Definitions and structural attributes of the ecosystems from natural forests – short review

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Abstract The most complex ecosystems, both by functional point of view and by complexity and the information offered, are the ecosystems found in the forests having a high degree of naturalness, the so-called „virgin forests”. These could be considered as true guides of sustainable management of the production forests. The first studies and research in the virgin forests of Europe were concentrated on the description of their structure. In all these early studies, the main objectives were to enrich the knowledge regarding the original structure of the natural forests. In the international literature, a large variety of attributes is used in order to characterise the structure of these forests.

Relatively recently, the interest in forest sustainable management in conjunction with biodiversity and nature conservation increased rapidly. A large number of scientific and research organizations emphasized the importance of unaltered regions and ecosystems from different parts of the world. Virgin forests, especially, had been given special attention. The high degree of biodiversity, the genetic variability potential, the naturalness and unicity of these areas were, also, subjects for political and public debates [14].

The indicators based on forest structure generate a considerable interest, both as practical substitutes for biodiversity (Uuttera et al. 2000, Lahde et al. 1999, Koop et al. 1994, Buongiorno et al. 1994) but also as a key for understanding the sources of biodiversity in forest ecosystems (Spies 1998, Franklin 1988, Franklin et al. 1981). A forest having a structural variability of its components is considered as capable of having a variety of resources and species which use these resources (Tanabe et al. 2001, Brokaw 1999, Pretzsch 1997, Williams et Woinarsi 1997). Consequently, there is frequently a positive relationship between biodiversity, variety and/or the complexity of the ensemble of structural components within the frame of an ecosystem (MacNally et al. 2001) [9].

Material and Method

The method of research consisted of collecting information, as exhaustive as possible, from as many sources possible. In this regard, they were used a number of papers and textbooks from the country and abroad dealing the issue of virgin forests or high degree of naturality forests.

Key words

Natural forests, structure, definitions

Results

a. The history of research regarding natural forest ecosystems

Some of the first papers dealing with natural forests was a description of the "Schattawa" virgin forest - Bohemia (Engler, 1904), and a report regarding the establishment of a forest reserve in Spessart, Germany, consisting of natural oak stands (Dingler, 1908) [14]. In Finland, research on forest unaffected by man began in the early 1900’s. Ilvessalo (1920, 1937) and Cajander (1926) did pioneering research especially regarding the structure, growth and productivity of the natural stands. In the same time, a large number of permanent sample plots were established and the measurements on them are undertaken even nowadays. Another approach regarding the research in forests undisturbed by man was to establish control surfaces within similar forest types, but subject to a forest management, in order to compare the results. This approach aimed to gain knowledge necessary to improve the existing silvicultural and management methods. This approach was undertaken in 1920 in Finland (Ilvessalo 1920) and in other European countries like Austria, Switzerland and Germany [14].

Morosow was the first scientist preoccupied to study the dynamics and development of forests, especially in the Boreal zone, since 1914. He is considered the founder of forest ecosystem research (Morosow, 1914 in: Ellenberg, 1973) [14].

The research activities in North America on virgin forests are, mostly, interdisciplinary. They are focused on soil research, studies of deadwood and other dead materials, and also aspects linked to zoology [14].
Leibundgut emphasized the necessity of virgin forests research after the Second World War. He promoted the importance of studying these natural ecosystems. As a result, in 1971 the IUFRO Workgroup on virgin forest research was founded, presided by Leibundgut. The main task of the Workgroup was to intensify the research on virgin forests and to promote this objective at global level.

The main criteria for examining natural stands were the following:

• Using permanent sample plots,
• The analysis of stand development stages,
• The description of the stands' structure [14].

In Romania, the scientific interest for the study of the virgin forests existed since the end of the XIX century, when the French forester G. Hüffel described the virgin forest „Pîscul Câinelu” from Sinaia Forest District, the same author describing the Romanian virgin forests in a French journal [8].

