.
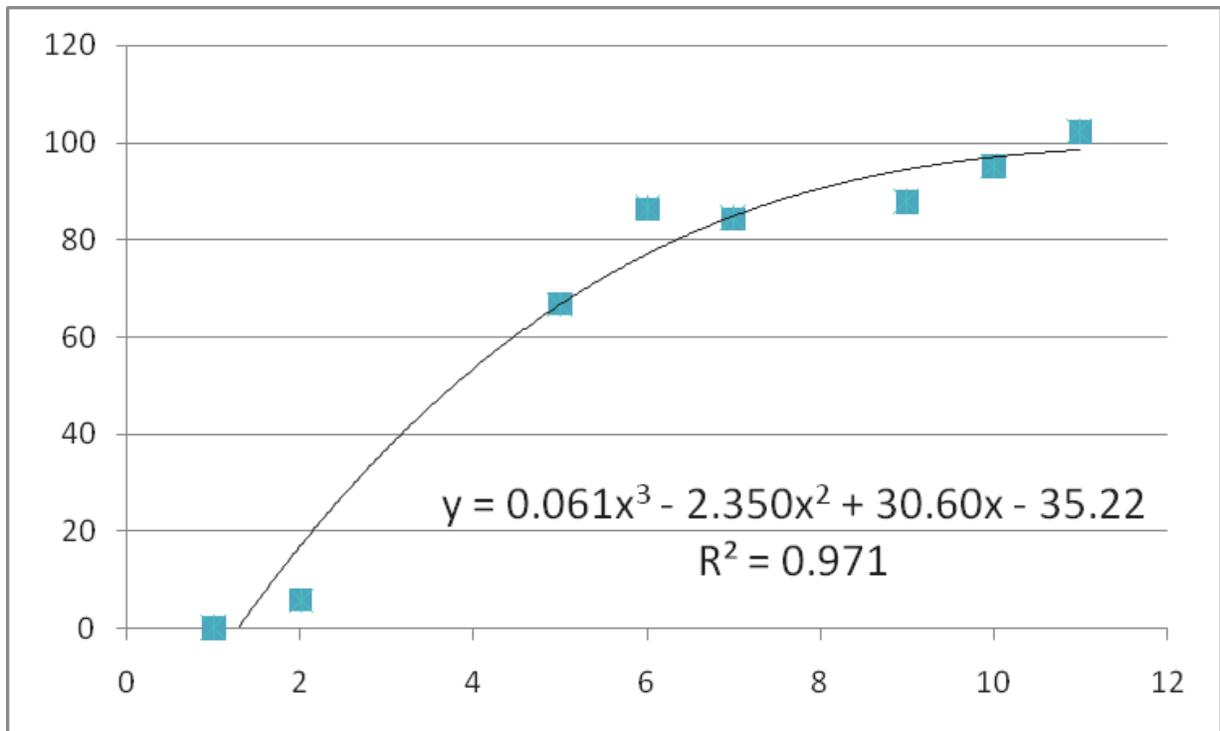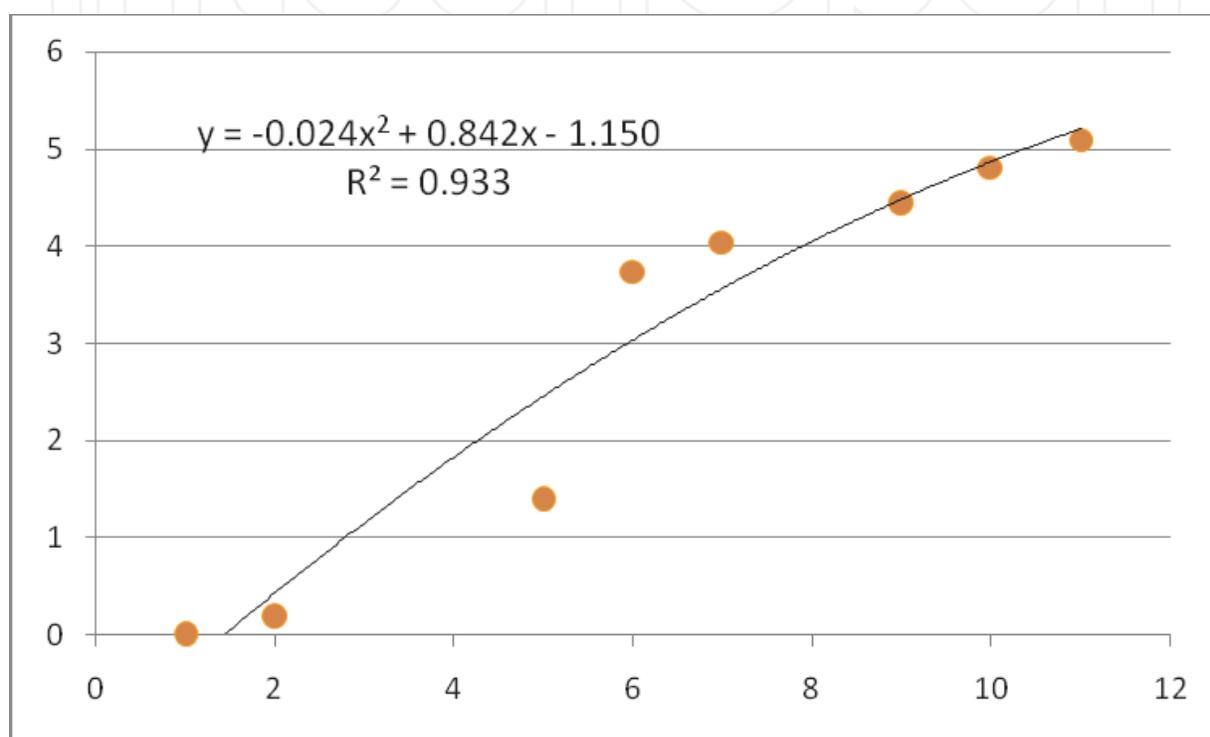
Fig. 9. The development of the total production of biomass accumulated in the stems during succession expressed in drymass [t*ha-1]
