DETERMINATION OF CRITERIA AND INDICATORS FOR SUSTAINABLE FOREST MANAGEMENT ON THE BASE OF FOREST INVENTORY AND MONITORING DATA

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Status and dynamics of 11 quantity indicators for 3 criteria for sustainable forest management were assessed on the base on data of sample-statistical forest inventory and monitoring of National Park "Gomilshanski lisi".

Statistical forest inventory, criteria and indicators for sustainable forest management, national park ”Gomilshanski lisi”.

Introduction. Sustainable development is the main aim of national forest programs and policies. During the Ministerial Conference on the Protection of Forests in Europe (MCPFE) 6 criteria that include 35 quantitative and 17 qualitative indicators for sustainable forest management were adopted [9]. Fulfillment of national programs on forest inventory and monitoring gives the possibility to obtain information for part of these indicators on national and regional levels. In Ukraine, which has ratified proper MCPFE resolutions, programs on forest inventory and monitoring are developed now, assigned on information obtaining on forests and forest lands, that is required for assessment and monitoring of criteria and indicators for sustainable forest management.

The aim of our study was the assessment of criteria and indicators for sustainable forest management on the base of sample statistical forest inventory and monitoring on the territory of the National Park (NP).

The object of study – forest stands of NP "Gomilshanski lisi". The National Park is located in Kharkiv region. Sample- statistical inventory was conducted in 2005 and

2009 over an area of 3377.3 hectares transferred to the permanent use of the park, of which about 99% is covered with forests. Assessment of quantitative criteria and indicators for sustainable forest management (according to MCPFE [9]) and their dynamics was carried out on the base of data of two cycles of statistical inventory of NP [4, 5].

Methods of forest inventory and monitoring were detailed in following publications [4, 5]. Field works on data collection were carried out with program and technologic complex Field-Map [3]. For statistical data processing and analysis specialized software module Inventory Analyst Field-Map [8] was used. For leveling of differences in the analysis only permanent inventory plots that were surveyed in both inventory cycles (116 plots) were chosen. All results of data treatment were presented as a statistical average, confidence intervals and percent with the accuracy $\alpha = 0,2$. Stem volumes were calculated from the ground level, over bark. Standing dead wood volume was estimated by the same models as for live trees. To assess the volume of stems of aspen, birch and alder models from the literature were used [1]. Stem volumes of oak, ash and linden trees were calculated on the base of experimental data of stem profile measurements.

Calculations of carbon stock and its dynamics was carried out for two main components – phytomass of woody tree species and dead wood (standing and lying); but such components as soil, litter and ground vegetation were not taken into account. To calculate carbon stocks the total stock (volume) for the components was converted into mass (using basic density for tree species and stages of decomposition) [2, 6, 7] and in carbon stocks (formulas 1-3). In 2005 the lying deadwood was mostly represented by oak timber of I and II stages of decomposition, and in 2009 – of II and III. In the calculations of carbon stocks for the component "lying deadwood " it was assumed that: a) all dead logs are formed by oak debris, b) as basic density in 2005 the value 507.5 was used (average basic density of oak between the I and II stages of decomposition), and in 2009 – 397.5 (average basic density of oak between the II and III stages of decomposition) [7].

Carbon stock in phytomass of forest stands was determined by the formula (1) [2]**:**

$$C_{trees} = \sum M_{si} \cdot BEF_{si} \cdot D_i \cdot (1+R_i)\ 0{,}5 \qquad (1)$$

where C_{trees} – total stock of carbon in phytomass of living trees (thous. tons C);

M_{si} – total stock of timber of *i*-tree species (thous. m^3);

BEF_{si} – conversion factor of stem biomass in total with branches for *i*-tree species;

R_i – ratio of underground biomass to aboveground for *i*-tree species [2];

D_i – basic density of *i*-tree species (t/ m^3);

0.5 – conversion factor used for conversion of organic matter in the dry mass of carbon.

Carbon stock in standing dead wood was determined by the formula (2):

$$C_{deadtrees} = \sum M_{dti} \cdot D_i \cdot 0{,}5 \qquad (2)$$

Where $C_{deadtrees}$ – carbon stock in standing dead wood (thous. tons C);

M_{dti} – the total amount of dead wood of *i*-forest tree species (thous. m^3);

D_i – basic density of *i*- forest tree species (of I stage of decomposition) (t/ m^3).