In 1911, P. Antonescu and A. Nedelcovici undertake an inventory of virgin forests from the Sinaia Forest District. Remarkable contributions were made by J. Fröhlich (1925, 1930, 1937, 1940, 1954). I. Popescu – Zeletin, L. Petrescu and M. Stănescu identify in 1943 and establish in 1949 five surfaces for the study of the dynamics of virgin forests in the South-Eastern Carpathians. C. Costea (1957) elaborates an analysis of the virgin forests located in the superior basin of the Prahova Valley. A detailed analysis of the structure of the beech virgin stands from the Făgărăș Mountains was published (various papers) by Leahu and Dîscu, while information regarding the structure and the regeneration of the beech virgin forests from Parâng Mountains can be found in the PhD thesis of D. Târziu. In 1989, V. Giurgiu studies the structural characteristics of the forests from Retenet National Park [8].

Smejkal et al. (1995) in the book “Pădurea seculară – Cercetări ecologice în Banat / Old-growth forest – Ecological research in Banat” show large amounts of data regarding the virgin forests from South-Western Romania. In 1999, C. Iacob analyses the structure and development stages of beech and fir quasi-virgin forests from Bucegi and Piatra Craiului Mountains [8]. Notable is the monograph “Pădurile virgine din România / The virgin forests of Romania” which presents the historical, taxonomical, ecological, dendrometrical and structural characteristics, including the description of 12 virgin forests considered representative for the [8].

b. Basic definitions of virgin, quasi-virgin and natural forests

In order to have a common basis for debate on natural forests, the terms and definitions must be described in an international context. The different historic development of forests, their use, the location and diversity of the forest ecosystems generate various national classifications [12].

The concept of "naturalness" refers to how natural is a forest. The naturalness of a forest ecosystem or of the vegetation can be defined as the extent to which the composition of species of the existing vegetation corresponds to the natural potential of the vegetation of the same site (Naturnähe Österreichischer Walder 1997). The term "hemeroby" is often used for the purpose of defining the degree of human influence on forests. The hemeroby includes all anthropogenic influences, such as management, impact of cattle grazing, of hunting, tourism and other types of human impact. The degree of naturalness can vary from “virgin forest” (extremely high degree of naturalness) to plantations of exotic species (extremely low degree of naturalness) [12].

"Virgin forest" could be defined as it follows: it has an original structure, it developed without being influenced by man, in natural conditions. Virgin forests do not limit themselves to the climax stage, although most of them are old forests. The term “primary forest” is often used alternately to the term “virgin forest” (Schuck et al. 1994) [12].

There are, also, other definitions for virgin forests. Fröhlich (1954) defined the virgin forest as “a forest composed by all diameter and age classes, which developed naturally, without the intervention of man and which was not systematically subject to forest management. Characteristic are the fallen trees (by wind, snow, old age or other causes), fallen on the ground, unusable, decaying”. [13].

Josef Fanta (Wageningen University, Holland) issued a definition relatively recently (2002) : „[The virgin forest is] a natural forest, where the species of trees and shrubs are in different stages of their life cycles (seedlings, young growth, advanced growth, maturity and old growth) and where dead wood (standing or laying) is in different stages of decay, thus resulting more or less complex vertical and horizontal structures, as a result of a dynamic process, which assures to the natural community of trees a continuous existence without a limit in time, on the specific territory. In the virgin forests, the own dynamics of the living systems is closely related to the ecological characteristics of the dominant tree species (including their longevity), to the impact of other organisms (for example, the insect attacks) and to the impact of the abiotic factors related to the soil, climate, the topographic complex and the level of waters (such as the floods, abundant snowfalls, windbreaks). One sequence of this dynamics is constituted by the temporary appearance of gaps, or even stages without trees on larger surfaces in the forest. Inside a specific phyto-geographical zone, the virgin forests are different, forming many specific types of forest communities with characteristic composition, spatial structure, dynamics and global diversity, determined by the altitude, topography, macro-climat, nutrients and water resources. Hereby,
the virgin forests reflect the natural harmony between the forest community and the abiotic conditions, perfectly consolidated during a millenary development, continuous from the Holocene Era” [13].

**Primary forests** are usually areas constituted by old forests which became virgin forests without human intervention (UNCED, 1992). A definition issued by Mayer and Brünig (1980) describes the primary forests as natural forests – having natural structure, lacking anthropogenic influences from the past to present, these forests being stated equally to virgin forests. Mayer and Brünig (1980) also describe secondary virgin forests. These are the forests being in a natural state (or almost natural) which do not show nowadays any obvious anthropic influence, or shows such influences at a minimum rate. Many times, this kind of forests developed from managed (cut) forests or grazed forests, but nowadays they show characteristics which are specific for the virgin forests (comparable to the natural forest). It is very important to take into account that the virgin forest term does not necessarily refer to the final development stage, but to all stages of development [14].

