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Practical approaches to establishing the dynamics of stand stability of breeding facilities

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Abstract. The study considers the concept of stability of tree stands and their establishment at breeding facilities considering the dynamics of the intensity of using environmental conditions. The protective properties of the forest environment, which are identified with the preservation of genetic diversity, are determined by the amount and quality of natural renewal and are associated with environmental stability (renewability), can be effectively assessed by the loss of this stability according to the above method. The study analyses approaches and areas relevant for assessing the biotic and eco-resistance of tree stands. For breeding facilities, these issues are relevant when assigning reforestation measures in forest genetic reserves, assessing the stability of stands at the time of selection of positive plantings, and evaluating selected permanent forest seed plots from the standpoint of determining the volume of planting and care. The methodology for assessing stand stability is based on determining stability indicators (stability coefficient, loss of biotic stability, loss of ecological stability), which are calculated based on a parametric (taxonomic) assessment of trees, their sanitary condition, and natural regeneration in the area under study. Using the values of the given stability indicators, plantings can be divided into three categories: stable, conditionally stable, and unstable. Appropriate forestry measures are proposed that require a separate parametric assessment of forest-forming tree species, economic groups of forest types, forest categories, target measures, or research area. During studies of the living space tension indicator, it was found that the use of forest-growing conditions occurs according to the assessment of the process of development of stands as normal, non-stressed, and stressed. To establish the indicator of normal and weakened state, a basic scale for assessing biotic stability based on state indices is proposed

Keywords: stability assessment, stress indicator, gene pool conservation, sanitary condition, area dynamics

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Introduction

In forestry science, along with the issue of increasing the productivity of stands, a great deal of attention is paid to assessing and increasing the biotic stability and eco-resistance of stands, and forest selection, accordingly, becomes more relevant in breeding and shaping sites for stability. The main factor for assigning specific economic measures, primarily in non-operational categories of forests, is the loss of stability and protective properties by plantings. Therefore, there is an obvious need to quantify the loss of biotic stability of stands by forests. These issues remain relevant for breeding facilities, especially during the appointment of reforestation measures in forest genetic reserves. It is important to assess the stability during the selection of positive plantings and permanent forest-seed plots, considering the prospect of their transfer to positive (breeding) stands or withdrawal from the registers of objects of the permanent forest-seed base.

The term “stand stability” has been widely used in the scientific literature, and relevant forestry studies have been significantly updated recently (Tretyak & Chernevyy, 2020; Maliuga, 2020; Oliynyk & Blystiv, 2019; Gilliam, 2016; Holubets, 2013; Oliynyk, 2013; Shparyk, 2012 etc.). Resistance is defined in relation to a particular component of the forest (stand) as the biotic stability of the species (ecosystem engineer), and in relation to the phytocenosis (forest environment). In forestry science, the concept of ecosystem stability (biogeocenosis) is introduced, in this case, this refers to the stability of the functioning of the forest environment (Holubets, 2008). It is noted that the concept of stability in modern forestry research has a two-way meaning depending on the area and object of study (Brang, 2001). Stability is also considered as a high resistance to external influences and as a property for maintaining a functional forest environment. First of all, stable stands include: native stands of ecological and forestry typology (Stoiko, 2011; Parpan, 2008; Holubets, 2008, etc.), indigenous forest types in phytocenological classification (Sukachev, 1964; Holubets, 2008), nodal stages in successions and changes (Yaroshenko, 1958), stands of stable forest ecosystems (Holubets, 2013; Parpan, 2005 *et al*.). In forestry, the concepts of resistance and reproducibility (elasticity) are most often used (Brang, 2001, Oliynyk *et al*., 2019). To assess stability, the concept of “standard” is sometimes used, which concentrates all the best signs of planting in specific growth conditions (primarily productivity), in particular, durability, biotic stability, and the ability to fully manifest its protective functions.