Carbon stock in lying deadwood was determined by the formula (3):

$$C_{deadlogs} = M_d \cdot D_{oak} \cdot 0{,}5 \qquad (3)$$

$C_{deadlogs}$ – carbon stock in dead logs (thous. tons C);

M_d – total volume of lying deadwood (thous. m^3);

D_{oak} – basic density of oak wood of *i*- stage of decomposition (t/ m^3).

Results.

Criterion 1. Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles.

Indicator 1.1. Forest area. Forest stands of the National Park "Gomilshanski lisi" are mainly formed by deciduous tree species (Table 1) with a predominance of pedunculate oak, the last one is growing on the area of 2153 ha (63.5%). Stands with the main species of *Tilia cordata* L. (10-11%) and *Fraxinus excelsior* L. (13.9 - 16.5%) are comparatively well represented. Share of coniferous stands (Scotch pine) a mere 2.6% (88.5 ha). The total share of underrepresented stands area is 3.5 - 2.7%.

1. Forest areas distribution by main tree species and forest types

Species	Area, ha	%

	2005	2009	2005	2009
Quercus robur L.	2153,4	2153,4	63,5	63,4
Acer platanoides L.	29,5	29,5	0,9	0,9
Tilia cordata Mill.	383,5	354,0	11,3	10,4
*Populus tremul*a L.	147,5	118,0	4,3	3,5
Pinus sylvestris L.	88,5	88,5	2,6	2,6
Fraxinus excelsior L.	472,0	560,5	13,9	16,5
Other species	118,0	88,5	3,5	2,7
Total deciduous	3303,9	3309,9	97,4	97,4
Total coniferous	88,5	88,5	2,6	2,6
Total	3392,4	3392,4	100	100

Estimated values of forest areas by main species by two observations allowed identify main trends in time: area of oak stands remained unchanged, the area of ash increased (by 88.5 ha or 18.8%), and stands with predominance of lime and aspen, in contrast, slightly declined.

Indicator 1.2. Growing stock. One of the main indicators is growing stock of forest stands. The total growing stock of NP stands (Table 2) in 2005 amounted 937.9 thous. m^3 and in 2009 – 1039.6 thous. m^3, of which the largest value has oak trees (about 56% of all species), the next is ash (about 16%), and the third – lime (about 15%). Timber volume of Scotch pine, maple and aspen is about 30-35 thous. m^3.

2. Growing stock by tree species

Tree species	Growing stock, thous.m^3		Growing stock, %		Changes for 4 years	
	2005	2009	2005	2009	thous.m^3.	%
Pinus sylvestris L.	28.4	30.9	3.0	3.0	2.5	8.8
Quercus robur L.	526.0	579.6	56.1	55.8	53.6	10.2
Fraxinus excelsior L.	140.7	170.6	15.0	16.4	29.9	21.3
Populus tremula L.	30.3	33.6	3.2	3.2	3.3	10.9
Tilia cordata Mill.	140.5	151.8	15.0	14.6	11.3	8.0
Other spp.	72.0	73.1	7.0	6.9	1.1	1.5
Total	937.9	1039.6	100	100	101.7	10.8

For four years it was registered the increase in total growing stock of forest stands in NP by 84 thous. m^3, or 8.8%, mainly due to oak (by 53.6 thous. m^3), ash (29.9 thous. m^3) and lime (11 thous. m^3). It should be noted that compared to 2005 the growing stock of ash increased by 21%, while oak only by 10%, so in the park there is more active growth of ash trees than oak.

Indicator 1.3. Age structure and / or distribution of the diameters. According to the inventory methods that were used in NP, each sample tree was assigned to a specific class by value of its diameter (Table 3). Such approach allows assess complex uneven-aged forest stands. For evaluation of indicator 1.3 the growing stock distribution by diameter classes was calculated.

3. Growing stock distribution by diameter classes

Stages of growth	Diameter class, cm	Stock, thous.m^3		Stock, %		Changes for 4 years	
		2005	2009	2005	2009	thous. м^3	%
Young I	7-12	2.6	1.1	0.3	0.1	-1.5	-57.7
Young II	13-19	33.9	34.6	3.6	3.3	0.7	2.1
Middle-aged	20-35	385.6	443.3	41.1	42.7	57.7	15.0
Maturing and mature	36-43	228.0	291.9	24.3	28.1	63.9	28.0
Overmature	44+	287.8	267.3	30.7	25.8	-20.5	-7.1
Total		937.9	1038.3	100	100	100.4	10.7

According to total growing stock middle-aged trees (41% in 2005 and 42.7% in 2009) are dominated in the park, also large proportion of trees is overmature (30.7% in 2005 and 25.8% in 2009). Aged overmature trees and stands are very valuable in terms of biodiversity conservation in the park. Share of young trees is low and makes 3.9 – 3.4% of total stock.