The term “forest unaffected by man” was especially recommended by FAO and the Ministerial Conference for the Portection of Forests in Europe MCPFE (1993) and this term is frequently used as a synonyme for “virgin forest”. The definition for the forest unaffected by man is still less restrictive than the definition for virgin forest. The “forest unaffected by man” is driven by natural forest dynamics, and the area is large enough to maintain the natural characteristics. More than that, there was no significant known human intervention, or the last human intervention was long enough ago to premit natural processes and species to re-establish [12].

Regarding the term “old-growth forest”, it was used mainly in North America and it mainly refers to the forests which are totally natural or remained unaltered by man for several hundred years (Dudley, 1992). According to Kaufmann et al. (1992), old-growth forests are defined as it follows: “distinct ecosystems consisting of old trees which show structural characteristics specific to the last developmental phases of stands and their successional development. These are different from the structure of stands in initial phases of development, also the composition and function are different” [14].

The term “natural forest” is quite controved and the definitions are based on diverse factors. “Natural forests” develop and regenerate by natural succesion, but they can show anthropic influences from the past (Schuck et al. 1994). The difference between “virgin forests” and “natural forests” consists of the human influences from the past. The term “natural forest” is much more relevant for the practice, because some types of human influences can be almost always found in the European forests [12].

Leibundgut (1987) defines natural forests as “forests which evolved as a sequence of natural succesion and which show, many times, anthropogenic influences from the past, or which developed on un-managed pastures or abandoned crop fields”. These characteristics establish a similar ground for virgin forests and secondary forests. Such types of forests are to be found in Finland, Russian Karelia and Central Sweden (Heiikinheim, 1915; Parviainen, 1993) [14].

Mayer and Brunig (1980) define the natural forests differently: “The development of forests is unaffected by human intervention; the structure of the forest is linked to the climax development stage, in the case when the natural development processes are not affected by natural catastrophic events such as fire, wind, snow or insect attacks”. This definition brings natural forests close to virgin forests by emphasizing the climax stage of the stand development [14].

"Ancient forests" and "semi-natural forests" are the terms most frequently used in the UK and sometimes they are found in the literature of other European countries. “Ancient forests” refer to the sites which were continuously covered by forests since a few centuries, or at least from the issue of the first map of the area. Some could be the remnants of the pre-historic forests, while others are secondary forests on lands where they were cut down at some point in the past (Peterken 1993, Forestry Commission, 1994) [12]. These forest could be more than 400 years old, but that doesn’t mean that the present trees are that old, even that is is possible (Peterken, 1987, Forestry Authority, 1994) [14].

"Semi-natural forests" are affected by human influences, but nor the composition and the structure were modified, directly or indirectly. The stands are composed mainly by native species of trees, with local origin. They are the result of natural regeneration, or of the sylvicultural systems applied, in some cases even originating in plantations (Schuck et al. 1994; Forestry Commission, 1994) [12]. The term "semi-natural forest" was first used by Tansley (1939) and it was incorporated in the specialized literature from other countries because almost all European forests were managed at some extent in the last centuries [14]. The Wilderness Society from the United States used and reshaped the definitions described above for its own studies. They defined 20 categories of forests, clustered in 3 main groups (Morrison, 1991):

- "classical" old-growth forests
- "early" old-growth forests
- "mature" stands [14].

Virgin forests and natural forests are important remnants of rare and valuable forest ecosystems. They constitute a base for “close-to-nature” silvicultural research and applications, and for the planning of the national network of protected forests. It is generally accepted that natural forests are a basic model for implementing close-to-nature forestry. In strict forest reserves, following the way how natural forests
develop and evolve can be observed, elucidated and analyzed, and the further results can be “imitated” in multifunctional forests. The management of forests is generally based on a combination of information obtained through research on natural forests and from silvicultural experiments in conventional forest areas (Schutz 1992; Parviainen et al. 2000b) [12].

c. Characteristics of natural forest ecosystems

Ecosystems are frequently characterized in terms of species and genetic composition (Hunter 1999), even though this approach ignores the ecological processes (e.g. natural disturbances, decomposing woody debris, nutrients’ cycles, etc.), which are critical for maintaining biodiversity (Noss 1990). An alternative approach, suggested for the first time more than two decades ago (Franklin et al. 1981) is to describe the forest ecosystems by their characteristics that refer to their structure and function, in contrast with only describing their composition (Franklin et al. 2002, Noss 1990, Franklin 1988) [9].

