[Łukaszkiewicz, 5(12): December2018]
DOI- 10.5281/zenodo.2244458
ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

SHAPING OF TREE STANDS IN LARGE PARKS IN EUROPE FOR THE NEEDS OF OPTIMAL RECREATIONAL BIOCLIMATE, BIODIVERSITY AND ECOLOGICAL SUSTAINABILITY

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Abstract
The structure of parks tree stands has a direct impact on so-called recreational bioclimate. Obtaining such a goal is possible, if the stand reaches among others the optimal spatial, species and age structure. Thus the regulation of the park's stand over the years should strive to create sustainable, self-regulating systems, adapted to the leading function – recreation. The mature stands of large parks usually have a layered structure of vegetation and a specific age structure – both of high quality and ecological importance. An important feature of the stand is a degree of crowns closure – it affects the development of canopy and phytoclimate of the stand's interior. In terms of achieving high recreational comfort, the best qualities has a luminous stand - it is characterized by higher resistance to recreation movement, higher health and lush growth of trees, undergrowth more dense and resistant to trampling and at the end more favorable phytoclimatic conditions.
The aim of the paper is to present the principles of shaping park stands for obtaining high recreational comfort and preservation of biodiversity.

Keywords: *Park's tree stand, Recreational bioclimate, Tree stand's composition and structure, Urban parks.*

I. INTRODUCTION

All over the world large urban parks with an area of over a few hundred hectares which are integrated with city urban structure, usually have a well-developed recreational programme properly suited to social demand, i.e. adapted to high number of daily and occasional visitors[1]. Such sites have to provide optimum recreational space to a broad spectrum of users - allowing for games, entertainment and recreation [1]. However adapting park's recreational programme to needs of the population is dependent to a large degree on a number of natural conditions (both biotic and abiotic), which may significantly improve or limit human comfort or "well-being" (Fig. 1). A set of interconnected physical, chemical, biological and metrological factors may be summed up as a bioclimate (climate, as it influences - and is influenced by - biological organisms) [2-8]. In the context of the topic of this article bioclimate is inherently connected with recreation. Consequently, **recreational bioclimate** should by understood as a set of all natural variables within the air layer (so called "recreational level") above ground level, where recreational activities take place. In parks - apart from terrain and surface water - vegetation has the most profound impact on recreational bioclimate, especially the tree stand. Depending on its surface area and ecological diversity park's tree stand may to a large extent influence bioclimactic conditions both inside the forested area and in surrounding areas - e.g. in its border zone [9-15]. The decisive factor in this case is tree stand structure developed through long-term shaping and maintenance activities - aesthetically pleasing [16-19] and ensuring a favourable

[1] International conference „Large parks in large cities" by WWF (World Wide Fund for Nature), Association for Ekoparken and others, Stockholm, Sweden, 2-4 September 2015. The world-wide conference devoted to the topic of large parks, in which the authors took part, along with representatives from all continents.

recreational bioclimate, i.e.: optimum lighting and temperature, ventilation and composition of atmospheric air, etc. [5-8, 11, 13, 20]. Ultimately the tree stand should evolve into a potent and self-regulating system which does not require expensive maintenance activities [9, 21-23]. The goal of this publication is to present general interconnections between park tree stand structure and recreational needs using examples of chosen European large area parks, where authors have conducted their research.

Fig. 1. The recreational bioclimate is a sum of all natural variables the effect of which can be seen in air zone ("recreational layer") with a depth of ca. 2.0 m above ground level which is used for recreation. Green Park, London, UK (photo.: J. Łukaszkiewicz, IV 2015)

II. MATERIALS AND METHODS

Ecology and bioclimate of forest communities has been the focus of scientific research for years now [e.g. 10, 11, 20, 24-26]. Great variety of forest ecological systems (which depends among other on diversity of species, shape and structure of the tree stand) influences both forest interior and its surroundings. Authors of this publication assumed that due to a well-developed forestry research methodology, tree stand structure of large area urban parks may be, by analogy, researched similarly to forest tree stands. However unlike in forests, where timber production often necessitates specific management solutions (e.g. felling, thinning, renewal), the primary goal of shaping and maintenance activities in parks is subject to requirements of broadly defined **recreation**. This is why all aspects of forestry methodology and terminology [e.g. 17, 20, 26] quoted by authors of the publication are used in the context of landscape architecture [e.g. 14, 18, 19, 22, 23, 27, 28] which being an interdisciplinary branch of science uses research tools of many domains.

In accordance with its goal, the publication presents general links between tree stand structure and its potential to provide optimum recreational environment - a primary function of an urban park - with special emphasis on natural, spatial and cultural aspects. This part of the publication is based on literary review, one of the basic research tools. [29]. Next, results of author's observations in chosen reference sites in Europe are presented, including those from **England, France, Germany, Italy, Poland, Switzerland and Ukraine** [e.g. 28, 30, 31]. Authors have evaluated tree stands of large parks focusing among other on their spatial, age, species, and general health structure. The discussion part contains a comparison of theoretical data with results of in-situ research. Conclusions consist of general guidelines for adapting a tree stand to recreational functions in urban parks.

III. RESULTS AND DISCUSSION

A. Chosen tree stand properties

Spatial structure

A tree stand of every large area urban park may be evaluated in terms of its suitability for recreation, by analysing among other its spatial structure (vertical and horizontal), age (of trees), species composition, health etc. In the context of the goal of this research the park's tree stand spatial structure should ensure a favourable bioclimate in recreational layer. Tree stand's spatial structure is analysed in its vertical and horizontal orientation. **Vertical** structure can be classified into: **single layer structure** – there is little variation in tree height and crowns are located at similar height; **2 layer structure** – trees form at least 2 distinct layers of different height, with the tips of the lower layer trees not penetrating deeply into the upper layer; **multilayer structure** – a number of vegetation layers (high, medium, low), with crowns of trees in various layers interconnecting.

Horizontal layout includes among other **spacing** (or density) between individual trees. In a loose tree stand it is usually **irregular** as opposed to regular afforestation (such as alleys, espaliers, bosquets) [15, 16, 20, 22, 23, 26, 27, 32]. The spacing is strongly correlated with **tree canopy closure** (or - positioning of tree crowns in relation to each other). This aspect is decisive for lightning conditions within the tree stand, which consequently influence development of tree habits[2], as well as growth of sub-canopy vegetation which in turn influences natural succession. Canopy closure has a strong influence on recreational bioclimate (lightning, temperature and humidity). The denser the canopy closure the less rainwater penetrates through the crowns, the greater qualitative impact on lightning conditions inside the tree stand, the slower evaporation of surface water, in general the higher air relative humidity in the layer above ground, the more difficult exchange of air between forest interior and atmosphere above it.

Strength of tree layer influence depends on its **translucency**. It is partially connected with canopy closure (Fig. 2). It is also dependent on tightness of crown closure. High variability of crown translucency is present especially in deciduous forests (small in peak of vegetation period and larger in the period before and after it) [11, 13, 15, 26].