In the four years on the overall increase of growing stock redistribution was observed: significant increase in stock of middle-aged, premature and mature trees (by almost 60 thousand m^3.) and a slight increase in young II class were registered. In group "overmature trees" it was stated sufficient decreasing of growing stock by 20.5 thous. m^3, or 7% compared to 2005, which may be explained by old oak trees mortality and formation of dead wood.

Indicator 1.4. Carbon stock. Carbon stocks and their changes in the main components of forest ecosystems in 2005 and 2009 were calculated (Table 4, 5).

4. Phytomass, mortmas and carbon stock by woody tree species of NP

Tree species	Forest stand				Standing deadwood			
	Phytomass, thous. t		Carbon stock, thous. t		Mortmass, thous. t		Carbon stock, thous. t	
	2005	2009	2005	2009	2005	2009	2005	2009
Pinus sylvestris L.	16.1	16.8	8.1	8.4	1.3	0.8	0.6	0.4
Quercus robur L.	431.1	463.9	215.5	232	14.3	23.5	7.1	11.8

Fraxinus excelsior L.	113.7	130.7	56.8	65.3	2.3	2.5	1.1	1.3
Tilia cordata Mill.	64.9	69.8	32.4	34.9	0.5	0.3	0.3	0.2
Other spp.	63.2	68.8	31.7	34.4	0.9	1.5	0.4	0.7
Total	689	750	344.5	375	19.3	28.6	9.6	14.3

The total carbon stock in phytomass of forest stands in 2005 amounted to 344,5 thous. tons, and in 2009 – 375 thous. tons. In total deadwood carbon stocks amounted to 18.6 thous. tons in 2005 and 24.9 in 2009. As of 2009, the total the value of the indicator in forest stands of NPP is 356.5 thous. tons, that is approximately about 125 tons C per ha.

5. Carbon stock by compounds of forest ecosystems

Compounds	Carbon stock, thous. t		Changes for 4 years	
	2005	2009	thous. t	%
Lying deadwood	9.0	11.2	2.2	24.7
Standing deadwood	9.6	14.3	4.7	48.6
Total deadwood	18.6	24.9	6.3	33.9
Forest stands	344.5	375	30.5	8.9
Total	381.7	425.4	43.7	11.4

For four years, total carbon stock in forests of the NP "Gomilshanski lisi" increased by 43.7 thousand tons (or 11%), which made 10.9 thous. tons year-1. The largest contribution to the increase in carbon stock had a pool of live trees. Carbon stocks in dead wood increased by 6.3 thous. tons or 33.9% compared to the value in 2005 (mainly due to standing deadwood).

Criterion 2. Maintenance of Forest Health and Vitality. According to the method of inventory used in NP defoliation of trees wasn't estimated, but the state of vitality of trees was evaluated by IUFRO-classes. According to this index, which reflects a significant defoliation and damage (Table 6) the majority of trees had normal vitality (95-96%) while low vitality was observed only for 4.3% of trees in 2005 and 5.1% in 2009. Generally for four years the state of vitality of trees tends to decrease, but these changes are not significant.

6. Portion of trees (in %) by vitality classes by IUFRO

Tree species	Normal vitality		Low vitality	
	2005	2009	2005	2009

Populus tremula L.	97.3	85.7	2.7	14.3
Quercus robur L.	92.4	92.2	7.6	7.8
Fraxinus excelsior L.	97.0	97.2	3.0	2.8
Tilia cordata Mill.	99.2	98.4	0.8	1.6
Pinus sylvestris L.	86.7	86.7	13.3	13.3
Total	95.7	94.9	4.3	5.1

The largest proportion of trees with low vitality and the worst condition was among pine trees (13.3% of trees had low vitality), and aspen (14.3% of trees in 2009). Among oak trees 7.8% had low vitality. Sufficient deterioration of vitality in 2009 compared to 2005 was marked for aspen trees.

Indicator 2.4. Forest damage. To calculate this indicator it is necessary to estimate the area of forests with severe damages caused by biotic, abiotic and anthropogenic factors that cause growth decreasing and/or trees and stands mortality [10].

According to forest inventory data the general sanitary condition of forest stands of the park is satisfying, the majority of trees doesn't have signs of damage. There were no severe damages at the level of forest stands.

