The influence of age on the functional effect of forest stands with simplified spatial structure

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Abstract

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The aim of this article is to present research on the relationship between forest stand age and its functional effect. Forest ecosystem (forest stand) age together with its stocking and health condition is specified as criterion characterizing forest stand (with simplified structure) actual stage, dynamics and functional effect on a base of realized analysis of wide spatial and time forest stand parameters data set. The criterion "forest ecosystem development phases" is used for forest age structure expression. It represents the percentage of forest stand age from a predicated period of its existence – rotation period. There were realized development dynamics analyses of particular forest functions and actual functional effects; forest stand age weight development as a reducing criterion for different forest stand conditions and model real effect of the forest functions development for chosen stand types. Research was carried out at the state enterprise Lesy ČR, s.p., organization unit Židlochovice. The results present a synergistic effect of functional reduction criterion on the real effect of forest stand functions. Simultaneously, the higher the forest stand age, the higher the importance of the forest stand condition and stocking.

Key words

function-reducing criteria, forest functions, forest stands age, real effect of forest functions, rotation period

Introduction

An increasing number of authors are concerned with the evaluation of forest functions on the base of parametric quantification at the present time. The reason is primarily the requirement of forest functions value quantification as the primary presumption of objective poly-functional forest management.

The processes and functions are not the end services directly used by people. They are only the biological, chemical and physical interactions among ecosystem units (features, attributes) (Boyd and Banzhaf, 2006; Kline, 2007). Although, e.g. Kline (2007) presents on the example of forests ecosystems that the forest utilities come from social-utility outcomes of ecosystem functions. These functions are produced by the attributes and conditions of forest landscapes. Kline´s statement (2007) is in accordance with Vyskot et al. (2003) that the forests functions are produced primarily without human interventions (Vyskot et al., 2003). Only on the basis of the functions abilities and effects quantification it is possible to define the end services for the public (Kline, 2007).

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Phua and Minowa (2000) introduce the next example of ecosystem approach. The authors define the Environmental functions of the tropical forest in Kinabalu Park as biodiversity conservation and, soil and water conservation functions, including landslide, flood and drought prevention functions. Biodiversity indexes such as Fisher's alpha index and Shannon-Wiener index, Annual Rainfall, Soil Depth, Geology, Topography and Slope are used as determination criteria.

Except for the terms "forest functions" and "ecosystem forest services", the terms "non-timber forest products (NTFP)", "non-wood forest products (NWFP)", and "non-timber value (NTV)" are used in professional literature (e.g. Scarpa et al., 2000). Scarpa et al. (2000) has calculated the non-timber value (NTV) in the forests in the state of Maine (USA) using the FIA database (Forest Inventory and Analysis). According to Scarpa et al. (2000) the NTV is affected by three categories of variables: ecological attributes of the area, physical (geographical) location and socioeconomic context. From the FIA database four variables were used – the stand index SITE, the distance of forests from the water element DWATR, the slope of the land SLOPE and the distance from the transport network DROADS. As a main characteristic of the forests having impact on their functional effects the species and spatial structure of the forests were set.

The forests´ functions in the ecosystem approach of Vyskot et al. (2003, 2013) stem from the forest ecosystem existence itself. This is based on the existence of single material elements as well as energy-material flows and information flows among them and their mutual influence. This influence is present in the forest ecosystem as well as between this ecosystem and its surroundings. As an example, the influence of the forest on the micro-climate characteristics dynamics could be used, e.g. the development of the air temperature or the relative air humidity during the day in the forest is less dynamic than compared to open space (e.g. Schneider et al., 2011). Likewise, the role of protective forest belts and their spatial structure on the air flow is well known (e.g. Lampartová et al., 2015; Brandle et al., 2004; Středa et al., 2007; Peri et al., 2002). The next forest function that is described by many authors, is the ability of the forest with differentiate species composition, age structure and stand structure to fix carbon (e.g. Schneider et al., 2015; Muukkonen, 2007; Cienciala et al., 2006; Zhang, 2009 etc.). The impact of the forests on the hydrological regime and run-off conditions in the catchment area is also important. The changes of the spatial structure (extreme cases of states of calamity) of the forest have an impact on the partial components of the water balance. By this the moisture conditions or the total character of the run-off are affected (e.g. Hlásny et al. 2013, 2015).

Comprehensive overview of the forest functional effects are presented e.g. by Čaboun et al. (2010), who in principle and systematically describe the impact of the trees and forests on single ecosystem processes. These are then aggregated into functional groups – edaphic, atmospheric, hydric, lithic, phytobiotic, zoobiotic, microbiotic and anthropic. Tutka et al. (2009) states the example of these functions' structuring on market and non-market. This is the step bonding the forests' functions and ecosystem services.