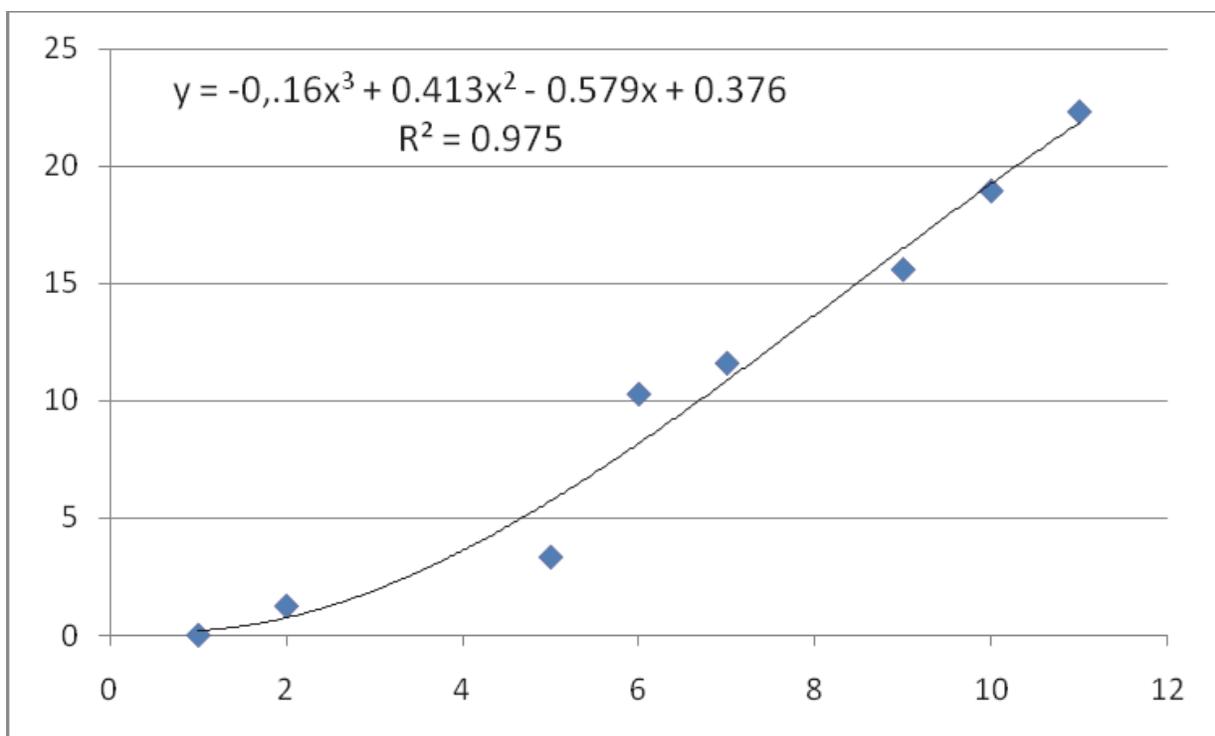
Fig. 10. The development of the total production of biomass accumulated in the branches during succession expressed in drymass [t*ha-1]

