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Review

Experience of Forest Ecological Classification in Assessment of Vegetation Dynamics

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Abstract: Due to global climate change and increased forest transformation by humans, accounting for the dynamics of forest ecosystems is becoming a central problem in forestry. We reviewed the success of considering vegetation dynamics in the most influential ecological forest classifications in Russia, the European Union, and North America. Out of the variety of approaches to forest classification, only those that are widely used in forestry and forest inventory were selected. It was found that the system of diagnostic signs developed by genetic forest typology based on the time-stable characteristics of habitats as well as the developed concept of dynamic series of cenosis formation allows us to successfully take into account the dynamics of vegetation. While forest dynamics in European classifications is assessed at a theoretical level, it is also possible to assess forest dynamics in practice due to information obtained from EUNIS habitat classification. In ecological classifications in North America, the problem of vegetation dynamics is most fully solved with ecological site description (ESD), which includes potential vegetation and disturbance factors in the classification features. In habitat type classification (HTC) and biogeoclimatic ecosystem classification (BEC), vegetation dynamics is accounted based on testing the diagnostic species and other signs of potential vegetation for resistance to natural and anthropogenic disturbances. Understanding of vegetation–environment associations is fundamental in forming proper forest management methods and improving existing classification structures. We believe that this topic is relevant as part of the ongoing search for new solutions within all significant forest ecological classifications.

Keywords: forest dynamics; forest ecological classification; Russia; European Union; North America

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1. Introduction

To understand the topical biospheric role of forests, e.g., carbon deposition, climate buffering, and water/erosion control, more intensive research is necessary. At the same time, the ability to obtain large amounts of data on forests (including remote sensing) creates new opportunities for not only classification and monitoring of natural/altered habitats but also for their management [1–3]. However, the amount of new quality data creates a new issue of structuring and analyzing the data. New data opportunities derived from available data sources, such as GIS and forest inventories, along with new hardware and software that create a new level of quality in analyzing data, demand a revision of traditional concepts and forest science theories to potentially develop new insights into methods of forest ecosystem classification and monitoring [4,5]. This includes searching for measures aimed at increasing management efficiency under conditions of climate change and anthropogenic pressure on forests, considering achievements of various forest ecological classification schools in the area of vegetation dynamics, and revealing strengths and weaknesses of the different approaches. The most intensive development in the forest classification field in the Northern Hemisphere occurred from the end of 19th century to almost the end of the 21st century. Forest classification/typology schools were formed as a result of ecological research [6–11].

The experience of creating a unified European classification of forest types is extremely interesting for world forest science [8]. The joint efforts of many specialists from different scientific fields have made it possible to link the European forest types (EFT), European Nature Information System (EUNIS), and European vegetation classification (EVC). The successful implementation of these classifications is a good example of mutual complementation, detailing, and generalization of classifications of plant communities and habitats. These classifications are currently being successfully used, and their experience is important for sustainable forest management.

The experience of the Russian forest typology is no less interesting and useful [5,12]. Ecological–silvicultural classification, phytocoenotic forest typology, genetic forest typology, and dynamic forest typology are actively used in modern forestry in the Russian Federation. All of these classifications are based on the ideas of Krudener [13] and Morozov [14] and were developed in parallel in various regions of Russia. The phytocoenotic forest typology by Sukachev was developed to classify primary forests [15]. This typology is based on the concept of biogeocenosis. It is assumed that the type of forest is not only the composition and structure of vegetation but also a certain structure of relationships between plants, animals, and their habitat. Ecological–silvicultural classification was formed in Ukraine and in the southern regions of the Russian Federation [16]. The genetic forest typology was developed from the study of exceptionally complex forests of the Far East with a dynamic cycle of about 2000 years [17,18]. Individual age stages of the 2000-year cycle of Far Eastern forests differ sharply in composition and structure of tree stand and subordinate plant layers. The phytocoenotic forest typology turned out to be unsuitable for the Far East. The dynamic forest typology is aimed at classifying the initial stages of forest successions. This typology originated from the study and classification of vegetation of Russian northern territories [19,20], which are distinguished by a simple structure and clear dependency of vegetation on the habitat.