A


B

Fig. 2. Examples of open/loose park stands with a significant coefficient of canopy's translucency, especially in the winter-spring period: A/ RHS (The Royal Horticultural Society) Wisley, Surrey, UK; B/ Borde Hill, West Sussex, UK (photo.: B. Fortuna-Antoszkiewicz, IV 2015)

Age structure

Park's tree stands have a specific age structure. Trees have different biological properties depending on their age (e.g. speed of growth, physiological maturity, regenerative and reproductive capabilities) as well as habitat preferences (e.g. lightning, water and nutrient requirements).

Depending on park's origin (e.g. Silesia Park in Chorzow [30, 31]) it may be composed of tree stands of varying age (mixture of tree of different age) or homogenous age (trees planted and grown in the same period - one age class) – Fig. 3. In terms of ecological balance and biodiversity homogenous age of a tree stand, especially if coupled with

[2] In practice **level of closure** is estimated using spacing between tree crowns. Closure is evaluated using a 4-grade numerical scale: 1) **complete closure** - when tree crown edges meet or partially overlap; 2) **moderate closure** - when tree crowns are separated by narrow empty spaces; 3) **broken closure** - when spaces between tree crowns are large enough to accommodate individual trees; 4) **open closure** - when spacing between crowns is significantly larger, and trees no longer influence each other [15, 23, 26, 33].

low species diversity, is an unwanted feature(!). Such conditions created fierce competition for light, nutrients and water as well as potentially make the tree stand more susceptible to disease and pests as well as harmful abiotic conditions (tree damage caused by heavy snowfall, strong winds etc.) [11, 15, 22, 23, 26, 34, 35].

Fig. 3. Stand's age structure in Silesia Park, Poland: A-B/ the oldest trees aged approx. 80-100 years; C-D/ mature trees aged 50-60 years; E-F/ the youngest trees aged: 20-30 years (photo.: B. Fortuna-Antoszkiewicz, J. Łukaszkiewicz, P. Wiśniewski, 2013-2015)

Species composition

Park's tree stand may be entirely or mostly composed of **single species** (monoculture) or **multiple species** (a composition of various tree and shrub species, which is more beneficial ecologically-wise and more aesthetically pleasing). Species in multiple species tree stands may be **intermixed** to a varying degree: 1) **singular** – species are mixed on individual specimen level and do not form groups; singular intermixing may be regular or irregular; 2) **group** – intermixing of single species groups composed of a number of specimens of one species; 3) **cluster** – intermixing of single species clusters of any shape; 4) **row** – tree species planted in rows; 5) **uneven** – completely irregular intermixing [27] (Fig. 4, 5).

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A

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Fig. 4. Examples of multiple species park stand with irregular intermixing:
A/ Park in Łańcut, Poland (photo.: B. Fortuna-Antoszkiewicz, IX 2013);
B/ High Beeches Gardens, Sussex, UK (photo.: B. Fortuna-Antoszkiewicz, IV 2015)


A

B

Fig. 5. Examples of single species park stand's forms of homogenous age (trees aged approx. 60 years), Silesia Park, Poland:
A/ part of the park with a monoculture of Fagus sylvatica* L. *with irregular intermixing
(photo: B. Fortuna-Antoszkiewicz, I 2015);
B/ the regular double row of Populus xberolinensis (K. Koch) Dippel* 'Berlin' *(photo.: B. Fortuna-Antoszkiewicz, VIII 2013)

B. Recreational bioclimate inside the tree stand

Lightning conditions
Lightning conditions inside the tree stand significantly influence its recreational bioclimate. They depend on climactic and geographic conditions, change daily and seasonally as well as are subject to local vegetation [10, 11, 26]. For example in a dense tree stand approximately 80% of solar radiation reaching earth through atmosphere gets absorbed or reflected by tree crowns. Amount of light reaching ground in a tree stand depends also on its species structure, age and density, and in deciduous forests on amount of foliage (Fig. 6).

Light reaching the bottom of a tree stand is of great importance to habitat conditions. With up to 16% of daylight passing through the crowns (compared to open spaces) the soil remains dead (biologically inactive), with 16-18% some infrequent patches of shadow tolerant moss appear, with 22-26% dwarf shrubs, and with 30% seedlings and young trees [10, 26]. Plant lightning requirements are higher on poor soils. Too intensive and prolonged overshadowing causes malnutrition and muffles plant growth, while too strong exposition to sunlight causes chlorophyll decomposition, disturbance of water balance, upsetting of physiological balance or even necrobiosis [11].

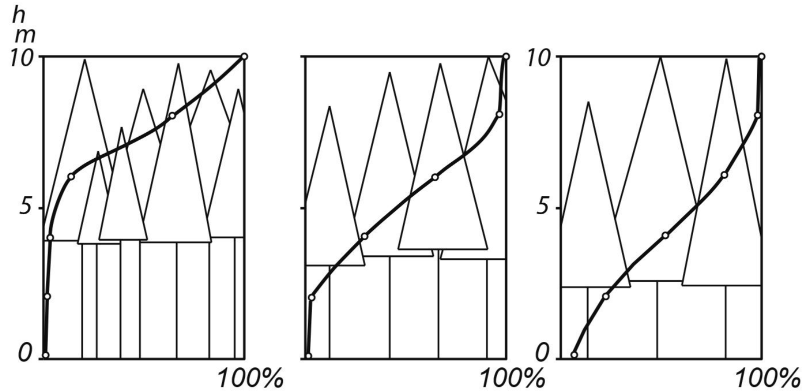

Fig. 6. The influence of stand density and canopy's translucency on the intensity of daylight (0-100%) during the summer day inside exemplary young spruce stands with varying degrees of canopy closure, depending on the density/spacing of trees and height above ground level: left / 300 pcs/100 m², middle / 43 pcs/100 m², right / 17 pieces/100 m² (after [24], figure by P. Wiśniewski)

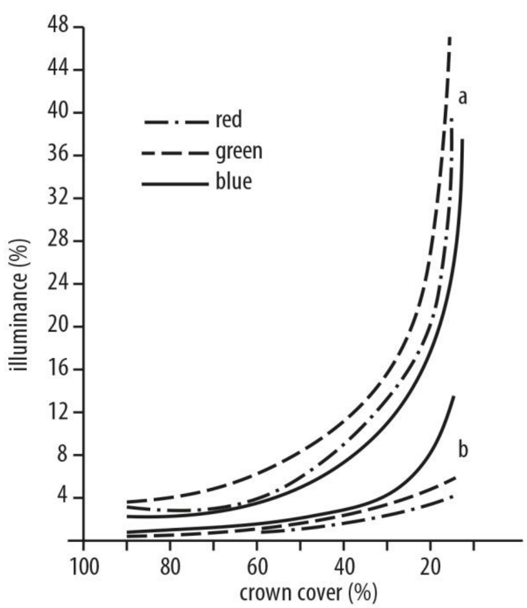

Fig. 7. Intensity and spectral composition of daylight under the canopy (compare to the open area), depending on the density of crown cover (%); (a) - dispersed light; (b) - direct light (after [11, 12], figure by P. Wiśniewski)

Tree stand layer is most effective at absorbing direct radiation. This is especially pronounced in sunny weather. In cloudy weather the dispersed light coming from the sky is not absorbed by leaves and more readily reaches bottom of the tree stand (Fig. 7). This causes stand interior to have more uniform lightning conditions compared to sunny weather. In sunny weather lightning conditions inside the tree stand are significantly more varied. This is because it is composed not only of diffused light but also direct light, which passes through open spaces in tree canopy and forms bright, moving light patches in the ground. Sunlight is also filtered in the tree crown layer. Tree leaves absorb different wavelengths of sunlight spectrum. Short wavelengths (blue and ultraviolet) are absorbed to a greater extent than long wavelength (yellow and red) [4-6, 10, 11, 26].