3.4.3 Branch drymass

The branch biomass can also be used as an energy material. The drymass accumulated in the branches is visualized in Fig. 10. At the eleventh year of the community succession, the branch drymass reaches 22.29 t*ha^{-1}, which is considerable 17% out of the total biomass.

3.4.4 Leaf drymass

The development of the assimilation apparatus expressed by the leaf drymass in the individual years of succession shows an increasing production capacity of the community (Fig. 11).

$$y = -0.024x^2 + 0.842x - 1.150$$
$$R^2 = 0.933$$

Fig. 11. The development of the total production of biomass accumulated in the leaves during succession expressed in drymass [t*ha^{-1}]

In the eleventh year of succession the leaf drymass exceeded 5 t*ha^{-1}; it was 3.9% out of the total drymass of the above-ground biomass accumulated in the stand.

3.4.5 Total drymass

The total production of the above-ground biomass of the community is a sum of the drymass of the stems, branches and leaves. Its development in the individual years of the succession is presented in Fig. 12. At the age of 11 the total production of the community above-ground biomass reached 129.4 t*ha^{-1}.

Fig. 13 shows the relative proportions of the drymass of the stems, branches and leaves in the total drymass of the above-ground biomass. The proportion of the stem drymass in comparison with branch and leaf drymass is the lowest in the initial stages of succession (80%). At the age of 5 the proportion of stem drymass is the highest and since this moment the proportion of branch and leaf drymass increases at the expense of the stem. Finally, in the eleventh year, the relative proportion of stem drymass is again 80%.
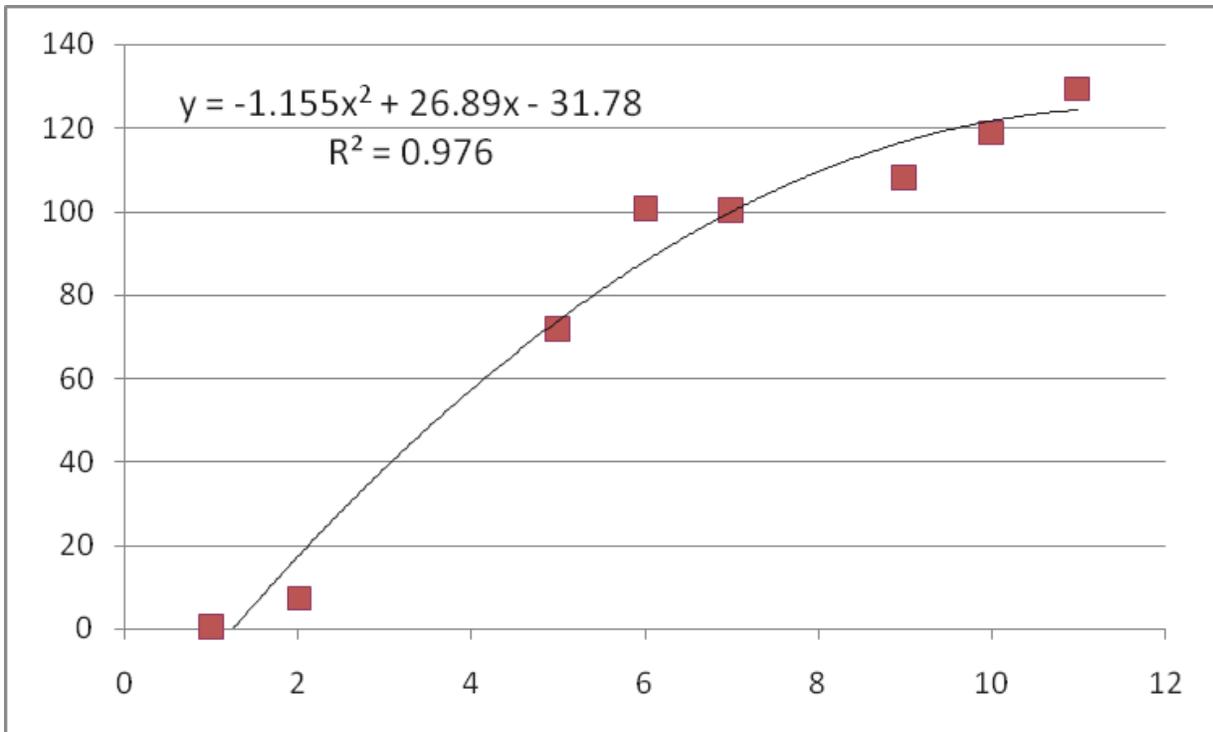
$$y = -1.155x^2 + 26.89x - 31.78$$
$$R^2 = 0.976$$