In different regions of the United States of America and Canada, the following classifications of habitats and forest types have become the most widespread: habitat type classification (HTC) [7], biogeoclimatic ecosystem classification (BEC) [6], and ecological site description (ESDs) [7]. Habitat type classification was developed based on the study of the northern part of Idaho and the eastern part of Washington State [7]. It is based on the concept of potential vegetation. Biogeoclimatic ecosystem classification was developed by Krajina [6,21] after studying complex mountainous landscapes of British Columbia (Canada) and has been successfully used as a basis for environmental management and wildlife protection in this region since the early 1970s [22]. Vegetation description and classification is performed using the Braun–Blanquet approach and nomenclature [23,24] combined with elements of landscape ecology and the climax concept by Clements [25]. BEC was developed using the biogeocenosis concept by Sukachev [15] and edatopic grid by Pogrebnyak [16]. Ecological site description or the ESD classification is widely used in Western USA. Key publications describing this approach include the Interagency Ecological Site Handbook for Rangelands [9], National Ecological Site Handbook [26], and several technical guides [27,28]. Initially, the approach was used to classify pasture sites using soil and vegetation descriptions. Later, the classification also included forests.

Thus, forest ecological classifications utilize various approaches and methods with specific development and unique practices in different fields, including vegetation dynamics. Nowadays, due to global climate change and increased anthropogenic-driven transformation of forests, accounting for forest ecosystem dynamics is recognized among key problems of forest management [3,29].

This review is devoted to the study of the peculiarities of accounting for vegetation dynamics in various forest ecological classifications in the Northern Hemisphere. The aim is to (i) review the experience of vegetation dynamics in classification of forest types in Russia, the European Union, and North America and (ii) analyze the potential of the classifications for ensuring ecological stability and sustainable utilization of forests.

2. Russian Forest Ecological Classification

Accounting for the dynamics of the forest community is a key issue for all modern Russian ecological classification [5]. Natural classifications, including ones based on forest ecology and concepts of Sukachev's biogeocenosis, consider forest type from the point of view of spatial homogeneity of the characteristics (composition and structure) displayed by forest community components [15,16]. For these approaches, the forest type includes sites that are uniform in terms of characteristics (composition and structure), so the forest type is determined on the basis of the forest site spatial uniformity criteria [5,12]. In genetic classifications, the spatial uniformity criteria for forest sites are replaced with criteria that determine similarity in genesis, dynamics, and development (i.e., temporal uniformity) [5,30,31] (Table 1).

Table 1. Assessment of vegetation dynamics in Russian forest ecological classification.

Forest Ecological Classification	Assessment Specifics
Ecological–silvicultural classification	Initially based on abstract terms. Later, attempts were made to consider succession dynamics in classification patterns.
Phytocoenotic forest typology	At the level of abstract terms (classification schemes have features for forecasting changes of tree strata based on renewal data).
Dynamic forest typology	Cutting and burnt area typology was developed as a stage of restoration dynamics preceding forest type formation, with the ability to assess forest type transition included in the theory. Typology was initially developed for northern regions. When it was reapplied to southern taiga, mixed, and hardwood forests, it became more similar to genetic forest typology.
Genetic forest typology	Both theoretical terms and classifications. Age and restoration dynamics are presented using a series of possible biogeocenoses types that replace each other under certain forestation conditions. The classification patterns were developed for logging site type and formation series of biogeocenoses. Several patterns were proposed to be applied in forestry management.

In genetic typologies, the forest type is selected based on the range of forest and vegetation conditions, including the following parameters: relief, illumination, physical and chemical properties of bedrock soils, water regime, and water and mineral feed of the plants. Therefore, the series of biogeocenosis development within similar forest and vegetation conditions refer to a single forest type, which is the stage of forest genesis described within a generic approach [18,31].

In order to assess forest dynamics that occur during forest use, both genetic and dynamic forest typologies form a hypothesis on multiple forest succession dynamic lines in similar habitats [11,32–36]. A number of terms have been introduced in forestry-related literature, such as "development type", "reafforestation directions", "silviculture restoration and development series", "ecodynamic series", "logging category", "variant of a logging type", "restoration type", and "type of silviculture formation" [11,34–36].

The following key factors have been noted to determine forest vegetation formation type and increase chances of replacing edificator plants: amount and viability of previously generated undergrowth, availability of seeding sources in the openings, and structure of herb and shrub layer [11,35,36]. For example, for each forest type present in the drained soils of Kola Peninsula, five ecodynamic series were formulated [37]: 1—from previously generated undergrowth; 2—resulting from mixed forest restoration at logging sites with well-developed soil cover and sources of coniferous tree seeds; 3—resulting from mixed forest restoration at logging sites with well-developed soil cover lacking sources of coniferous tree seeds; 4—following restoration of burnt sites provided with seed sources for coniferous trees; and 5—following restoration of burnt sites without seed sources for coniferous trees. These types of forest vegetation formation differ in terms of restoration intensity, trends in forming tree stratum, transformation sequences for structure and composition of forest stand, and other layers of forest biogeocenoses, thus requiring different forest management scenarios.