The qualitative characteristics of growing conditions (edatopes) are determined based on a comparison of the potential and actual productivity of plantings. It is believed that under different conditions, the stability of stands and forest tree species is not the same. Molotkov (1966) has found that in the conditions of wet hornbeam and beech forest, plantings are characterised by high productivity and stability. In general, native stands in beech forests are considered stable, this thesis is confirmed by P.S. Kaplunovskyi and V.I. Parpan. This approach is typical for the ecological and forestry typology from the standpoint of reforestation.

To evaluate individual trees in the forest, various classifications are used (Kraft, Shedelin, Zhylkin, etc.), which can be used to give a general description of stand structure, but its stability is not evaluated. The issue of loss of resistance due to damage by pests or forest diseases is considered depending on the needs of a particular area of forestry – forest protection (Meshkova *et al*., 2018). In forestry, the assessment of the sanitary condition of each tree in six categories is used in accordance with the sanitary regulations in the forests of Ukraine (Sanitary Forests Reg. Ukraine, 1995), and based on the results, economic measures are assigned for a specific site. To solve the problem of rapid assessment of the state and structure of forests, there is an international system for evaluating each tree in six classes, which are known as "IUFRO classes". It is also proposed to assess the life status of trees that have a biotically determined potency of the species for growth and development under certain conditions (Debrenyuk, 2017). The Guidelines on forest seed production (Los *et al.*, 2017) present a methodology for assessing the condition of trees and stands in five categories, which is based on the concept of "viability", which is informative for seeds, seedlings (self-seeding), and undergrowth. To assess the state of plantings, an indicator of living space tension is proposed (Maliuga, 2020). The substantiation of the selected indicator is carried out, in which the average height of plantings reflects the bonus (a recognised indicator of qualitative productivity), and the sum of the cross-sectional areas of trunks at a height of 1.3 m (absolute density) comprehensively characterises forest-growing conditions. Tax collectors in their production activities use tables of the sum of cross-sectional areas and stocks of plantings at density 1.0, so this approach is taken as the main one. To a certain extent, the issue of stability assessment is worked out in the studies by Blystiv (2006, 2012), Oliynyk *et al*. (2019), scientific recommendations contain the papers by Hayda *et al*. (2013), Marchuk *et al*. (2021). The issue of evaluating the efficiency of living space use by plantings is discussed by Malyuha & Minder (2020). The listed studies on the stability of forest ecosystems are important for evaluating the functionality of forest genetic reserves, which may consist of many taxation plots. The assessment of a certain designated territory (forest ecosystem, part of the population) can be based on the ratio of the state of individual plots by area. This approach for estimating the area of reserve stands was proposed by researchers (Syrota, 2021): with the classification of the condition as "normal", which includes healthy stands, and "weakened", which includes damaged stands.

According to Oliynyk *et al*. (2019), Blystiv (2006, 2012), the concept of general forest stability can be divided into the following four main components:

1. Resistance to internal biotic factors or living organisms.
2. Resistance to anthropogenic impact.
3. Resistance to weather factors and other factors of inanimate nature.
4. Potential for the possibility of restoring and forming stable (indigenous) stands (maintaining homeostasis and protective properties).

The first two components can be combined by the concept of "biotic resistance", or resistibility (resistance). It is consonant with the concept of "natural stability", introduced on the basis of typological studies.

Forest typology is crucial for understanding and evaluating the stability of plantings. To assess the natural stability of plantings, an indicator of the typological potential (typological productivity) of a certain type of forest and modelling of the growth of ecotypes and indigenous stands as the main component of the stability of forest ecosystems are used. The term "naturalness" is also used in relation to the environment as an assessment of the inviolability of ecosystem connections or the level of its transformation. The naturalness of its individual components may correspond to the concept of biotic stability of indigenous stands, which, first of all, concerns the correspondence of the ecological optimum of a species to the growing conditions, the biology of species, and their mutual influence. For stands from the standpoint of forest selection and conservation of valuable gene pool and genetic diversity, the concepts of autochthony and corresponding local origin, which are associated with stable stands, are used (Hayda & Yatsyk, 2013). However, the most important element in an integrated approach to determining the stability of stands remains the biotic component, which is the basis for ensuring eco-resistance.