Fig. 12. The development of the total production of the community above-ground biomass during succession expressed in drymass [t*ha^{-1}]
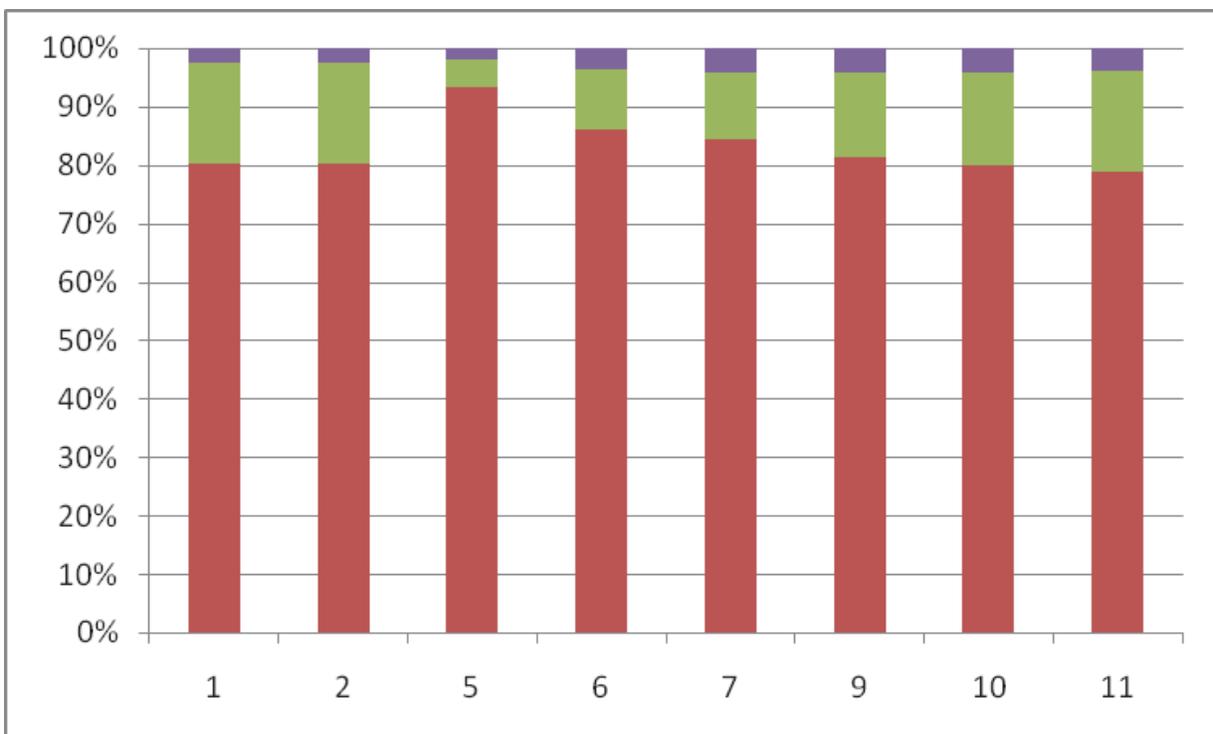
Fig. 13. The relative proportion of stem drymass (red), branch drymass (green) and leaf drymass (blue) during succession

Another visualization of the distribution of drymass of the above-ground biomass in the stand during the succession is provided in the following graph (Fig. 14). In the initial stages of succession the lowest DBH classes are of the highest production significance in the community. This continues until the age of 5. Between the fifth and the sixth year of succession a significant change occurs in the structure of the stand. As the lowest DBH class trees had died, the trees of higher DBH classes gained space and their diameter increments started to increase fast. This trend, although slower, remains in the following years up to the age of 10. The eleventh year brought about another big leap of the plants into the higher DBH classes.