Virgin and quasi-virgin forest has the following structural characteristics:
- it has a large volume of biomass;
- there are present exemplars having large dimensions, also with old ages, exemplars that can reach the maximum potential of development for the species;
- large amounts of deadwood in various stages of decomposition are present;
- the structure is heterogeneous, with a mosaic-based repartition of components [13].

The structural attributes. functional attributes and the composition of the stand are often inter-dependent, such that the attributes of one group could be also a surrogate for the attributes of another group (Franklin et al. 2002, Ferris and Humphrey 1999, Noss 1990). For instance, a structural attribute such as deadwood could be a good functional indicator for decomposition and cyclic nutrients processes [9]. Deadwood, originating from trees which finished their natural life cycle, has become the main indicator for including a stand in one category or another. Trees are in this case umbrella species, their high longevity giving them this attribute. Building a structural complexity index implies taking a decision about the type and number of attributes necessary to be used and their share for computing the index. In order to emphasize the way that this can be done, there is need to:
- Identify the range of attributes, at stand level, which were used to describe the biodiversity;
- Analyze the existing structural complexity indexes [9].

A large variety of attributes is used in the international literature for characterizing the structure of the stand.

- The trees’ diameters

The diameter is the most common measurement of the trees’ dimensions which is described in the scientific literature for characterizing a forest. It is usually quantified in terms of: diameter at 1.3 m, standard deviation of diameter at 1.3 m and the number of trees larger than a certain threshold of diameter (the number of large trees) [9].

The diameter increases by stand age and can be used to differentiate the successional stages in broadleaved forests, or to highlight the differences between managed forests and virgin forests or those having a high degree of naturalness [9].

The basal area of the stand is an attribute directly dependent on the diameter at 1.3 m. It is also an indicator for the volume and biomass of the stand. The standard deviation of the trees’ diameters is an indicator of the variability of the trees’ dimensions and it is considered as an indicator of diversity of the microhabitats from a certain stand (Acker et al. 1998, Van Den Meerschaut and Vandekerkhove 1998). It is a simple attribute which helps quantifying and permits comparisons to other attributes and complex indexes such as structural descriptors of the stands’ structure (Neumann and Starlinger 2001). Zenner (2000) discovered that the structural complexity index based on a tridimensional model of the forest was significantly correlated with the standard deviation of the diameter, and Neumann e al. (2001) observed that the standard deviation of the diameter was significantly correlated with the tested 7 indexes of structural complexity [9].

The number of large trees indicates the potential number of hollow trees and of fallen trees, all of them providing important habitats for Arthropods, birds and mammals (Acker et al. 1998). The large trees were also associated with 4 distinct key structural attributes:
1. Old trees of large dimensions having the diameter > 100 cm;
2. Standing dead large trees;
3. Fallen dead large trees;
4. Decomposing large dead logs [9].

The threshold used to define a large tree varies within different studies, from diameter > 70 cm in Tyrrell and Crow (1994) to diameter > 100 cm in Spies and Franklin (1991). The ecological bases for these thresholds are not clear, although they reflect only the potential of growth within a time interval necessary for an individual tree to grow, become mature and then old; this indicator doesn’t show the degree of how trees finished their natural life cycle [9].

One of the disadvantages in using the diameters’ distribution as a structural attribute of the forest is the complexity of comparing the distributions from different stands. Many authors used consequently the Shannon-Weiner index in order to describe the diameters’ distribution from one stand using one index (H’), where $H' = -\sum (pi \times \ln(pi))$ where $pi$ is the proportion of trees from diameter class $i$ (Wikstrom
and Erickson 2000, Gove 1996, Buongiorno et al. 1994). This measure permits direct comparisons between diameters’ distributions and offers also a simple attribute which can be modelled under different management strategies [9]. Likewise, it is a proven fact that in natural forest, considering the trees from the lower canopy, the diameter distribution is not positively correlated to tree age.