The use of living space by artificial plantings can be normal (optimal), non-stressful, and stressful (Malyuha, 2020). Tension characterises certain processes – the loss of stability or its increase, therefore it can be used to assess processes in the stand (dynamics of stability). To make decisions on the stabilisation of processes in forest ecosystems, it is important to assess the ratio of the state of the object's territory to the areas of stable and unstable stands. The indicator "normal condition" corresponds to the set of stable stands on the site by area, "weakened" – conditionally stable and unstable. The dynamics of areas in the context of changes in these indicators by period characterises ecosystem changes and the succession process in them and is important for objects of conservation of valuable gene pool and genetic diversity.

The purpose of the study is to update the proposals for using the concept of stability in practice and express its assessment in measurable units for stands, considering the peculiarities of breeding facilities. In accordance with this goal, it was planned to achieve a comprehensive solution for assessing the state of biotic and eco-resistance by the coefficient of stability, the living space tension indicator, and the dynamics of stability by its relative loss with age.

Materials and Methods

The methodology for assessing stand stability is based on the use of taxation indicators and their sanitary condition, which are calculated based on a parametric assessment of trees in the study plot based on test area. Basic for determination are the tree list and the scale of sanitary conditions used in production (Sanitary Forests Reg. Ukraine, 1995). Assessment of the stability of plantings is based on the method of calculating the loss of stability (LS), which is proposed for determining the stability of spruce derivatives in beech forests (Blystiv, 2006) and further for assessing the development of stability of hornbeam and beech plantings (Oliynyk & Blystiv, 2019). The calculation of the stability coefficient (SC) is based on the ratio of the average volume of a stand trunk, the average volume of a dry stand trunk, and the average volume of a healthy stand trunk. Sometimes it is sufficient to evaluate the total reserves of dry and healthy wood (Brang, 2001). This approach is effective in evaluating conditionally single-aged stands, which, as a rule, are dominated by the normal distribution of trunks by diameter. Accordingly, there is a need to adjust the formulas when evaluating complex plantings of different ages. In the case of using the scale of sanitary condition, healthy trunks for deciduous trees are assigned I–III categories of condition, and for pine trees – I and II. Normal (optimal) use of living space occurs at a relative density of 1.0 with maximum productivity of stands.

To calculate the stability coefficient (*SC*), the study used the ratio of trunk volumes (*V*) of stands for their condition and ratio coefficients (*Kv1* – the ratio of the average volume of healthy trunks to the average volume of all trunks; *Kv2* – the ratio of the average volume of dry trunks to the average volume of all trunks):

$$SC = Kv1 - Kv2, \quad (1)$$

at the same time: $Kv1 = V_{heal} \div V_{avg}$, $Kv2 = V_{dry} \div V_{avg}$,
where V_{dry} – average volume of dry trunks; V_{heal} –

average volume of healthy trunks; V_{avg} – average volume of all stand trunks.

Accordingly, the loss of stability (LS) of the stand will amount to:

$$LS = 1 - SC \cdot \Sigma V_{dry} \div \Sigma V_{avg}, \quad (2)$$

where ΣV_{dry} – stock of dead wood in the stand; ΣV_{avg} – stock of stands.

In young trees, the appearance of deadwood is mainly the result of natural falling due to selection in the process of species and interspecies competition, and the total percentage of deadwood also depends on previous long-term management impacts, so the loss of stability is determined using a simplified equation:

$$LS = 1 - SC. \quad (3)$$

The same feature is distinguished by the approach for sparse and multi-age stands. Thus, the formula for calculating the loss of biotic stability of plantings has the following form: weighted average sum of stand stability coefficients (*SC*), proportional to the average sums of the respective age coefficients and inversely proportional to the value of the loss of density, is the loss of stability. For pure stands, the equation will be as follows:

$$LS = (1\text{-}SC) \cdot \Sigma V_{dry} \div \Sigma V_{avg} \cdot Ka1 \cdot Ka2 \div LD, \quad (4)$$

where *Ka1* – age range coefficient (*A* – age) of the stand: $A_{min} \div A_{Max}$; *Ka2* – coefficient of relativity of the age of the stand: $A_{tent} \div A_{stab}$ (conditional age by forest-forming species, which correlates with biotic ripeness); *LD* – loss of density = *1 – D*, where *D* – stand density.