The average annual production of the above-ground biomass expressed in drymass reaches 11.77 t*ha^{-1}; however, the maximum values are ascertained for the age of 6, when the average annual production was 16.72 t*ha^{-1}.
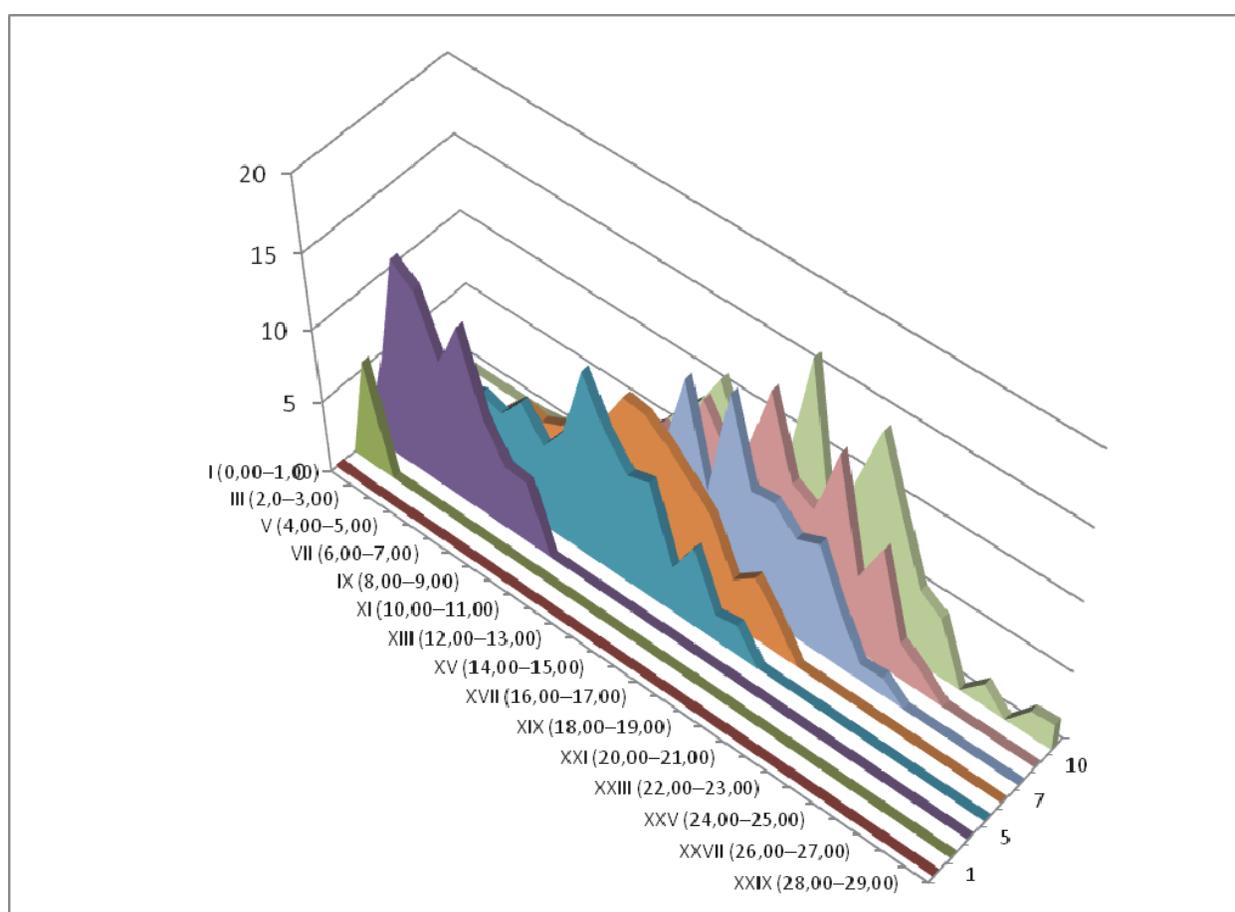
Fig. 14. The distribution of the total drymass of the above-ground biomass [t*ha^{-1}] in DBH classes during succession

3.5 Community energy output

The content of energy accumulated in the above-ground biomass (of leaves, branches and wood) is presented in the following graph (Fig. 15). The average content of energy measured was 18.15 KJ*g^{-1} for leaves, 18.16 KJ*g^{-1} for branches and 17.83 KJ*g^{-1} for wood.