The aim of the paper was to find out, if there is any influence of the forests' age on the ability of the function production, and if so, by what way. The theoretical model according to Vyskot et al. (2003, 2013) was verified on the development trend of the real forests.

Material and methods

Methodological basis of this work is the original method; The Quantification and Quantitative Evaluation of the Societal Forests Function (Vyskot et al., 2003, 2013) (next only "Method"). This method claims that forest ecosystem influence to the environment is defined by its all-society functions (Vyskot et al., 2003) – bio-production, ecological-stabilization, hydric-water management, edaphic-soil conservation, social-recreation and sanitary-hygienic. These forest functions are evaluated on two levels. The first level is called the real potential of the forests functions. This is given by the biotope parameters which present functional-determination criteria. The real potential of the forests functions represents the potential of the forest functional ability. This is the maximal reachable forest function production, which the given forest is able to reach in a given area.

The second level is given by the actual state of the forest. This is described through the functional-reduction criteria affecting the real effect of the forest functions. These criteria are set separately for structurally differentiated (rich) forests and stands with the simplified space structure.

The recent state (as well as the functional affects) of the structurally differentiated forests determine the functional-reduction criteria: a) the frequency distribution of the breast-height diameters; b) the height differentiation of the forest; c) the horizontal distribution of the wood and d) health condition.

These criteria could also be used for the forest with simplified space stand structure. The value of a–c criteria would be however, more or less constant. That is why the criteria of age, stocking and health condition are used for these types of forests. On the other hand, it is clear, that the criteria of age and stocking lose their sense of widely structured forests with very differentiated age structure on the same area. Therefore, the only universally used functional-reduction criterion is the forests health condition.

Solving the steps of forest age influence to real functional effect of forest stand consists in a) quantification and evaluation of forests potential functional ability – real potential of forest functions (RP_{fl}), b) quantification and evaluation of forests actual functional effects – real effect of forest functions (RE_{fl}), c) analysis of age development influence in conditions of Forest Enterprise Zidlochovice (Forest of the Czech Republic Company).

Function-reducing criteria determination

Forest stand status is determined by tree species composition, stand age and spatial structure parameters and influenced by actual health disposition. Tree species composition is a direct determinant of potential functional ability of concrete forest ecosystem and is defined for the long term. It is the constant criterion for actual functional effect of the forest ecosystem evaluation.

Three suitable usable criteria for characterizing the dynamic effects of forest ecosystems were obtained by wide analysis of chronological and spatial forest stand parameters:

- Forest stand age (stand development stage)
- Stocking
- Health condition.

Their suitability and practical utility is defined by the following qualities:

- Reflect important natural processes and anthropic interventions in forest ecosystems
- Their value defines actual forest ecosystem status
- Their full value defines optimal forest ecosystem status
- Integration in legislation standards for forest stand status valuation
- Easy availability, measurability and verification.

If the value of the function-reducing criterion decreases, the effect of the forest ecosystem to fill its function decreases too – real potential of forest functions is reduced to real effect of forest functions.

Criterion "forest stand age" (forest ecosystem development stage) is used for the expression of age. The forest ecosystem development stage represents the percentage of forest stand age from a predicated period of its existence – rotation period (Table 1). The rotation period represents the frame production period of the forest management unit (rotation period limits are recommended under legislation). These parameters usage supports their utilization for forest stands with a different age of felling maturity (Vyskot et al., 2003).

Table 1. Function-reducing criterion of forest stand age (forest ecosystem development stage). Source Vyskot et al., 2003

Forest ecosystem development stage	% of rotation period
Unstocked area	0
Non-established young plantation, regeneration	to 7
Established young plantation, young growth	8–15
Small pole stage	16–25
Pole stage	26–40
Large-diameter stage of smaller dimension	41–60
Large-diameter stage	61–80
Mature stands	80+

Functional effectiveness depending on reducing criteria

Particular function-reducing criteria specifically influence the real effects of forest functions value (recent functional effects). The actual functional effects of forest ecosystem determination on the basis of functional-reduction criteria result from current scientific knowledge and results of parameters forest stand age (Table 2), stocking and health status research. Functional effects level = real effect of forest functions value = percentage of real potential of forest functions fulfilling (Vyskot et al., 2003).