ISSN 2348 – 8034
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Fig. 8. The first sunny and warm weekends of April - people gathering on park's lawns „catching sun rays":
A/ Park Pole Mokotowskie, Warsaw, Poland (photo: J. Łukaszkiewicz, IV 2018);
B/ St. James Park, London, UK (photo.: J. Łukaszkiewicz, IV 2015)

Canopy closure is a decisive factor for microwave radiation reaching the bottom of the tree stand. It should be noted that this radiation, in its shorter wavelength range, has important therapeutic effects for humans. It is invigorating and stimulating [3-6, 26]. **Controlled, short-term** exposition of possibly largest area of the body to ultraviolet radiation of the sun is very beneficial in terms of quality of recreation (Fig. 8). This is because of, among other, stimulation of vitamin D_3 synthesis in skin [36, 37]. Neglecting this need for photosynthesising results in a common vitamin D deficiency and the necessity to use oral supplementation (pharmaceutics, food) [38, 39]. The limited possibilities of this dermal synthesis in Central and Eastern Europe latitude (only in spring-summer season) are further worsened by a lifestyle change of young people ("computer generation") which makes them spend most of their time in front of a computer in closed rooms[3] [37].

Atmospheric air

Composition of air in the recreational layer inside dense tree stand differs significantly from what is considered typical in an open area. It varies considerably depending on weather conditions, daily and annual cycles. Among atmospheric gases the most variability inside the tree stand can be seen in O_2 and CO_2 concentrations. This is associated with soil respiration, duff decomposition, respiration of over-ground parts of plants and level of photosynthesis.

Concentration of oxygen in air inside a tree stand is variable and depends on weather, time of day and seasons. This seasonal variability is related to photosynthesis and respiration of plants - processes which are also species dependent. Oxygen is released mainly in tree crown layer, which constitutes the largest biologically active layer (foliage). **Its size to a large extent depends on canopy closure.** For example tree stands with a dense and closed canopy and single layer vertical structure produce most of their green matter solely in crown layer. Due to climactic conditions in such a tree stand penetration of O_2 into lower parts of the tree stand is limited at best. Dense tree stands have a much lower oxygen concentration in the recreational layer under the canopy in the range between 12-15% of air (dry) - while in normal conditions is it approximately 21%. This is why in **very dense tree stands oxygen deficiency** may be observed which becomes more pronounced in the morning, especially in terrain depressions. While in **open tree stands** with a multilayer structure which have **a significantly larger mass green matter** there is sufficient aeration and a better vertical air movement [5, 6, 10, 11, 24].

[3] Vitamin D apart from being part of **mineral management** regulation mechanisms (co called classic effect which ensures proper concentration of calcium and phosphorus for bone growth) has also pleiotropic effects in the entire organism. It is believed that it prevents some **tumours, immunological and cardiologic problems, infections, metabolic and neurological problems** [36, 37].


A


B

Fig. 9. A/ The example of almost unlimited access of daylight to the bottom of the stand (even on cloudy days) and free aeration of "recreational layer" inside loose park stand - bright oakwood (Potentillo albae-Quercetum) in Zofiówka Park, Humań, Ukraine (photo: B. Fortuna-Antoszkiewicz, IX 2013);
B/ Limited daylight access and aeration conditions in a dense mixed broadleaved stand, Silesia Park, Poland (photo: B. Fortuna-Antoszkiewicz, VI 2014)

The concentration of CO_2 in recreational layer results from respiration of soil (70%) as well as flora and fauna (from 5 to 25%). These factors cause **increase in carbon dioxide concentration above ground**, which e.g. in early morning in tree stands growing in fertile habitats may reach up to 20% of air mass, so **exceed amount of oxygen** in air. Usually CO_2 concentration in the recreational layer of a tree stand is 2 to 10 times higher than in air mass outside of it [5, 6]. CO_2 concentration inside the tree stand usually drops during the day and increases during night. In the vegetation period this phenomenon is visibly less pronounced as a result of an increase in assimilation by tree leaves. In Autumn CO_2 concentration in atmospheric air inside park tree stands is relatively highest due to a decrease in photosynthesis and intensive "soil respiration" [11]. Despite trees absorbing a large amount of O_2 and CO_2 in the vegetation period to produce biomass, its quick dissipation in the atmosphere is made difficult by high density of the tree stand. In a dense, thick tree stand with poor aeration **CO_2 concentrations are significantly higher** (especially in terrain depressions), compared to open tree stand - mature (proper age structure) with loose spacing and low density, well aerated (especially on elevated terrain) with a rich undergrowth [9]. Summing up, atmospheric air inside **open tree stands** has lover CO_2 concentration and better influx of O_2 to the recreational layer removing the risk of potential oxygen deficiency present in a dense and thick tree stand [5, 6, 10] (Fig. 9).

Thermal conditions

The tree stand has a great impact on temperature changes in a park (as does terrain and related with it exposition to sunshine.) Presence of a tree stand in a park causes differences in thermal conditions (Fig. 10) compared to open areas or urban setting [10, 11, 26]. During the vegetation season (trees with full foliage) the process of daily atmospheric air temperature changes is in general fairly typical. Before sunrise the temperature is lowest in tree crown layer, and highest near the ground - under the canopy. After sunrise air temperature in the tree crowns increases while the shaded tree stand interior remains much cooler with the lowest temperature at ground level. During the day air temperature under the canopy continues to slowly rise. It however remains much lower (sometimes even by 10° C) than at tree crown level, as well as at ground level in open areas surrounding the tree stand (Fig. 11). In the afternoon temperature changes the fastest in the crown level while near the ground changes proceed slower. This is because radiation of heat from soil (undergrowth) is to a large extent slowed down by the canopy which forms a barrier for long wavelength radiation similar to cloud cover in exposed areas. This is why at night air temperature near the ground in dense tree stands is higher compared to neighbouring open areas. Consequently, daily and annual air temperature changes inside the tree stand of large parks (in the vegetation season) are smaller (lest drastic) compared to expansive open spaces of park interiors or urban areas without trees [10, 11, 13].