A similar pattern for divergence of forest vegetation dynamics series of the Urals was described by Sannikov [34,35]. This pattern illustrated dependence of succession directions upon the type and intensity of destructive impact (fire, windfall, or logging), soil substrate type (undamaged, burnt, and mechanically "mineralized"), and presence or lack of seeds and undergrowth of coniferous trees in gaps. The stages and phases of age and restoration dynamics for tree stands and classification criteria for spruce and Siberian cedar forests were described in detail by Smolonogov [38].

Our special research has revealed that logging and wildfires result in many plant communities within the same habitat (one type of indigenous forests) [39]. For many years, these ecosystems differ dramatically in the structure of all vegetation layers. They also differ in direction and intensity of reforestation. The photos taken by us clearly show the qualitative differences between forest communities of various dynamic series (after logging and wildfires) (Figures 1–3). Such an understanding of the forest type (as aggregates of forest communities of all successional stages of dynamic series) is crucial to forest management of modern ecosystems under anthropogenic impact and climate change [39].

Figure 1. Primary forest type: herb and moss spruce forest type according to Kolesnikov [40] in the Ural Mountains (the stand age is 180 years). Photo by Natalya Ivanova.

The use of genetic typology approaches for vegetation classifications reveal similarities between ecodynamic series with the same names in different growth conditions, which support the hypothesis concerning convergence of dynamic series [37]. At the same time, secondary plant communities growing in quite different conditions and derived from different primary coniferous forests display substantial physiognomic similarity [37,41], which is supported by works of Degteva [42] on typology of secondary plant communities in Komi taiga forests, where the author revealed specifics of changes in species and structure of edificatory and subordinate layers. On the other hand, results of detailed quantitative studies also demonstrate the occurrence of convergence in primary forests. For example, bilberry spruce forests have a wide ecological amplitude, but restoration series occur differently depending on differences between forest vegetation conditions and only similarities are displayed for primary forests [33]. This fact demonstrates that vegetation features alone are not enough for classification of forest types. Due to this fact, research on convergence and divergence is important [37] and requires improvement in classification of the initial restoration stages, including logging, burns, windfalls, etc.

Figure 2. Reforestation after timber harvesting in herb and moss spruce forest type in the Ural Mountains (Russia) (the age of timber harvesting is 70 years old). Photo by Natalya Ivanova.

Figure 3. Reforestation after wildfires in herb and moss spruce forest type in the Ural Mountains (Russia) (the age of timber harvesting is 70 years old). Photo by Natalya Ivanova.

The abovementioned problem was resolved in genetic and dynamic typologies that include continuously developing classification schemes for the types of logging and burn sides [17,19,20,32,43,44].

3. European Forest Ecological Classification

3.1. European Forest Types

In 2006, a consortium of international experts presented the results of a research on the types of European forests as a white paper [8] for MCPFE (Ministerial Conference on the Protection of Forests in Europe). The white paper included the so-called EFT classification, which was developed using sustainable forest management indicators. In EFT, assessment of succession dynamics for forest biogeocenoses was developed theoretically, and its practical assessment is implemented using data obtained from EUNIS (European Nature Information System) by mapping the forest types in EFT with data on habitats in EUNIS [45]. EFT has an advantage of including anthropogenic impacts into key diagnostical characteristics of a forest type, which describes the degree of forest naturality (Table 2).

Table 2. Assessment of vegetation dynamics in European forest ecological classification.

Forest Ecological Classification	Assessment Specifics
European forest types	Mainly theoretical. In some cases, assessment of succession dynamics is possible using data from EUNIS classification. Assessment of anthropogenic-driven transformations is among the key parameters that describe forest naturality. The results are used to determine forest categories and types. Short description of key anthropogenic impacts is provided for forest types. The classification accounts for invasive species.
European vegetation classification	Vegetation dynamics assessment is based on the idea of dynamic combination of species within a community. This principle is applied for developing spatial and time-based dependencies, scale-based dependency analysis methods, and the synphytoindication method. The classification introduces sigmetum as a succession system, which is a combination of climax vegetation type and all secondary communities representing stage successions. The classification accounts for invasive species.