Function-reducing synergy criteria

With regards to mutual cohesion and dependence of ecosystem processes in the forest ecosystem it can be claimed that function-reducing criteria take effects to real effect of forest functions value synergistically. Ecosystem relations are not constant in time. They change and dynamically transform depending on forest stand status. Real effect of forest functions resulting value is influenced by significance of separated functional-reduction criteria. The significance of function-reducing criteria was determined on the base of analysis of databases and scientific results of forest stand age, stocking and health status research.

Analysis of the real effect of forest functions development dynamics and dependence on time

Given scientific announcement presents part of the long-term research of forest stand age influence to the

Table 2. Real effects of forest functions in relation to forest stand age. Source VYSKOT et al., 2003

Forest ecosystem development stages (% of rotation period)	Forest function							
	Bio-production	Ecological-stabilization		Hydric water management	Edaphic soil conservation	Social-recreation	Sanitary-hygienic
		Resistance	Resilience				
0	0	10	100	10	10	10	10
to 7	10	10	100	30	10	10	10
8–15	10	10	100	50	10	10	10
16–25	10	30	70	70	30	30	30
26–40	30	50	50	100	50	50	50
41–60	50	70	30	100	70	70	70
61–80	70	100	10	100	100	100	100
80+	100	100	10	90	100	100	100

real effect of forest functions on an example of stand type C5 – pure oak stand type within the forest site type 1S1 – hornbeam-oak wood on sands with Narrow-leaved meadow-grass. Forest stand age is expressed by forest ecosystem development phases (in percentage of the rotation period). Data sets present an actual functional effect trend for different health status of forest stands. Damage degree 0 characterizes normal health status (healthy forest stand), for comparison there is also shown a trend under damage degree IIIb – dead forest stand. The value of stocking is 9–10 (full stocking); the value occurring over a prevailing part of the rotation period.

The overall development of the real effect, modeled on the existing forests (chosen forests groups) comes from the data of the forest management plan. The meaning of the stand group choice is the simulation of the RE_{fl} development of the given forest during its life cycle using real variables. The choice of the stand group of the given stand type has followed the below mentioned rules from the point of view of particular functional reduction criteria and further characteristics:

– The age reduction criterion – all the presented age stages are represented (resp. % of the rotation); the same rotation.
– The stocking reduction criterion – the chosen represented value for the given age interval.
– The health condition reduction criterion – the represented value for the given age interval is used.
– Further characteristics – the same forest type is calculated as well as the similar area and position in the forest complex.

The dynamics of the real effect development is shown in two ways. The first consists of the expression of the functional value levels. By these levels the real potential is qualified. If the real effect RE_{fl} equals e.g. 1 it means that, under the Czech Republic conditions, the actual functional effects of the solved forest are very low. The second way is the percentage expression of RE_{fl}. The value (%) shows to what extend the actual functional effects (RE_{fl}) fulfill the total ability of the forest (real potential RP_{fl}).

Results

Forest stand age influence to topical functional effect of forest ecosystem is presented by the example of forest stand type C5 – pure oak stand type in the forest site type 1S1 – hornbeam-oak wood on sands with Narrow-leaved meadow-grass. Real effects of forest function are valuated for all groups of all-society functions – bio-production, ecological-stabilization, hydric-water management, edaphic-soil conservation, social-recreation and sanitary-hygienic. They are expressed in percentage of real potentials of forest functions and also in value grades 0–6 (Table 3).

The development trend of real effect is shown by an example of the sanitary-hygienic function.

The trend of development of the real effect of the sanitary-hygienic function has identical behavior as the real effect of the social-recreation function. This fact confirms the mentioned functions cohesion. Thanks to higher real potential the real effects of the sanitary-hygienic function obtain higher values in value degrees.

The stand age also involves the influence of two functional-reduction criteria on the real effect of the forests. Figure 1 presents the synergistic influence with the health condition. The mutual relation of stocking and age is shown in Fig. 2. There are evidently more signifi-

Table 3. The values of real potentials of forest functions (RP_{fl}), functionally reducing criteria and real effects (RE_{fl}) for selected stand type C5 – oak monoculture (the forest site type 1S1 – hornbeam-oak wood on sands with Narrow-leaved meadow-grass, Forest Administration Valtice)