During the economic assessment of the stability of stands, the equation considers the stand composition and its age.

Equation for calculating the loss of biotic stability of mixed stands (*stand*) accordingly, will be as follows:

$$LBS\ stand. = (LS\ 1s \times s.units.comp. + LS\ 2s \times s.units.\ comp. + \ldots LS\ dens. \times s.units.comp..) \div 0 \times \Sigma Ka1 \div n \times \Sigma Ka2 \div n \div LD, \quad (5)$$

where *LS 1s, LS 2s* – loss of stability for forest-forming species in the composition (*1s* – 1 species, *2s* – 2 species ...); *n* – the number of forest-forming species in the composition for which the calculation is carried out; *s. units. comp.* – share of units in the composition (1-9).

When determining the eco-resistance of stands (which is based on maintaining the functionality of the protective properties of the forest environment), it is advisable to consider reproducibility (regeneration) by to the presence of undergrowth, namely, calculate the coefficient of the age range of undergrowth (UarC), which is the ratio of the minimum age of undergrowth to the maximum:

$$UarC = A_{min} \div A_{max}, \quad (6)$$

where A_{min} – minimum age of undergrowth in the stand; A_{max} – maximum age of undergrowth in the stand.

UarC partially characterises the viability of undergrowth for reforestation, so it is necessary to add the UarC value to equation 5. In practical use, this is not difficult. Undergrowth appears in stages due to the frequency of seed years, and its minimum and maximum age can be linked to this. However, in general, it is more logical to consider the protective properties of the forest environment, and therefore, not only the age parameters, but also the amount of undergrowth, when designing measures with an appropriate assessment, determining the undergrowth availability coefficient (UaC) for it. The latter is calculated as the ratio of its amount per 1 ha to the optimal value for reforestation or natural conditions with the corresponding addition to equation 5:

$$UaC = N_{fact} \div N_{opt}, \quad (7)$$

where N_{fact} – amount of undergrowth, actual value; N_{opt} – amount of undergrowth, optimal value.

For *UaC*, the basic average value of 12 thousand units per 1 ha is conditionally accepted (without distribution by tree species), although it is advisable to detail the norm in calculations. Thus, the equation for calculating the loss of eco-resistance – loss of protective properties (LPP) of the stand, respectively, will be as follows:

$$LER = LBS \cdot UarC \cdot UaC, \quad (8)$$

where *LER* – loss of eco-resistance; *UarC* – undergrowth age range coefficient; *UaC* – undergrowth availability coefficient

The situation is similar with the density of plantings. When assessing the condition for assigning economic measures, its loss (*LD*) should also be considered when determining eco-resistance (protective properties), adding equation 8 in the denominator.

The assessment of the living space tension indicator is based on the methodology described by researchers (Malyuha, 2020; Maliuha & Minder, 2020). Indicator of living space tension (*N*) represents the ratio of the average height (H_{avg}) to absolute density (*G*) of the stand:

$$N = H_{avg} \div G, \quad (9)$$

where H_{avg} – average height, m; *G* – absolute density, m^2/ha; the dimension of the living space tension indicator is $m \cdot (m^2)^{-1}$.