This indicator is implemented using assessment of the forest species number, type and intensity of anthropogenic impact, and brief description of key anthropogenic impacts [8]. Specialized assessment demonstrates that it is possible to use EFT for interpreting dynamics of forest expansion and reduction, including forests with presence (or prevalence) of introduced species, dynamics of the share of old forests, and deadwood accumulation dynamics [46]. Assessment of forest conditions and consideration of geographical principle connects EFT with genetic forest topology. However, there is no complete similarity. The forest type in EFT is a larger unit of vegetation cover compared to the Russian genetic forest topology (and, of course, natural Russian classifications). To a lesser degree, EFT also accounts for forest restoration specifics after catastrophic impacts.

3.2. European Vegetation Classification

In 2002, a group of European scientists presented a review of phytosociological alliances (European vegetation classification) [47] used as a basis for unified syntaxonomic systems of the EuroVegChecklist (EVC) [10]. The classification was considered by authors to be an intermediary link between EUNIS and international scientific ecological and floristic research [48–51]. An alliance is a moderately broad vegetation unit that either has one or several absolute character taxa or that can be interpreted as the central alliance of an order [52]. The use of the strengths of the Braun–Blanquet approach allows detailed ecological analysis of plant communities within European vegetation classification to be performed in order to draw conclusions about successions [48].

Vegetation dynamic assessment is based on the idea of dynamic combination of species within a community. This principle is applied for developing spatial and time-based dependencies and scale-based dependency analysis methods [53]. Thus, for example, results of a research performed in the coastal woods of Poland allowed selection of eight uniform groups of rare species, reflecting the complexity and dynamics of shore zones [54].

The synphytoindication method [55] was designed to forecast the dynamics of forest species and types based on the impact intensity of environmental factors. The method is based on a wide range of front edge mathematical methods for data analysis, thereby allowing quantitative assessment of habitat parameters, including climate factors, based on the ecological specifics of plant species. For example, it was found that an increase in annual average temperatures of 1–3° starts succession processes, including changes in species and forest types [55].

Significant advantages of EVC include introduction of sigmetum, defined as a succession system that combines a climax vegetation type with all secondary communities that are formed later as part of successions [48]. Research on succession systems is well represented in publications [56–58]. For example, detailed characteristics of succession systems were determined for bilberry spruce forests of a middle-taiga subzone of North Eastern European Russia [56]. The use of a floristic approach in that research not only revealed the extinction and reappearance of certain species at different succession stages but also assessed the time necessary for restoration of floristic composition [56]. Examples of in-depth succession systems also include research performed in the Tula region of Russia [58]. This study included assessment of plant species diversity with regard to restorative succession gradient, with the ratio of natural to synanthropic plant species diversity serving as a succession status indicator.

It is also necessary to note that assessment of impacts for invasive species used in both EFT and EVC allows the dynamics of plant communities to be judged and is widely used in research [47,59,60].

4. North American Forest Ecological Classifications

4.1. Habitat Type Classification

Based on the concept of potential vegetation, Daubenmire in 1952 suggested a habitat type classification (HTC) system to be applied in northern Idaho and eastern Washington [7]. The habitat type aspect in HTC is close to the forest type interpretation in Russian genetic classifications by Ivashkevich, Kolesnikov [18], and Melehov [19,20], while the characteristics of vegetative cover and soils are close to those suggested by Sukachev [15]. HTC is supplemented with description of successions and anthropogenic transformations in order to account for plant dynamics. The main task for researchers while developing the classification was to determine potential vegetation. Comparison of actual and potential vegetation is a key aspect for description and research of successions in HTC, revealing the stability and variability of various characteristics for different types and intensity levels of disturbances. This approach has certain advantages for assessing successions and anthropogenic transformations in classifications compared to typologies based on classifications of actual vegetation as the deviation of the structure of actual plant communities from the structure of potential forests allows assessment of the level of ecosystem transformation (Table 3).

Table 3. Assessment of vegetation dynamics in North American forest ecological classification.

Forest Ecological Classification	Assessment Specifics
Habitat type classification	Represents general descriptions of plant community types that reflect succession dynamics of vegetation cover that occur in course of natural disturbances. Some classification variants can be supplemented with succession descriptions. Typology is based on the potential (climax) vegetation. Comparison of actual and potential vegetation allows alternative patterns to be described.
Biogeoclimatic ecosystem classification	The classification unit cypher allows description of potential vegetation, stage of actual vegetation dynamics, and also type and intensity of anthropogenic impact.
Ecological site description	The classification represents dynamics of plant communities and accounts for different variants of vegetation status on site. Disturbances that cause transitions from one state to another are described by state and transition models. Transitions can be initiated by natural disasters (such as fires) and economic activities (cattle grazing, fighting fires, recreation, or logging). Anthropogenic factors causing community transitions from one state to another are included in transition descriptions.