Rotation period: 120									RP_{fl}:	4	3	3	3	3	4
Criterion				Real effect (in %)						Real effect (reduced real potential)					
Age	Stocking	Health condition	% rotation	BP	ES	HV	EP	SR	SH	BP	ES	HV	EP	SR	SH
1	0	1	1	20	25.5	36	21	16.5	15.5	0.8	0.8	1.1	0.6	0.5	0.6
25	10	1	21	23.5	44	76	44	35.5	37	0.9	1.3	2.3	1.3	1.1	1.5
27	10	1	23	28	58	79	51	41	44	1.1	1.7	2.4	1.5	1.2	1.8
31	10	1	26	44	70	100	65	57	60	1.8	2.1	3.0	2.0	1.7	2.4
38	10	1	32	44	70	100	65	57	60	1.8	2.1	3.0	2.0	1.7	2.4
51	10	1	43	65	85	100	85	76	85	3.3	2.6	2.0	2.6	2.3	3.4
64	9	1	53	65	85	100	85	76	85	2.6	2.6	3.0	2.6	2.3	3.4
73	9	1	61	79	100	100	100	94	100	3.2	3.0	3.0	3.0	2.8	4.0
74	9	1	62	86.5	100	100	100	91	100	3.5	3.0	3.0	3.0	2.7	4.0
91	9	1	76	86.5	100	100	100	91	100	3.46	3.0	3.0	3.0	2.73	4.0
105	9	1	88	100	100	97	100	91	100	4.0	3.0	2.91	3.0	2.73	4.0
118	9	1	98	100	100	97	100	91	100	4.0	3.0	2.9	3.0	2.7	4.0

Forest function: BP, bio-production; ES, ecological-stabilization; HV, hydric-water management; EP, edaphic-soil conservation; SR, social-recreation, SH, sanitary-hygienic.

cant differences in the real effects of young forests than compared to the adult stands, caused by stocking.

The dynamics of the real effect of the societal forest functions are presented on the example of the forests groups of the forest type C5 – oak monoculture. Real effects are expressed in percent of the real forest function potential (Fig. 3) and also a reduced potential in absolute values 0–6 (Fig. 4). From the evaluation of both charts it is evident that the complex view of actual forest functional effects' development is convenient to use in both ways of expression. The connectors' course in Fig. 3 involves crucially the value level of the real potential of the particular functions, e.g. with high real potential (e.g. RP_{flSH} – value level F_v = 4) is the real effect of young forests (in age of 30 % rotation) on the value level of 3 (average). Figure 4 indicates how quick are actual functional effects (real effect) near the potential functional availability (real potential).

Discussion

The individual works identify the influence of age on the partial ecosystem components and processes and their dynamics. The production ratios, expressed like growth increments, are the traditional object of the long-run forest research (e.g. Assmann, 1970). Lehtonen et al. (2004) investigate the influence of the forest age on

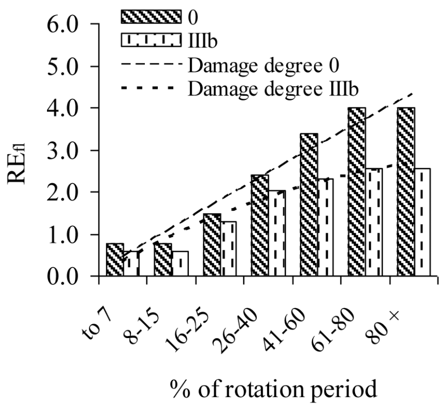

Fig. 1. Trend of real effect of sanitary-hygienic function development of forest stands with stocking 9–10.

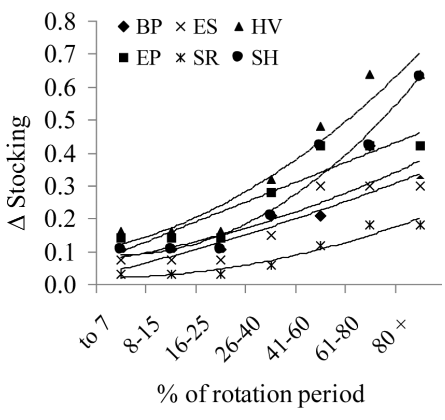

Fig. 2. Difference development of real effect of forest function in forest stand with full stocking and stocking 3 and less. For explanation see key to Table 3.

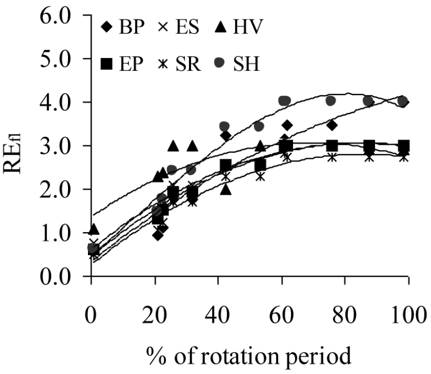

Fig. 3. The development trend of the real effect of forest stands modelled on existing stand type C5 – oak monoculture (the forest site type 1S1 – hornbeam-oak wood on sands with Narrow-leaved meadow-grass, Forest Administration Valtice) – the value expression 0–6. For explanation see key to Table 3.