To estimate dynamic processes in space (by area) and in time (by periods), two values of the stand stability indicator are proposed, which is used to compare the state – "normal" or "weakened". The estimate of relative loss of stability is based on the methodology described in the paper (Syrota, 2021). The normal state corresponds to a stable forest ecosystem, which is the facilities for the needs of forest seed production and the preservation of the gene pool for the duration of certification. These are normal and plus stands according to the assessment from the standpoint of forest selection. Therefore, at the time of selection, their condition is assessed as 100% normal in terms of area. Relative loss of stability (*RLS*) of the forest ecosystem of the object under study is determined by the equation:

$$RLS = Weak.S \div Nor.S \times 100, \quad (10)$$

where *Weak.S* – weakened state, ha; *Nor.S* – normal state, ha; dimension as a percentage.

Results and Discussion

Using the values of the given indicators (*SC*, *RLS*) according to the stability assessment, plantings are proposed to be divided into three categories: stable (*SC* in the range of 0.99-0.8), conditionally stable (*SC* in the range of 0.79-0.4) and unstable (*SC* is 0.39 or less).

1. Stable – without the risk of loss of stability at a specific moment (do not require economic measures). These are normal and positive stands, the cores of genetic reserves. Their functioning as objects of a permanent forest-seed base requires monitoring of stability to ensure compliance with

reproductive properties. On the other hand, it is also a promising forest fund for transferring pure stands to mixed ones for artificial monocultures, which can also take place among the selected objects of a permanent forest seed base that are not used, and this also requires monitoring of a satisfactory sanitary condition.

2. Conditionally stable (weakened stability) – objects with a risk of loss of stability that require preventive economic and selective measures, and options for implementing reformation systems and reforestation logging if it is advisable to preserve the valuable gene pool and genetic diversity at the place of origin.

3. Unstable – stands that are candidates for removal from the register of objects of permanent forest-seed base, forest fund for continuous sanitary logging. In some cases, they may be objects of preservation of a valuable gene pool by individual selection primarily for resistance outside the facility – in plantations or collections.

For such categories, appropriate forest management measures are proposed, which require separate parametric substantiation. This applies to the economic group of forest types, the category of forests, the age and spatial structure of the stand, the target measures or the line of research – in this case, the loss of stability of breeding facilities.

Studies on living space tension have established that the use of conditions occurs according to the assessment of the process as normal, non-stressful, and stressful.

1. Normal (optimal) use of conditions occurs at a relative density of 1.0 with the maximum productivity of stands. This static characteristic is inherent in the selection of positive plantings, the core of a reserve or tree stand for permanent forest-seeded areas based on an assessment of the breeding structure. Under such conditions, there is a natural compromise between productivity and biotic stability of plantings.

2. Non-stressed – with incomplete use of the potential of forest-growing conditions by sparse stands, which is associated with varying degrees of loss of productivity, but provides optimal fruiting conditions and extends the period of functionality. By forming forest-seed plots with a density up to 0.6, the tension is reduced for a certain period, ensuring further stable growth in non-stressful forest-growing conditions.

3. Intensive use of conditions precedes the process of loosening a dense tree stand with a relative density of more than 1.0. With regard to positive stands of monocultures (in particular introducers), their subsequent development with increased productivity can be achieved by reducing biotic resistance. Further strenuous (excessive) use, teetering on the brink of destruction, and the so-called salvo falling, correspond to a loss of stability and will be assessed as unsustainable and require preventive measures. This stage is reached by artificial forests of green zones, forest parks, protected categories, and the corresponding ripe and over-mature stands that are mistakenly classified as objects of natural reserve fund.

To assess the indicator of the normal and weakened state of the site, reserve (its allocated part), a basic scale for assessing biotic stability is proposed by the sum of five basic indicators:

- damage caused by primary entomological pests;
- damage caused by secondary pests;
- exposure to phytopathological diseases;
- presence of non-viable and weakened trees;
- relative density.