4.2. Biogeoclimatic Ecosystem Classification

The biogeoclimatic ecosystem classification system was developed in a way users can classify a site using key characteristics of diagnostic species and soil properties independently of successional stages [22]. In order to do that, diagnostic species and other characteristics are tested for stability against natural disturbances and anthropogenic impacts. Indicator species are specially identified for each zone by calculating the indicator value index (including corrections for unequal size of the groups) [61]. Special “indicspecies” software package for R was developed to analyze indicator capabilities of species [62]. It is possible to assess ecosystem structure transformation or restoration after natural or anthropogenic impacts by analyzing species and other characteristics with different resistivity against impacts. For example, analysis of species diversity in course of successions allows assessment of transformation and determination of the duration of ecosystem restoration to the floristic composition that is typical for a certain biogeoclimatic zone [63].

4.3. Ecological Site Description

Succession dynamics in ESD are represented as dynamics of plant community phases and include different variants of vegetation conditions on-site. Disturbances that cause transitions from one state to another are described by state and transition models (STM) [64,65]. STMs synthesize data on a possible spectrum of ecosystem conditions and analyze reasons and conditions of transitioning from one state to another depending on climatic zone (subzone), position on a landscape, soil conditions, and plant community formation history [65]. STMs combined with plant community parameters allow forecast of the ecosystem stability and reveal thresholds for factors that cause transitions [64,66]. Transitions can be initiated by natural disasters (fires) or economic activities, including cattle grazing, fighting fires, recreation, or logging. A substantial advantage of the method is inclusion of anthropogenic factors that cause transitions from one state to another into classification. All of the above allows ESD to be used for interpreting landscape potential as a whole and increases chances of making successful decisions in the field of managing natural resources [67]. There are examples of including alpha- and beta-diversity characteristics in state and transition models of ESD [67]. This increases ESD value for preservation of biological diversity and environmental protection in general.

Advantages of ESD also include a working tool for interpreting ecosystem dynamics known as the ecosystem dynamics interpretive tool (EDIT) [68], which is a well-structured storage of data on ecological objects collected by the United States Department of Agriculture Natural Resources Conservation Service (NRCS USDA). It is also possible to use EDIT for analysis of vulnerability against droughts, potential of invasive species, and assessment of habitat quality.

5. Conclusions

We analyzed the available experience of using forest ecological classifications in assessing vegetation dynamics in Russia, the European Union, and North America. From the multitude of approaches, only those that are widely used in forestry and for forest inventory purposes were selected.

It was found that the system of diagnostic signs developed by genetic forest typology based on the time-stable characteristics of habitats as well as the developed concept of dynamic series of cenosis formation allows us to successfully take into account the dynamics of vegetation. While forest dynamics in European ecological classifications are assessed theoretically, it is also possible to assess forest dynamics in practice using data from EUNIS. The Braun–Blanquet approach has the advantage of allowing detailed ecological analysis of plant communities within the framework of the European vegetation classification in order to draw conclusions about successions. Vegetation dynamic assessment is based on the idea of dynamic combination of species within communities and is used to implement methods for analyzing dependencies based on space, time, and scale.

Among the North American forest ecological classifications, ecological site description (ESD) provides the best solution by factoring in potential vegetation and destructive factors into classification. Vegetation dynamic assessment in HTC and BEC is based on the examination of diagnostic species and other characteristics of potential vegetation in terms of resistivity to natural and anthropogenic impacts. Research has also demonstrated that the issue of accounting for vegetation dynamics in forest ecological classifications persists. The ongoing search for new solutions is based on in-depth ecological analysis of continuously renewed information of forest cover status using detailed quantitative research, GIS technologies, and modern statistical methods for data processing and analysis. Research results will be significant for further development of Russian, European, and North American forest ecological classifications.

Assessment of relative stability of tree species composition, i.e., ecosystem/forest type dynamics, has become a key forestry problem because of global climate change and related disturbances. Considering their broad theoretical acceptance and high applied value, forest ecological classifications should foster formulation of not only sustainable management but also local forestry and conservancy legislation. Understanding of vegetation–environment associations is fundamental to formulating proper forest management methods and indeed improving classification structures.

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