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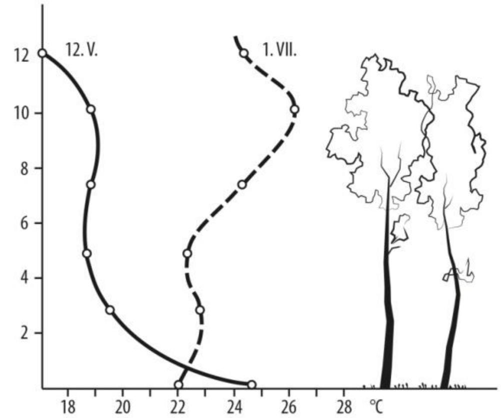
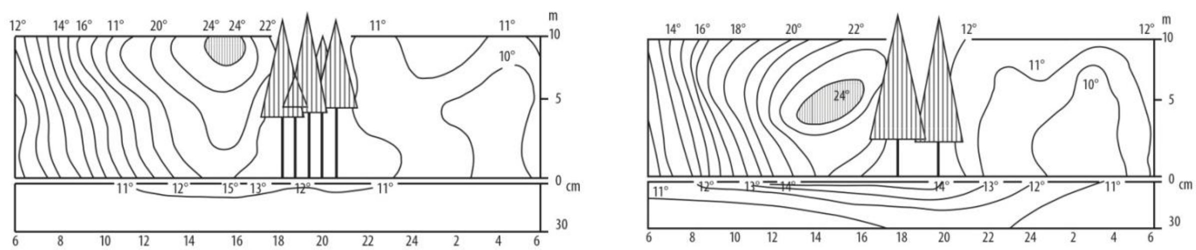


Fig. 10. The model of air temperatures in the afternoon hours depending on the height over the ground inside the oak stand before (12. V) and after the development of leaves (01. VII). Before the development of leaves, the highest temperatures persist at the bottom of the stand. After the development of leaves, the warmest place in the stand is the layer of tree crowns (after [24], figure by P. Wiśniewski).



A B

Fig. 11. The profile of daily average temperatures (end of July, from - until 6:00 o'clock) of atmospheric air and ground (up to 0.3 m deep) in a spruce stand with two different canopy degrees of crown closure: A / total canopy closure (100%); B / loose closure (65 - 85%). The maximum air temperature of 22-24º C in variant B is situated much lower in relation to the bottom of the stand (after [24], figure by P. Wiśniewski)

Specific thermal conditions inside **designed interiors - openings and gaps - within the tree stand** should also be noted. The larger the opening, the more its climate differs from that of the tree stand (under the crown canopy). It also depends on height and spacing of trees as well as terrain. As a result, there are greater daily and annual air temperature changes inside gaps in the tree stand. During the day the maximum air temperature inside the opening/gap is higher than under tree canopy. Such interiors, depending on their size, have different ventilation properties. At night inside tree stand interiors there is a notable drop in temperature due to intensive radiation of heat to the atmosphere. Additionally, cool and heavy air flowing at night to the bottom of a tree stand from its crowns may be propelled towards interior border zone even by light winds. Consequently in the morning, the minimum temperature may drop below that inside the tree stand compared to entirely exposed areas [10, 11, 13, 26].

Air humidity

In parks, the interior of a dense tree stand with limited ventilation may have high air relative humidity (water vapour content). This makes evaporation from skin and airways more difficult for people residing inside, which may cause the feeling of breathlessness under tree crown canopy [3, 5-8]. These symptoms are however lifted with an increase in air mobility. Throughout the year water vapour in air under the canopy is on an average 3-6% higher compared to open spaces. During summer (vegetation season) differences in mean monthly water vapour concentration in air inside the tree stand and on in open areas may exceed 10%, while in wintertime, those differences are negligible.

The cycle of air saturation with water vapour is important in the context of tree stand's recreational functions (vegetation season). It should be noted that relative humidity of air in an expansive and dense park tree stand is not

 ISSN 2348 – 8034
Impact Factor- 5.070

uniform vertically due to layered structure of a tree stand. At night before sunrise relative humidity of air both above tree crowns and under the canopy is high enough that it often reaches a so called saturated state. As a result dew forms mainly on upper surface of tree crowns. After sunrise a **morning humidity pattern** forms in the tree stand - characterised by drier air in upper parts of crowns and more water vapour saturated air under the canopy. During the day warmer air from the outside and air from under the canopy mix causing gradual drying of air inside the tree stand. Simultaneously water vapour is constantly being delivered from soil surface under the trees and from tree crowns. This forms a **noon humidity pattern** with two maxima of relative humidity layered on top of each other: lower is supplied with humidity from soil and the one above it with humidity from tree crowns. At this time of day the difference in relative humidity of air inside the tree stand and above tree crowns may reach up to 15-20%. In the evening this difference is slowly evening out - **evening humidity pattern** emerges. From midnight to sunrise relative humidity in various tree stand layers is equalising albeit higher than during the day [10, 11].

IV. SHAPING OF TREE STAND INTERIOR AND SURROUNDINGS FOR RECREATIONAL FUNCTIONS

A. Tree stand interior

Construction and maintenance works on park tree stands (both short- and long-term perspective) should be aimed at maintaining optimal recreational conditions, improving resistance to recreational traffic and general improvement of natural conditions including:

- improving air composition in recreational layer;
- improving lighting and thermal conditions;
- creating optimum conditions for proper ventilation of tree stand interior;
- reducing relative humidity of air;
- producing areas with dense undergrowth resistant to a relatively intensive recreational traffic.

These requirements may be relatively easy to achieve by shaping and maintaining young tree stands (up to 40 years old) - it is however more difficult with older tree stands, where achieving similar results may be more time consuming [9, 20-23, 26] (fig. 12.).

Fig. 12. Corrections (clearings) in even aged, dense, monoculture park stand (Ulmus laevis L.), Pole Mokotowskie Park, Warsaw, Poland (photo.: J. Łukaszkiewicz, IV 2018)

A tree stand adapted to recreational functions should have a multi-layered structure (layer A: trees; layer B: underbrush + very young trees; layer C: undergrowth + seedlings), varied species and age structure. Open/loose tree stands are highly resistant to recreational traffic, have dense and treading resistant undergrowth and provide more favourable climactic conditions for quality recreation. Trees growing in good lightning conditions have higher slenderness ratios (s=h/d) which are safe in terms of their stability - they are resistant to winds throws, live longer, bloom and bear fruit more profusely and are in better health condition [11, 13-15, 23, 33, 40].

Data provided before suggest that an **open tree stand with open crown closure** in the range of 40-65% provides the best conditions producing a favourable recreational bioclimate [5, 6, 9, 11, 13, 15-18, 21-23, 26]. Good exposition of the recreational layer to sunlight (both long and short wavelengths) makes the conditions in tree stand interior more favourable for recreation compared to a tree stand with full closure - e.g. the canopy does not prevent dermal vitamin D_3 synthesis [10, 11, 13, 36, 37]. During the day the interior of an open tree stand heats up more readily compared to a dense tree stand, which makes it easier to meet the conditions of so called thermal comfort for a lightly clothed human doing a light physical activity (air temp. 20-22° C, speed 0.5-0.25 m/s, relative humidity ca. 20-60%). This improves comfort and allows for prolonged physical activity [3, 5-8, 11, 13]. In a loose and open tree stand the relative humidity of air in the recreational layer is not too high due to proper ventilation and a more beneficial vertical movement of atmospheric air throughout the day [10, 11, 13]. Ventilation of the interior also reduces CO_2 concentration and ensures a better influx of O_2 into the recreational layer (fig. 13) – reduction of oxygen deficiency present in a closed and dense tree stand. [5, 6, 10].