- **The trees’ heights**

The quantitative relationships between the height and the diameter of the trees are well established in the literature (Martin and Flewelling 1998), so that to some extent, the structural attributes associated to diameter are strongly related to the attributes associated to tree height (Buongiorno et al. 1994). Even though, because the relationship between height and diameter is not a linear one, often it is recommended to use attributes directly associated to height when the elements of vertical structure are described. For instance, the standard deviation of the trees’ heights will be more useful in describing the vertical stratification of the crowns than the standard deviation of diameters (Zenner 2000) [9].

The simplest attribute associated to height is the height of the dominant layer. It is an easy to obtain attribute, especially using remote sensing (Bebi et al. 2001), and which indicates the successional stages (Kappelle et al. 1996), the number of layers present within a stand (Spies 1998) and the biomass of the stand (Means et al 1999). [9].

The variation in height of the trees is considered an important attribute of the structure, because the stands contain a variety of trees of different heights, a variety of trees of different ages and different species, which offers a large diversity of micro-habitats for the wildlife (Zenner 2000). Sullivan et al. (2001) quantified this type of variation using a simple term called „the structural richness“, which is based on a number of classes of tree height from a certain stand [9].

Zenner (2000), Svensson and Jeglum (2001) indicate that the variation in height of the trees is much more complex than the structural richness, because it is depending on the horizontal distribution of the trees, equally as their height. Consequently, Zenner (2000) used a tridimensional model of trees’ positioning in order to describe the variation in height of the trees using a structural diversity index [9].

- **The canopy closure**

Contrasting to Zenner’s (2000) approach, a series of other authors used the horizontal distribution of trees as an independent structural attribute. The eaisiest way to do this is to use the number of trees per hectare as a measure of the mean distance between individual trees [9].

A more complex approach is to describe the canopy closure in terms of variation more than in dimensional terms. This is probably more significant because it shows the size and distribution of the gaps from the canopy, which are critical to some processes like regeneration, competition and mortality (Svensson and Jeglum 2001). Usually, the variation of canopy closure is described by an aggregation index which quantifies the degree of grouping within the horizontal distribution of trees (Neumann and Starlinger 2001) [9].

A commonly used index for this purpose is the Evans Clark aggregation index (Pretzsch 1997). This index describes the proportion between the mean observed distance from a tree to the closest neighbour and de expected mean distance from a random distribution of trees. The values of aggregation smaller than 1 indicate a tendency for grouping, values close to 1 indicate a random distribution and values larger than 1 indicate a more and more regular distribution (Clark and Evans 1954). The main problem with applying this index is that it requires that the distance to the closest neighbour must be determined for each tree within the sample plot [9].

The Cox aggregation index approaches this problem by quantifying the variance as proportion of the trees from equal sub-plots, more likely than using the closest distances between neighbours (Cox 1971 cited by Neumann et al. 2001). A variation through which the proportion has teh value 1 indicates a random distribution, values bellow 1 indicate a regular distribution and values higher than 1 indicate a distribution with tendencies of grouping [9].

- **The species of trees**

Many of the attributes previously described could be linked to some degree to the presence of a variety of trees species. For instance, the presence of a mix of tree species, shade tolerant or intolerant, could develop a multi-layered canopy, a large variety of diameters and heights of the tree stems, but also a complex horizontal distribution of the stems (Spies and Franklin 1991). Consequently, it is not surprising that the literature shows a number of studies where the measurement of tree species richness and/or their diversity were used to characterize the stand structure (Sullivan et al. 2001, Maltamo 1997, Uuttera et al. 1997) [9].

Species richness and diversity are very important attributes of the tropical forests, in some cases there are more important (could be used to distinguish between primary and secondary forests) than other attributes, like the diameter and the average number of trees (Uuttera et al. 2000, Ferreira et al. 1999). This contrasts with the situation in some temperate forests, where the relative abundance of the key tree species or of the groups of species is more important than the richness of species that can be distinguished in the
successional stages. Spies and Franklin (1991) observed that the density of the tree species which are not shade tolerant was the most significant variable in a multiple regression referring to the age of the stand for a series of structural attributes [9].