As regards the average annual content of energy accumulated in the stand above-ground biomass (Fig. 16), the highest values were reached at the age of 6 – 298,827 MJ*ha^{-1}. The
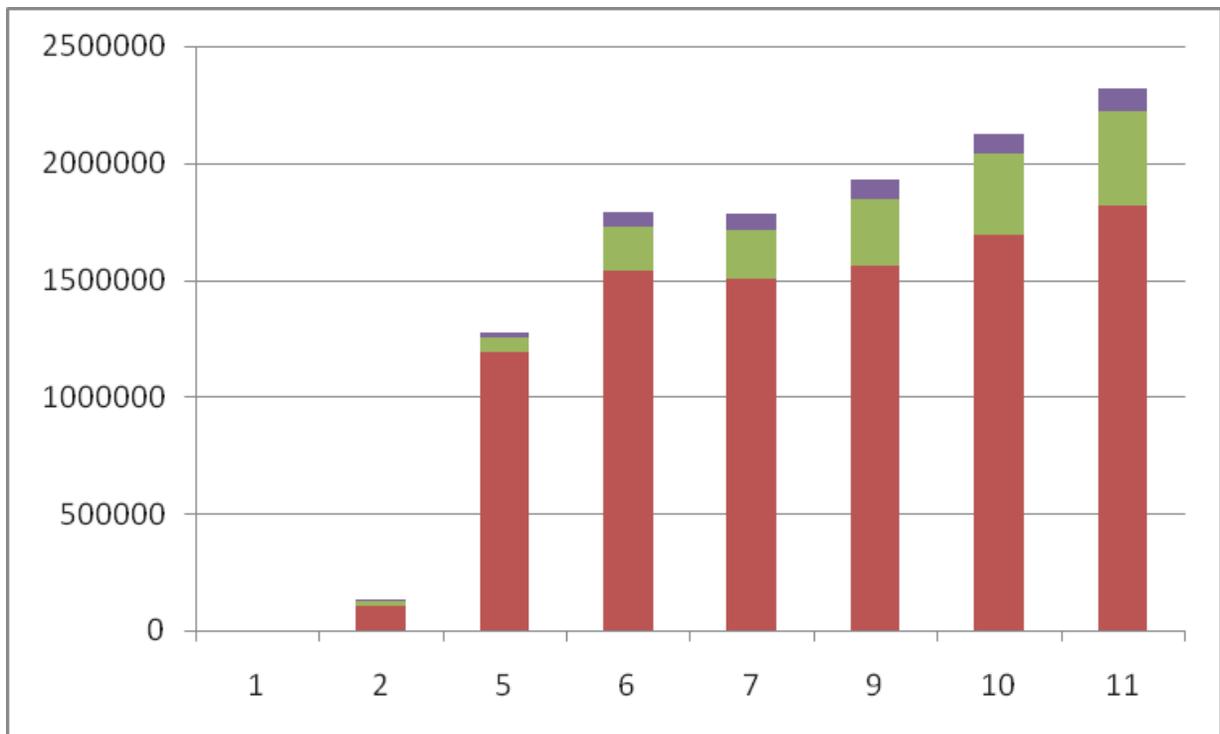
Fig. 15. The content of energy (MJ*ha⁻¹) accumulated in stems (red), branches (green) and leaves (blue) of the stand during the succession
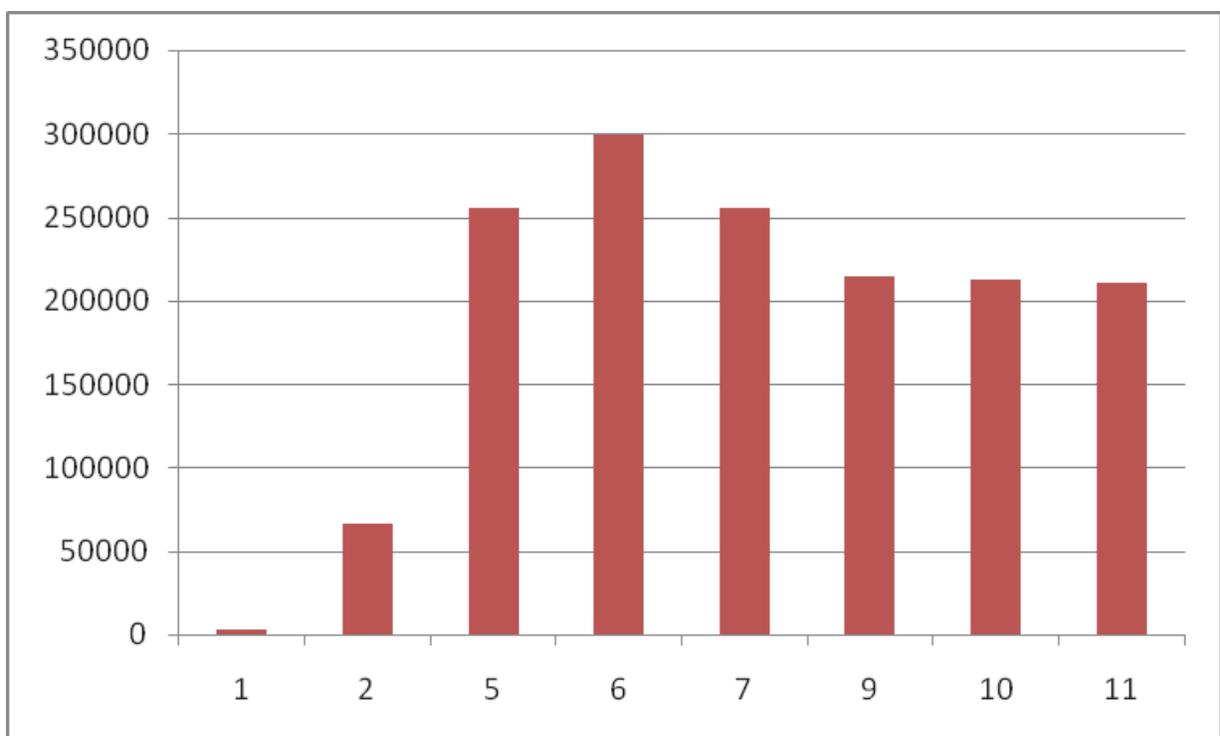