Fig. 13. Optimal sunlight exposition (both short and long wavelengths) of the bottom part of the loose tree-stand makes light conditions more advantageous for recreation - such as vitamin D3 skin synthesis. Borde Hill, West Sussex, UK (photo.: J. Łukaszkiewicz, IV 2015)

B. Tree stand border zone

In the context of the topic of this research **tree stand border zone** in every park is especially valuable, as it may potentially provide good recreational bioclimate (Fig. 14). Within this zone, with a width equal on an average to 5-10 heights of trees, atmospheric air has among other higher humidity, more active ionisation, higher oxygen and ozone concentration, more equalized temperatures - compared to open spaces. This is most pronounced in south expositions (SE, S, SW) and is related with the so called "**daytime wind from within the tree stand**" which is present even in sunny, windless summer days counteracting atmospheric calms and unwanted, in the context of recreation, feeling of breathlessness. This phenomenon is caused by thermal contrasts between interior of the tree stand and open park spaces [5, 6, 9-11, 22]. This results in both vertical and horizontal movement of air masses from cooler points (tree stand interior) towards warmer points (open spaces). These phenomena are present mainly during the vegetative season on sunny days with slow winds.

Due to its potential to accommodate high recreational traffic the border zone of a park tree stand is especially well suited for adaptation to various forms of recreation. (Fig. 15). This potential is significantly higher compared to inside of the tree stand and its width, subject to needs and terrain, may reach even up to 200.0 m from the front face of the tree stand. In each park there are in general freely accessible areas with S, SE, SW, E and W expositions. One of the major landscaping solutions should be vast and resistant recreational lawns of pasture type [41]. Of special importance in these areas are loose compositions of trees with a broken crown closure of without closure, which, as per classical compositional principles [27] may take the **form** of:

- **single trees** – individual trees or shrubs, loosely distributed within park interiors[4];
- **groups** - trees or shrubs planted in small groups of any shape, composed of a few or a dozen or so specimens[5];
- **rows** - single rows of trees or trees and shrubs; in parks - usually regular pattern[6];
- **belt layout** – a linear grouping of trees and shrubs in a multi-line or irregular layout; width of a belt not exceeding 10.0 m;
- **areal layout** – trees and shrubs growing on and area exceeding 10 acres surrounded by expansive park lawns.

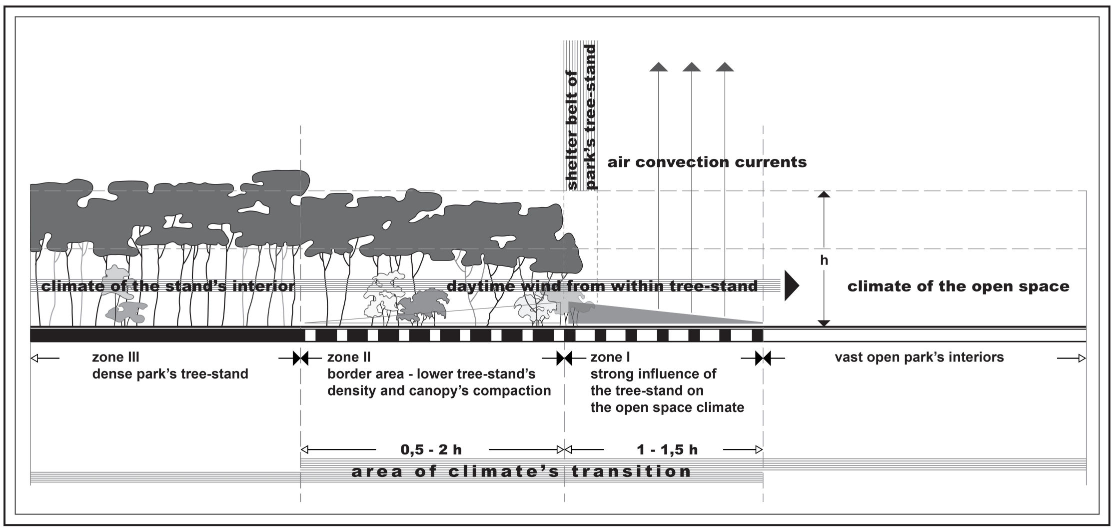


Fig. 14. Climate of an over 40 years old park tree-stand vs. climate of open area and their interconnections. System analysed in a vegetation period, S, SW, SE, W and E exposition (after [9], figure by P. Wiśniewski)

In the border zone area adapted for recreation tress should not occupy more than 20-30% of the surface area, and they should be distributed perpendicularly to compact tree stand front face (fig. 16). Such a layout allows for free movement of air towards open spaces, stimulates effects beneficial for recreation: daytime wind from within the tree stand [5, 6, 9-11, 16, 17, 20, 22].

[4] **Single trees** – individual trees (or shrubs) growing in a specific space - landscaping interior. Usually these are dendrologicaly valuable specimens (valuable native or alien species or their rare varieties) with high aesthetic value (attractive habit, decorative organs: sprouts, leaves, flowers) [22, 42].

[5] **Group of trees or shrubs** – a few or a dozen trees of shrubs forming a consistent composition, used as a free-standing element in a defined, open space - landscaping interior [42, 43]. May take various forms, e.g. irregular (free-form), regular, compact, loose.

[6] **Espalier** – is a regular, usually single row of trees, the crowns of which form a compact wall with a height of over 220 cm. [42, 43]. This effect is achieved by proper pruning or using trees with natural geometric habit [22]. In gardening art pruned espaliers were used to create geometric garden interiors (e.g. saloons, offices, labyrinths, hippodromes), to emphasize perspective depth of the spatial composition (overlapping layouts) [43], to frame main roads and important prospectuses [44].

ISSN 2348 – 8034
Impact Factor- 5.070

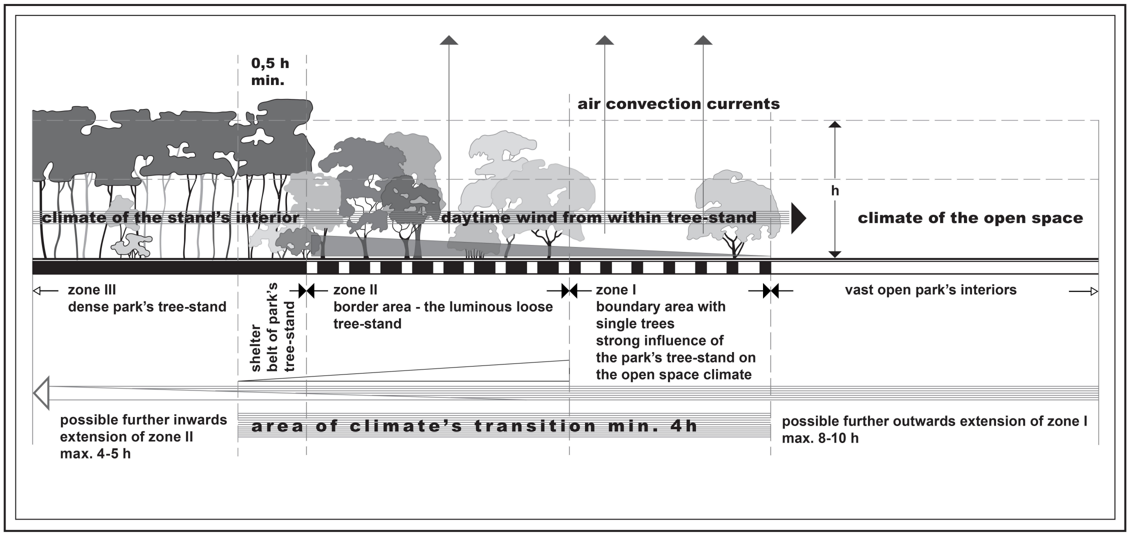


Fig. 15. Climactic conditions after transformation of a border zone of over 40 years old park tree-stand (zone I and II) and its relation to an open area in vegetation period. S, SW, SE, W and E exposition
(after [9], figure by P. Wiśniewski)