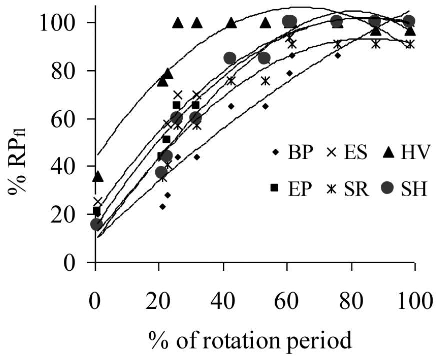

Fig. 4. The development trend of the real effect of forest stands modelled on existing stand type C5 – oak monoculture (the forest site type 1S1– hornbeam-oak wood on sands with Narrow-leaved meadow-grass, Forest Administration Valtice) – the percentage expression from 0 to 100 % of the real potential of forest function (RP_{fl}). For explanation see key to Table 3.

the biomass expansion factors (BEFs) for Scots pine, Norway spruce and birch. According to this study BEFs (biomass component/stem volume) change as a stand ages, especially in Norway spruce stands (Lehtonen et al., 2004). The influence of the age of the hydric functions was presented e.g. by Vertessy et al. (2001). They have investigated relations between stand age and catchment water balance in mountain ash forests. They measured leaf area index (LAI), sapwood area index (SAI) and various water balance components in several mountain ash stands, ranging in age between 5 and 240 years. They have demonstrated that old-growth mountain ash forests yield significantly more water than young regrowth forests of the same species because of lower evapotranspiration. They have estimated the difference in evapotranspiration for 15 and 240-year-old forests to be 460 mm per year for sites with 1,800 mm annual rainfall (Vertessy et al., 2001). Cseresnyés et al. (2006) recognized stand age influence on litter mass. They found a significant increase with age detected through the age classes of 21–40, 41–60, and 61–80 years, and then a significant decrease occurred in stands above 80 years for the needle litter. In case of branch litter, the age-dependent increase was again significant to its maximum quantity, but the decrease in old stands proved to be insignificant (Cseresnyés et al., 2006).

Their research is an example of the analysis of the influence of the forest age on the pedogenetic functions. The above mentioned works confirmed the trends of the age impact on the single forest functions. Other publications (e.g. Wang et al., 2013), confirm the forest age in not only the determining indicator but it operates in accordance with other factors like the forest type.

Conclusions

Ecosystem services have become a mainstream concept for the expression of values assigned by people to various functions of ecosystems (Bennett et al., 2015). This conception respects the principles of ecosystem functions, like the ecological provisioning base. The age of the forest is one of the detail criterion influencing the quantitative and qualitative effects and abilities of the forests to produce the ecosystem functions.

The criterion forest stand age is in affinity with the rotation period of the forest stand. It is given by the definition of criterion, when forest physical age was not ideal valuable criterion for tree species with different physiological and economical maturity. The influence of criterion forest stand age is the highest from all function-reduction criteria. It is given especially by the wide extent of criterion values. Every forest stand obtains values 0–100% of age of the rotation period in standard ecosystem conditions, but its stocking usually varies between 8 and 10, and health status is characterized as slightly damaged forest stand.

The importance of criterion stocking and health status increases for the older forest ecosystems and for the youngest forest age classes their importance is very low.

The trend of real effects of forest functions has for particular functions mostly an exponential character. Development of real effect marginal values is a very important descriptive parameter. This parameter determines the level of all society forest functions influence by the criterion forest stand age.

Comparable results obtained within forest management or forest mensuration are available especially for bio-production forest functions. Concerning other forest functions, the influence of forest stand age on functional effectiveness is not yet investigated relevantly.

Criterion forest stand age loses importance when the forests are richly structured. This can be substituted for example by the graph of DBH (diameter breast-high) frequency.

The real functional effect of the forests with simplified spatial stand structure arising from the model is, mainly in the first half of rotation, significantly dependent on age. Its wage is for all functions between 0.8 (09)–0.6. In the second half of rotation the weight of health condition is increasing as well as stocking (Vyskot et al., 2003). The structurally differentiated forests health condition stays as the crucial functional-reduction criterion. The age (age differentiated forests) and stocking lose importance. These criteria are replaced by the spread of the thickness classes and tree stratification.

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