Fig. 16. The average annual content of accumulated energy [MJ*ha⁻¹] in the stand during the succession

values then decreased until they dropped to 214,000 MJ*ha^{-1} in the ninth year; subsequently, the average annual content of accumulate energy remains more or less constant.

The same progress is also manifested by the stand output (Fig. 17), expressed in kW*ha^{-1}: the highest value, 9.48 kW*ha^{-1}, is reached at the age of 6, and in the eleven-year-old stand the output drops to 6.68 kW*ha^{-1}.
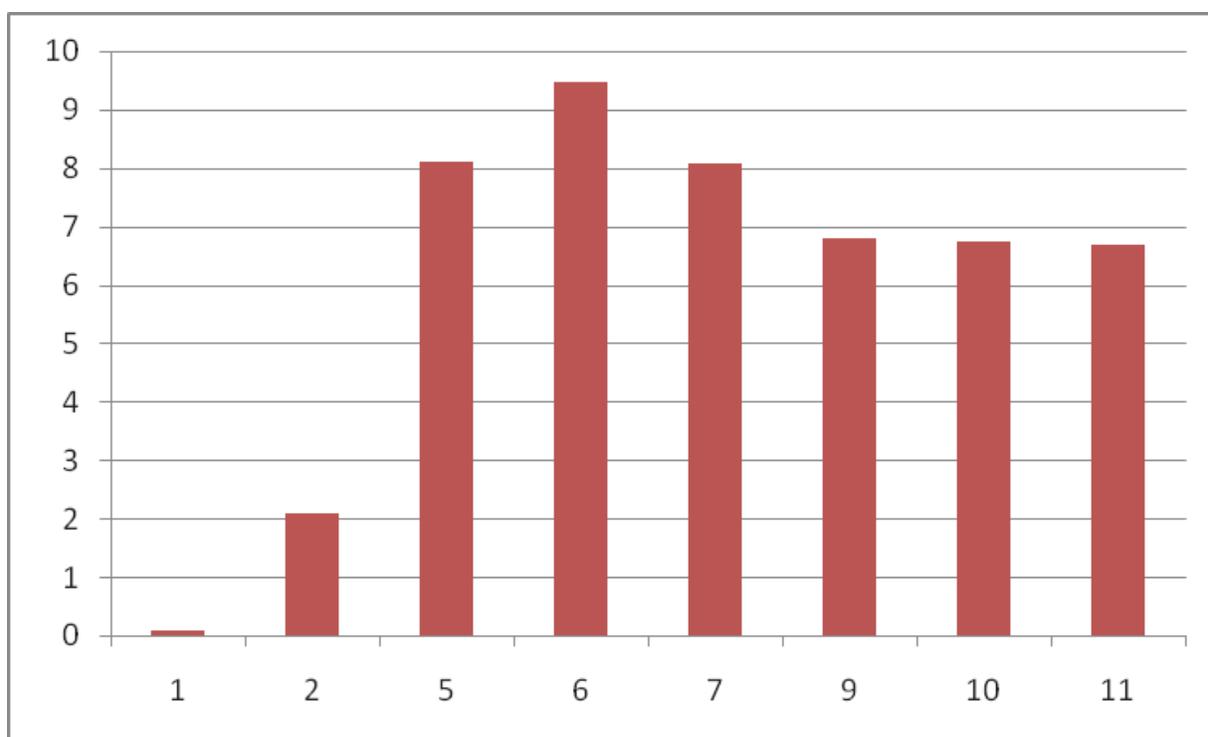
Fig. 17. The output of 1 ha of the stand during the succession [kW*ha^{-1}]