Fig. 16. Trees growing with better access to the sun light have lower slenderness ratios (s = h / d), live longer, flower and bear fruit more intensively and are more resistant to degradation. Hatchlands Park, Surrey, UK
(photo.: J. Łukaszkiewicz, IV 2015)

C. Resistance to recreational traffic of park tree stands and undergrowth

In shaping man-made park compositions it is important to ensure permanence of forms and vegetation layouts. Park vegetation is subject to succession and the changes are often determined by type of habitat and presence of synanthropic plants. Scope and speed of those changes depends among other on the size of gaps between plants and availability of light, nutrients and water necessary for growth. Spaces devoid of plants have an important part to play in their transformation - spontaneous appearance of plants is slower in areas with dense vegetation compared to areas with thin vegetation cover [4, 5]. For example - trees, which grow to large size limit the development of competitive species, both in the undergrowth and underbrush. The process of filling in of gaps in the tree stand may take even a few decades [46], while in areas with extensively maintained grass type vegetation drastic changes may come about even within one vegetation season. To ensure permanence of various vegetation types it is necessary to provide maintenance activities such as mowing, selective weeding, sometimes fertilizing[7].

Spontaneous changes in park compositions depend also on **resistance of the undergrowth** and vitality of the plants. The research covered resistance of park undergrowth to treading on border of the tree stand and in the area outside of tree canopy cover. Results confirmed a significant influence of anthropogenic pressure on diversity and species composition of tree stand undergrowth. The density of natural plant species in park tree stands equals 10.2-14.2/m^2, while in those subject to treading 7.4-11.5/m^2. Treading of the soil under tree canopy removes spring geophytes from the undergrowth. Calculated natural resistance of the undergrowth of park tree stands based on research data is lower than resistance of natural plant communities presented among other in [47] and equals 124 people/ha/week for active recreation and 437 people/ha/week for passive recreation. Translating these number for individual trees (with an area of 25.0 m^2) this resistance equals 2.5-10 people/week. The resistance varies largely with the lowest values in tree side interior and the highest at its border. **Meadows and lawns** were shown to have the highest resistance to treading in the distance of over 15 m from trees (i.e. outside of the shaded zone). In order to maintain biodiversity tree stands near meadows should be adapted for recreational use, ensuring thus protection of the interior of the tree stand from too intensive treading [41] (fig. 17).


A

B

Fig. 17. The examples of undergrowth in a luminous park tree stand - impressive especially in spring:
A/ Allium ursinum* L.*; Park in Radziejowice, Poland (photo.: P. Wiśniewski, V 2015);
B/ Chionodoxa* Boiss.*; Wakehurst Place - RGB KEW branch, Sussex, UK (photo.: B. Fortuna-Antoszkiewicz, IV 2015)

V. DISCUSSION

Presented data are a strong proof that parks with open tree stands provide significant benefits for recreation. It should be noted that the origin of the open tree stands / groves dates back far in time and is connected from its very beginning with development of civilisation and human management of nature. In Europe which was initially dominated by expansive primeval forests the advent of agriculture saw transformation of forest environments (burning, stubbing) into open grassy areas which were slowly converted into arable fields and crops. The effect of this transformation was creation of an agricultural landscape, with trees growing often in the boundaries of fields - individually or in small clusters. In later period this landscape was further influenced by herding - cattle grazing prevented reclamation of these meadows and pastures formed on former forest land through secondary succession by trees [48, 49]. The remaining forested areas were subject for ages to management centred around wood

[7] Low lawns (up to 5 cm high) require mowing every 1-2 weeks, park lawns – every 3/6 months, flower meadows – once a season, and areas with herbaceous plants once every 4-8 years. Natural park tree stand including undergrowth requires only selective weeding. Grass type undergrowth is the least resistant to conditions in dense tree stands, where regular mowing and raking leaves impoverishes the soil. The structure of man-made vegetation subject to extensive maintenance activities should be as close to natural as possible. Structures composed of introduced species and monocultures require intensive maintenance [41].

production, e.g. coppice forests (fig. 18), and due to their loose spatial structure differed from original forests [49, 50].


A


B

Fig. 18. A-B/ An example of shaping a stand in the form of the so-called coppice stand; Mużakowski Park (Park von Muskau, 1815–1845), Poland-Germany (photo.: B. Fortuna-Antoszkiewicz, V 2018)

At the same time ever since antiquity in Europe there was a tendency to adapt forests for various leisure and entertainment activities as well as recreation [1]. Examples of forests transformed in such a way include sacred groves (e.g. in ancient Greece). Such groves had a form of open tree stands with a loose structure and were designed to allow mystic contact with deities, also as a space for religious rituals or simply as a meeting place. Greek sacred groves build for deities were open for public access, a practice which was continued in ancient Rome. Mystical character of sacred groves was continued in the middle ages, next it was reinvented in Italian renaissance gardening art as *bosco*, in French garden art as *bosqet* while in English gardens in the 18th and 19th centuries - as a *grove* [51, 42, 44, 43]. A specific form of a grove is an open grove, which was planted for recreation and leisure by redesigning the entire interior and border zone of a tree stand, introducing roads and simple furniture such as: benches, sculptures, hard landscaping elements, etc. In this form open groves were popular in renaissance and baroque periods, and often constituted a transition between the formal garden proper and surrounding open landscape [21, 22, 42-44].

Shaped in a natural way, varied tree stands dominated garden art in the following periods - taking the form of a new style of a **landscape garden.** This thorough, nearly revolutionary approach originated in England, were a new ideological trend was born, later developed into the landscape garden style which remained immensely popular until beginning of the 20th century, while elements derived from it are still popular today. Presenting how this new style of gardening art originated is key to understanding the changes to popular awareness of issues related to natural environment and approach to conscious shaping of the landscape, which paved the way for discovering principles for creating park tree stands still holding true today.

The beauty of natural landscape inspired by the Arcadian myth[8] was a theme popular in 16th and 17th centuries, e.g. in European art - landscape as a stylised backdrop for genre scenes can be seen in works of many artists[9]. The change in focus towards nature was preceded with philosophical discussions and their reverberations in literature, especially in poetry. In England the ideological basis for the new style formed in 16th century and was developed in 17th century inspired by works of philosophers and poets from this period, among other: Francis Bacon, John Milton, James Thompson. In France Jean-Jacques Rousseau was a champion of cherishing the beauty of unconstrained

[8] „*Arcadian myth* – an ideological and artistic attitude [...] which relies in creating park landscapes with calm and dreamy qualities, harmoniously interconnected with surrounding areas, some times bucolic in nature, [...] while preserving picturesque, natural elements linked to archaeological artefacts from ancient Greece and Rome, which emphatically allude to tradition of the site. It utilised symbols of happiness, love and the tragedy of death [...]" [43].