Regarding the weakened state, three stages are identified to detail the planning of possible measures. After determining the absolute indicators of the first and second evaluation periods, the method of grouping the obtained data was applied. There are five groups of dynamics of natural processes and prospects for the development of the main breed, which generalise these processes from a positive to a negative trend:

1) dynamics of natural processes is positive; the development of the main breed, if there are no negative factors, is positive;

2) dynamics of processes is almost unchanged; the development of the main breed, if there are no negative factors, is favourable;

3) dynamics of natural processes has minor negative changes; the development of the main breed in it is conditionally unfavourable;

4) dynamics of natural processes is noticeably negative; the development of the main breed is unfavourable; there is a possibility of complete loss of functions;

5) dynamics of natural processes is negative; the prospect of loss of the main breed in the composition.

The application of the proposed methodology allows assessing the dynamics of the main natural processes in stands, comparing indicators for the time of selection of breeding facilities or their inventory.

Conclusions

In forest selection, breeding and establishment of tree stands for stability require defined parameters. For this purpose, it is proposed, respectively, to use the stability coefficient of stands in a complex. Protective properties of the forest environment, in particular, the preservation of genetic diversity, which are identified with a certain amount and quality of natural regeneration and associated with the ecological stability of stands, can be effectively evaluated by its loss according to the given methodology. Using the values of the above indicators (plantings can be divided into three categories of stability: stable, conditionally stable, and unstable, for each of which, according to forest-forming tree species, there is a need to work out the features targeted by stability criteria. Studies of the living space tension on the use of growing conditions have established that plantings with a somewhat dense three stand grow in stress. Plantations that have a density range of 0.7-1.0 develop optimally. Other plantings grow without stress, but do not fully use the living space due to the different degrees of sparsity of stands. Such medium-high plantings can be effectively used as selected and appropriately formed permanent forest-seed plots. Assessment of the condition by impact factors allows recording quantitative changes. The dynamics of areas and, accordingly, changes in basic indicators by period characterises ecosystem changes (stages of development) of the assessed forest ecosystems and is important for the objects of conservation of genetic diversity and valuable gene pool – primarily for forest genetic reserves. It is promising to use the presented results to combine the current tasks of eco-balanced forestry management with promising programmes for the conservation and formation of genetic diversity and a valuable gene pool of forest-forming species.

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Практичні підходи щодо встановлення динаміки стійкості деревостанів селекційних об'єктів

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Анотація. У статті розглянуто поняття стійкості деревостанів та їх формування для селекційних об'єктів з урахуванням динаміки напруженості використання умов середовища. Захисні властивості лісового середовища, які ототожнюють зі збереженням генетичного різноманіття, визначають за кількістю і якістю природного поновлення та асоціюють з екологічною стійкістю (відновлюваністю), можна ефективно оцінювати за втратою цієї стійкості за наведеною методикою. У статті проаналізовано підходи та напрями, які актуальні для оцінювання біотичної та екостійкості деревостанів. Для селекційних об'єктів ці питання актуальні під час призначення лісовідновних заходів у лісових генетичних резерватах, оцінювання стійкості деревостанів у момент відбору плюсових насаджень, оцінювання відібраних постійних лісонасіннєвих ділянок з позицій визначення обсягів формування та доглядів. Методика оцінювання стійкості деревостанів базується на визначенні показників стійкості (коефіцієнта стійкості, втрати біотичної стійкості, втрати екологічної стійкості), які розраховують на підставі параметричного (таксаційного) оцінювання дерев, їх санітарного стану та природного поновлення на досліджуваній ділянці. Використовуючи значення наведених показників стійкості, насадження можна поділити на три категорії стійкості: стійкі, умовно стійкі та нестійкі. Запропоновано відповідні лісогосподарські заходи, що потребують окремої параметричної оцінки за лісотвірними видами дерев, господарськими групами типів лісу, категоріями лісів, цільовими заходами формування чи напрямом дослідження. Під час досліджень напруженості показника життєвого простору встановлено, що використання лісорослинних умов відбувається за оцінкою процесу розвитку деревостанів, як нормальне, ненапружене і напружене. Для встановлення показника нормального й ослабленого стану запропоновано базову шкалу оцінювання біотичної стійкості за індексами стану

Ключові слова: оцінювання стійкості, показник напруженості, збереження генофонду, санітарний стан, динаміка площ