On 7.2 - 7.8% of trees mechanical damages were registered. Among abiotic factors there were single cases of trees damaged by frost (1.1-1.8% of trees). Among biotic factors there were stated signs of cancer at 1.3-1.9% of trees, mostly among ash trees (3.7-5.6%) and oak (1.4-2%). Signs of damage caused by insects were stated only for 0.4-0.5% of trees. In 2009 single cases of bark damage by hoofed mammals were registered. About 13-14% of trees in the park had signs of stem rot. The highest distribution of stem rot was observed in aspen trees (37.8% in 2005) and oak (17%).

There were no forest stands with severe damage registered in the park, thereafter the value of the index "damage" for all factors is zero.

Criterion 4. Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems.

Indicator 4.1. Tree species composition. NP forest stands are complex according to their structure and tree species composition (Table 7): the majority of

stands are composed of 3-4 tree species (62% of the total area of the park), and the proportion of stands with 5 species and more species amounts 20%.

7. Area of forests classified by number of tree species occurring in NP

Number of tree species	Area, ha		Portion, %		Changes for 4 years	
	2005	2009	2005	2009	ha	%
1	59.0	59.0	1.7	1.7	0	0
2	531.0	442.5	15.7	13.0	-88.5	-16.7
3	973.5	944.0	28.7	27.8	-29.5	-3.0
4	1150.5	1239.0	33.9	36.7	88.5	7.7
5	649.0	649.0	19.1	19.1	0	0
6	29.0	59.0	0.9	1.7	30	103.4
Total	3392.4	3392.4	100	100	0	0

For four years there have been some changes in forest stands composition – the area of stands consisted of 2 and 3 tree species reduced and the area of more complex stands of 4 and 6 classes increased: a tendency to increase the tree species composition diversity in forest stands of NP is observed.

Indicator 4.2. Regeneration. The area of artificial reforestation on cutting areas according to statistical inventory data is 28.2 ha or 0.8% of the park area.

Indicator 4.3. Naturalness. Almost all forest stands of NP belong to category “semi-natural”, the area of such forests is 3262.9 ha (99.1%), and “plantations” are growing on the 0.9% of area (29.5 ha).

Indicator 4.4. Introduced tree species. During statistical inventory in the NP there were reported two introduced tree species: invasive *Acer negundo* L. at 2 plots (as a non-dominant), and at one plot an artificial plantation of *Robinia pseudoacacia* L. According to statistical calculations the area of stands with predominance of introduced tree species was 29.5 ha or 0.9% of the area for both cycles of inventory. However, one should take into account the fact that due to the small number of such habitats, their area, estimated by statistical methods can be greatly exaggerated.

Indicator 4.5. Dead wood. This indicator can only by estimated by means of statistical inventory and monitoring. The calculations of the total stock of dead wood for: standing and lying dead wood (Table 9) were carried out.

8. Volume of standing and lying deadwood in NP

Category	Stock, thous. m^3	Stock, %	Changes for 4 years

	2005	2009	2005	2009	thous. m^3	%
Standing deadwood	36.4	47.0	50.7	46.8	10.6	29.1
Lying deadwood	35.4	53.4	49.3	53.2	21.0	59.2
Total deadwood	71.8	100.4	100	100	31.6	44.0

In 2005 the stock of dead wood in the park was 36.4 thous. m^3, of which 93.1% was maid by deciduous tree species, in 2009 the value of the indicator was 47 thous. m^3. The total volume of lying deadwood in 2005 was 35.4 thous. m^3, an average volume is 10.1 m^3 per ha.

For four years, significant increase in deadwood volume in the park was registered: standing deadwood volume increased by 10.6 thous. m^3, or 29.1% compared to the initial level, lying deadwood – by 21.0 thous. m^3, or 59%, which is the result of natural processes of trees mortality in the park and restrictions on forest management activities, including sanitary cuttings.

Conclusions. In the study on the base of the results of sample-statistical forest inventory of National Park "Gomilshanski lisi" 11 quantitative indicators of 3 criteria for sustainable forest management were estimated. For Criterion 1 (Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles) such indicators as of forest area, stock, age structure and carbon stock can be evaluated. For Criterion 2 (Maintenance of health and vitality of forest ecosystems) the indicators of vitality and damage of forests can be estimated. According to Criterion 4 (Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems) following indicators were evaluated: species composition, regeneration, naturalness, introduced tree species and dead wood. In addition, indicators of Criterion 3 (Maintenance and Encouragement of Productive Functions of Forests (Wood and Non-Wood) as increment and felling can be estimated by means of statistical inventory.

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