[9] E.g.: Titian, Giorgione, brothers Carracci, Salvatore Rosa, Albrecht Altdorfer, Peter Paul Rubens, Rembrandt van Rijn, Nicolas Poussin (creator of the "classical" landscape) and Claude Lorrain [27, 42].

nature [43]. A growing weariness with visual monotony and pomposity of geometric garden layouts surfaced in these contemplations (among other Joseph Addison and Francis Bacon) [42].

Landscape motifs were present at all times especially in Italian garden art, dating back to antiquity (e.g. Nero's gardens in Rome or Hardrian's Villa in Tivoli). Clear landscape themes appear in mannerist *Cinquecento* gardens (16th century) – as evidenced by gardens of Roman Montalto Villa (design. Domenico Fontana, 1590), with its poetic quality and picturesqueness and links with surroundings - foreshadowing the birth of the landscape style. Gardens showing clear influences of the new trends, championed among other by Alessandro Galiliei and Francesco Sanits, could already be seen in Italy in 18th century. These gardens used features taken from natural landscapes such as lakes, forests and meadows. Geometric shaping of trees and shrubs was also abandoned (popular *topiary* technique used for many years before) [27, 43]. Another factor which contributed to a change in how landscape was viewed and understood was an increased contact of Europe with Far East, especially with China. They resulted in great popularity of Asian culture and art, including naturalistic garden art [27, 43]. All this contributed to creation of an entirely different garden style - irregular, with a loose, **landscape like composition**. This new style has been taken on and beautifully developed by great English landscape architects – Alexander Pope, Charles Bridgeman, William Kent, Lancelot Brown [52]. Theoretical basis for creation of new landscaped gardens was prepared by Thomas Whately, William Chambers (Chinese garden enthusiast) and a leading theorist and designer of gardens – Humphrey Repton[10]. He was the first to introduce new concept of a **"*landscape garden*"** – and expansive area without clearly defined border (walls, fences), interconnected with surrounding landscape but at the same time constituting a synthesis of surrounding views. This landscape garden style popular all over the world in 18th and 19th centuries brought about a fashion for shaping the environment along naturalistic lines - using nature as inspiration.


A


B

Fig. 19. Examples of Polish 18th-century landscape parks:
A/ The Royal Łazienki, Warsaw (photo.: P. Wiśniewski, VIII 2017);
B/ Natolin Park, Warsaw (photo.: B. Fortuna-Antoszkiewicz, IV 2016)

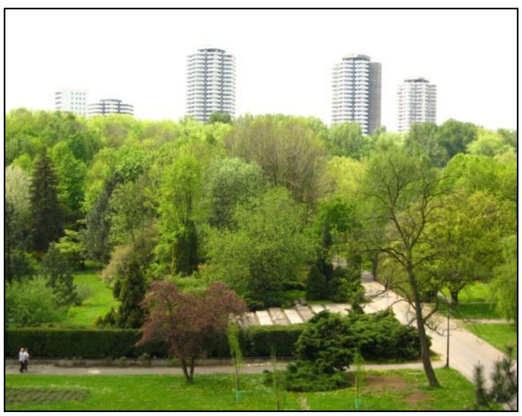
In Europe during the 18th century formal gardens existing to date have been adapted along the principles of this new style (in Poland e.g. *Puławy* of duchess Izabela Czartoryska, k. 18th century.; *Łańcut* of duchess Izabela Lubomirska, 2nd half of 18th century; Radziejowice of count Krasiński, 1817) while new gardens were built from scratch following this new innovative trend (in Poland e.g. *Royal Baths* of king Stanisław August in Warsaw, 1766 r.; *Arkadia* of duchess Helen Radziwiłłowa, 1778 r.; *Aleksandria* in Biała Cerkiew, established by count Branicki, 1784-1786; *Zofiówka* of duke Stanisław Szczęsny Potocki, 1796-1800) [42, 53] (fig. 19). The final form of the landscape style commonly known as **English style garden** relied on recreation of natural landscape, unique natural features and emphasising their untamed beauty. The difference relied only in the fact that terrain features and plant compositions formed expansive, sophisticated, scenes-images, a series of scenic views - inside the garden and of far, external vistas. Space in those new parks was formed to imitate natural landscape visually integrated into the garden.

[10] Author of: *Skeches and Hints on Lanscape Gardening* (1795), *Observations on the Theory and Practice of Landscape Gardening* (1803), *An Enquiry into the Changes of Taste in Landscape Gardening* (1806) [42], *Fragments on the Theory and Practice Landscape Gardening* (1816) [52].

Natural terrain features were used and emphasised as well as any water reservoirs - streams, rivers and ponds. Vegetation - the most important constituent of the composition - was given special attention. Existing vegetation was preserved while new artfully introduced vegetation was allowed to develop spontaneously. Artist's hand was to remain unseen[42, 53].

Park tree stands have been created using a rich palate of spatial forms - from dense massive compositions and clusters, through loose groves to separate forms (groups, clomps, flower-beds) and individual trees, exhibited against expansive, well-lit garden interiors. Skilful combination of such diversified elements allowed the designer to create sophisticated scenes clearly framed with formed tree stand. Even though the main goal of the garden composition was to create a picturesque scene and ensuring high aesthetic comfort the consequence of adopted solutions was a spatial systems which in contemporary terms may be described as providing highly comfortable bioclimate.

In Europe the landscape garden style became so prevalent that currently there is a great number of parks established in 18th and 19th century, but also in 20th century which build on and continue this tradition. In the latter one the achievements of the great forerunners are to an extent contradicted by new design trends (return to geometric spaces in modernist gardens), but acceptance of naturalistic forms, interwoven into park compositional structure is here to stay. An example of such eclectic design is Silesia Park in Poland (designed by prof. Władysław Niemirski with associates, established between 1953-1968). Here, in Chorzów in a centre of a massive Silesia conurbation (an industrial district) a lot of thought, efforts and assets were put into building the 600 hectare Park (fig. 20), the goal of which was to provide "recreational space for everyone" while ensuring comfortable bioclimactic conditions [30].


A


B

Fig. 20. Mature (60-year-old), varied stand, Silesia Park, Chorzów, Poland:
A/ General view;
B/ One of the park interiors, deep inside - rare and valuable Salix fragilis* 'Bullata' *(photo.: P. Wiśniewski, V 2014)

Such parks remain extremely popular not only due to their historical and aesthetic qualities, but also because the ensure exceptionally good conditions for recreation [28]. Many of them have been for years maintained in good condition (mainly in Western Europe), while some, due to region's history (WWII and following communist management, e.g. nationalisation of privately held lands, economic crisis of the 80ties, etc.), have survived but were left without intensive maintenance (mainly Central and Eastern Europe).

Authors of this publication by examining such a diverse European material heritage had the opportunity to observe and compare results of various methods of maintenance, protection and care of individual parks (fig. 21 - 25). Sites in the first group (parks maintained in a good condition) confirm principles shown above for shaping tree stands (in terms of consistent maintenance of diversified tree stands and ensuring comfortable conditions for recreation). Sites in the second group (neglected parks) allowed to trace changes e.g. results of secondary natural succession (blurring of the spatial compositions, spontaneous growth of plants), which in some cases may destabilise recreational bioclimate.