- The regeneration

The regeneration process in virgin forests is periodical and discontinuous, due to the periodicity of the trees’ fructification, but also due the development stages of the stands. The stands having an absolute uneven aged structure, where trees of all ages do really exist in the stand, are rare and isolated cases. Usually, the stands are constituted by trees from a few generations, which appeared due to successive fructifications of the mature stand living its desaggregation / regeneration stages or, on smaller surfaces, due to the occurrence of canopy gaps [8].

The regeneration could be uniform only in the case of catastrophies which destroy the mature stand; these appear though only in the case of anemochore species, like spruce, pine, larch, which can re-occupy the affected surface very easily. In other cases, when the regeneration of the original species doesn’t happen immediately, longer successions could appear, having successional phases based on pioneer species. In the typical mixed virgin forests, alternations could appear between the species (local reversible successions) [8].

- The deadwood

In contrast to the elements of the lower stand canopy, deadwood appears in the specialized literature like a structural element comparable as importance to the trees from the upper canopy. Franklin et al. conclude that „at large extent, the success in managing the old-growth forests depends on learning to manage the dead organic material (stumps, logs and litter) in a suc intelligent way as the management of the living trees”. They assigned to the distinctive characteristics of the old-growth forests four structural elements, from which 3 linked to the deadwood as:
- standing large dead trees;
- large logs fallen on the ground;
- decomposed large logs [9].

These elements proved that they can play a key role in providing habitats for the fauna of the forest.

Standing dead trees

The importance of standing dead trees as a structural attribute was confirmed in many studies within a large variety of forest types (Bachofen and Zingg 2001, Svvensson and Jeglum 2001, Sullivan et al. 2001, Van Den Meersschaut and Vandekerkhove 1998, Tyrell and Crow 1994, Spies and Franklin 1991). Nevertheless, there is a weak consensus about the way that standing dead trees must be quantified. Franklin et al. (1981) quantified the standing dead trees from old-growth forests in terms of number per hectare and diameter at 1.3 m and described them, but they didn’t apply the system of classification using 5 decomposition classes, suggested by Cline (1980). Franklin et al. (1981) considered the decomposition classes to be an important attribute, because different vertebrate species use deadwood from different decomposition classes [9].

Subsequently, Spies and Franklin (1991) used a more elaborate set of attributes to describe the standing deadwood. These descriptions included the number of standing dead trees per hectare using two height classes and two diameter classes, the volume using 5 decomposition classes, the total volume and the coefficient of variation (CV) of the total volume [9].

Tyrell and Crow (1994) also quantified in detail the deadwood. They described the species, the diameter at 1.3 m, 4 height classes, 3 decomposition classes, basal area and total volume. The most useful of these attributes was the basal area, which linearly increased by the increase of the stand age. Van Den Meersschaut and Vandekerkhove (1998) evaluated the standing deadwood using 3 simple attributes:
- Basal area – for indicating the volume of deadwood;
- Number of standing large dead trees (diameter > 40 cm) – to indicate the potential of hollows;
- The standard deviation of the diameter – in order to indicate the variation of deadwood dimensions and to associate the hollows with the fauna diversity [9].

Fallen logs

The standing dead trees are a primary source of logs, so that at some extent, the indicators which quantify the standing deadwood could be also indicators for the potential source of logs. Nevertheless, a series of studies which quantified the deadwood treated the logs separately from the standing dead trees. For this purpose they were used a large variety of attributes, including the total volume of the logs, the volume or the density of the logs by diameter classes and decomposition classes, and the coefficients of variation of these attributes (e.g. Tyrell and Crow 1994, Spies and Franklin 1991). The most useful of these seem to be the attributes which describe the abundance of large logs and the variation of the number and size of the logs [9].

Conclusions

Even though in the last years significant progress was made, the results of research undertaken in virgin forests are still insufficient to be used as model for a forestry system close to the laws of nature, having an increased level of biodiversity. The study of the structural characteristics is considered appropriate and very important not only to improve and elaborate new silvicultural methods (such as “close-to-nature” forestry) but also to understand the structure and functioning of the virgin ecosystems, aiming to
elucidate the mechanisms and internal laws of the living world. The structural complexity of the stand is expressed by the number of different attributes and the relative abundance of each of them within a given stand. The structural complexity implies the interaction of different attributes, so that making quantitative comparisons between stands could require a complex multivariate analysis. As an answer to this problem, they were compiled a variety of indexes, strictly aiming at the structural complexity and facilitating such comparisons between stands.

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