4. Conclusion

The paper describes selected production characteristics of a community of the White Willow which originated by means of natural oecesis on a newly constructed island in the middle of a water reservoir. The community succession was monitored for 11 years. During this period the stand developed completely naturally without any human interventions. The results were used to create a model of production properties of a natural ecosystem which can serve as a foundation for possible management rules for energy stands of the same species in similar conditions, such as bank stands or polders (Maděra et al., 2009).

The results prove that the production of the above-ground biomass is very high in the monitored community of the White Willow. The highest average annual values of all monitored production characteristics were achieved at the age of 6 of the stand. The estimated value of drymass production is very favourable exceeding the majority of species which are grown for energy purposes in Central Europe. The values exceed the data measured by Bungart et al. (2000) in the region of Lusatia, Germany for 3–4-year-old stands of willows and poplars in mining areas approximately ten times. Kajba et al. (2004) mention that the overall mean DM production of all the investigated clones was 6.5 tons per hectare, the greatest production was exhibited by clones 'B44', 'V093' and 'V052' (10.2, 9.2 and 9.1 t*ha^{-1}, respectively).

Based on the obtained results, from the perspective of production the most appropriate moment for harvest in case of energy stands of the White Willow appears to be when a stand reaches six years of age.

5. Acknowledgment

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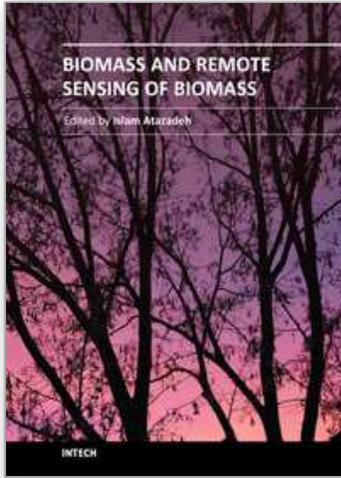
Biomass and Remote Sensing of Biomass

Edited by Dr. Islam Atazadeh

Generally, the term biomass is used for all materials originating from photosynthesis. However, biomass can equally apply to animals. Conservation and management of biomass is very important. There are various ways and methods for biomass evaluation. One of these methods is remote sensing. Remote sensing provides information about biomass, but also about biodiversity and environmental factors estimation over a wide area. The great potential of remote sensing has received considerable attention over the last few decades in many different areas in biological sciences including nutrient status assessment, weed abundance, deforestation, glacial features in Arctic and Antarctic regions, depth sounding of coastal and ocean depths, and density mapping. The salient features of the book include:
Several aspects of biomass study and survey
Use of remote sensing for evaluation of biomass
Evaluation of carbon storage in ecosystems
Evaluation of primary productivity through case studies

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