[Łukaszkiewicz, 5(12): December2018] ISSN 2348 – 8034
DOI- 10.5281/zenodo.2244458 Impact Factor- 5.070


A

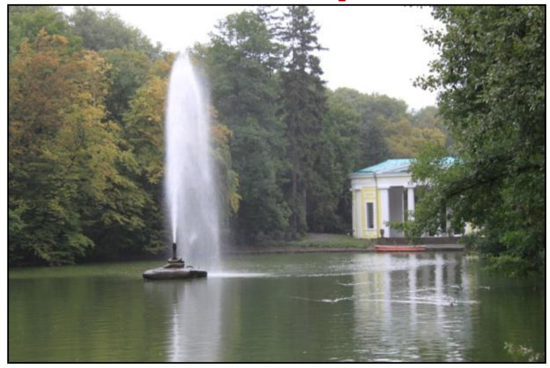

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Fig. 21. A dense park stand adjacent to the pond - restricts access to water, but at the same time - it emphasizes architecture, the scale of the interior, the values of space:
A/ Park Aleksandria in Biała Cerkiew, Ukraine;
B/ Park Zofiówka, Humań, Ukraine (photo.: P. Wiśniewski, IX 2013)


A


B

Fig. 22. Loose park stand adjacent to the pond - underlines the values of space (presence of water); water - exposes the richness of the tree stand:
A/ The Royal Botanic Gardens Kew, London, UK (photo: B. Fortuna-Antoszkiewicz, IV 2015);
B/ Park in Radziejowice, Poland (photo.: P. Wiśniewski, V 2016)


A


B

Fig. 23. Diversification of space (compact stand surrounding open, extensive interiors) and exposure of individual forms - valuable solitary trees:
A/ Park Aleksandria in Biała Cerkiew, Ukraine; (photo: P. Wiśniewski, IX 2013);
B/ Park in Radziejowice, Poland (photo.: P. Wiśniewski, IX 2014)

ISSN 2348 – 8034
Impact Factor- 5.070


A


B

Fig. 24. The vast open areas of the park allows the exposition of a separate spatial form (eg a group) and the variety of habits of trees:
A/ Fagus sylvatica L. *broadleaved trees, Mużakowski Park (Park von Muskau), Poland-Germany (photo.: B. Fortuna-Antoszkiewicz, May 2018);*
B/ Coniferous trees, Alexandria Park in Biała Cerkiew, Ukraine (photo.: P. Wiśniewski, IX 2013)


A


B


C


D

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Impact Factor- 5.070


E


F

Fig. 25. Attractive sceneries, distant views - obtained due to park stands with diversified structure:
A/ Park Mużakowski (Park von Muskau), Poland-Germany;
B/ The Royal Łazienki, Warsaw, Poland (photo.: P. Wiśniewski, VIII 2017);
C/ Westonbirt Arboretum, England (photo.: B. Fortuna-Antoszkiewicz, IV 2015);
D/ Natolin Park, Warsaw, Poland (photo: B. Fortuna-Antoszkiewicz, IV 2016);
E/ Borde Hill, West Sussex, UK (photo.: J. Łukaszkiewicz, IV 2015);
F/ Park in Branitz (1845-1871), Germany (photo.: B. Fortuna-Antoszkiewicz, V 2018)

Literature analysis and in-situ research results beg a question: whether shaping of tree stands in parks for recreational purposes threatens biodiversity? Quoted research [e.g. 5, 6, 9, 22] shows that park tree stands with less dense, non-schematic structure, formed towards achieving high recreational comfort at the same time are beneficial in terms of their expected environmental functions. Especially beneficial bioclimactic conditions and high biodiversity can be found in border zones of tree stands, the recreational resistance of which may be increased by skilful forming of spatial structure and species selection. [e.g. 9, 21]. In parks, the primary goal of **passive** protection of biodiversity may have **negative consequences**: maintaining tree stands of low environmental (too dense, with disturbed stability of overtly developed trees) and recreational value (unfavourable bioclimate), development of invasive species and no renewal of valuable ones, overgrowing of open spaces with meadows (park interiors), and blurring of the spatial composition created with recreational comfort in mind [30, 54] (fig. 26). Such conditions seem to require **balanced** transformation and maintenance of expansive park tree stands to preserve their desired form and condition both for recreation and for stimulation of biodiversity (fig. 27).


A


B

Fig. 26. Lack of control and maintenance of the park stand results in:
A / Degradation of tree stands (photo.: B. Fortuna-Antoszkiewicz, IV 2014);
B / Blurring spatial composition and the disappearance of open spaces; Silesia Park, Poland (photo.: P. Wiśniewski, V 2014)

ISSN 2348 – 8034
Impact Factor- 5.070


A

B

***Fig. 27. Constant monitoring and rational care are a prerequisite for proper maintenance of park stands:
A/ Park in Branitz, Germany - preservation of historical spatial composition (photo.: B. Fortuna-Antoszkiewicz, V 2018);
B/ Preservation of native plant communities (Ribeso nigri-Alnetum), Park in Radziejowice, Poland
(photo.: P. Wiśniewski, VIII 2015)***

VI. CONCLUSION

- If tree stands in large area parks (especially located in urban areas - sites of public recreation) are to fulfill the primary function of a park - recreation - they have to provide a favourable recreational bioclimate, which may be achieved only by **proper shaping** of tree stand structure.
- Stimulation of valuable, in the context of recreation, both living and inanimate matter (the impact of which can be seen not only within park's boundaries but also in its surroundings) relies to a great extent in maintaining park tree stand's **optimum structure** in terms of its spatial layout, species composition and age.
- Open tree stand with loose spacing and numerous openings, gaps and interiors - both historical (such as groves, landscape gardens) as well as contemporary (urban parks) creates **best bioclimactic / phytosanitary conditions** for recreation in term of daylight availability, temperature as well as movement, composition and humidity of atmospheric air.
- Every park has areas - fragments of the tree stand - best suited for transformation and shaping in order to recreate or maintain beneficial recreational bioclimate; this is especially true about **border zones**, which with proper maintenance may become perfect for intensive recreational activities outside of the dense tree stand.
- **Diversified structure** of the tree stand in a park - from open / loose (groves, gaps, openings, etc.) to dense, similar to that of a forest - provides users with more recreation locations (active or passive recreation - space for various games and entertainment), creates interesting scenic views and is more aesthetically pleasing (e.g. fully developed tree habits - typical for particular species or varieties, interesting tree compositions: individual trees, groups, clumps, clusters, etc.)
- Shaping of park tree stands in order to achieve high recreational comfort (introduction of an open structure) does not stand in contradiction with goals of **protecting the biodiversity** in a particular area (especially in urbanized areas) - on the contrary - it may even **stimulate** it (diversification of ecological niches, good phytosanitary condition of trees, control of expansive and invasive alien plant species, etc.)
- In parks, especially subject to strong anthropogenic pressure, maintaining optimum quality of tree stands (in terms of recreation comfort and maintaining true biodiversity) requires supporting activities such as **monitoring** of vegetation development and ensuring a rational and planned **maintenance** (long term maintenance schedules)

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 ISSN 2348 – 8034
Impact Factor- 5.070

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