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RESEARCH ARTICLE

Ecosystem Regulation of Pathogenic Processes in Forest Plantings

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Abstract

Traditional ways of forest protection against pathogenic organisms by means of chemical and biological pesticides are insufficiently effective and do not conform to modern ecological and social requirements. The problem of development of effective forest plantings protection without use of pesticides is relevant. The purpose of the offered researches is the regulation of pathogenic processes in forest plantings by means of the natural activation of natural adaptive mechanisms of the protected plantings. This purpose is achieved by means of formation of highly heterogeneous mosaic plants. The studied regulation mechanisms of natural regulation of pathogenesis in forest ecosystems are competition, natural selection, and inbreeding. *Competition* is the primary factor that is causing the long-term changes in tree survival and dying off, growth and development, origin of posterity and its safety. Both types of the competition trans-species and intraspecific are considered. *Natural selection* is considered as a key mechanism of adaptation of a population over generations, as a result the heritable signs of a population changes. During this long-term process the fitness of population of a model pathogen (*Erysiphe alphitoides*) decreased. This phenomenon is based on differentiation of survival and reproduction of individual in phenotype. The relevance of the presented work is that the effective method of protection of the forest plantings, based on rehabilitation of natural adaptive mechanisms of the protected forest plantings is opposed to the methods of forest protection, based on use of chemical and biological pesticides. The applied aspect of work consists in ecological, economic and ethical advantage.

Keywords: Mosaic Plantings; Populations; Organisms; Forests; Adaptability; Regeneration; Inbreeding

Introduction

The modern concept of sustainable development may be successfully achieved in forest by means of formation of mosaic highly heterogeneous forest plantings. Such plantings are capable to ecosystem regulation of pathogenic processes in forest plantings. In essence the processes of self-control of pathogenesis develop in them. Basis of self-control are the specific composition of forest species and structure of plantings. The most important mechanisms of ecosystem regulation of pathogenesis in forest ecosystems are the competition, natural selection, and inbreeding.

The purpose of the work is the regulation of pathogenic processes in forest ecosystems by means of activation of natural adaptive mechanisms: intraspecific and interspecies competition, natural selection in populations of host plants, and inbreeding in populations of pathogenic organisms. In essence, the effect of self-control in the protected ecosystem arises. The basis for it is the specific composition and structure of the protected forest plantings. The applied solution of the problem of self-control of pathogens is reached by means of a formation of mosaic highly heterogeneous forest plantings. Such plantings become capable to self-control of pathogenic processes. Key mechanisms of self-control are: competition, natural selection and inbreeding. *Competition* as the regulator of survival, dying off of, growth and development, origin of posterity and its safety. We have looked at the two types of competition – intra-and interspecific. The competition promotes formation of forest glades (gaps). It is important for natural renewal of forest plantings. It was established that smaller patches and cohorts of trees are not healthy for forest pathogens. An optimum of forests area for ecosystem researches depends on specific forest vegetation conditions. *Natural selection* as a key mechanism of adaptation of a population over generations. As results the heritable signs of a population change. During this long-term process the fitness of population increases. Spontaneous development of natural woods should be considered at management of the modern forests. Formation of each tree in planting is based on an individual phenotype. Participate in this process both the competition, and natural selection. *Competition and natural selection* as the pathogenesis regulators in forest plantings. They contribute to sustainable development of plantings. *Inbreeding* in pathogenic populations reduces fitness of their organisms, weakens populations of pathogens, and reduces their harm for the protected forest plantings. Inbreeding depression is important

factor of suppression of pathogenic populations in rather small sites of plantings. Inbreeding results in population homozygosity. In it case, the chances of offspring being affected by recessive or deleterious traits increase. The mechanisms of biotic regulation are formed on the basis of composition and structure of the protected plantings. The pure stands composed of essentially a single species are undesirable. The free choice of the Nature is understood here as formation of forest plantings under the dominating influence of natural adaptive mechanisms. The role of a human factor is minimized. The main mechanisms of natural regulation of pathogenesis in forest ecosystems are competition, natural selection, and inbreeding. By their impact the excessive reproduction of some pathogenic organisms is constantly suppressed While modern forest management focuses attention first of all to performance ecological roles of the woods and forest plantings, the real paramount task is in improving health of the woods, forests and greening plantings [1-3]. Convincing examples for the correct actions are self-regulating natural woods.

It is relevant solving problem of freedom action of natural mechanisms for biotic regulation in forest ecosystems. This problem is solved through formation of high-heterogeneous mosaic forest plantings [4-7]. Ecosystem regulation of regulation of pathogenesis in forest plantings come to autoregulation of pathogenic populations at admissible level as a process, resulting from an internal adaptive mechanism working to adjust the system's response to stimuli. A new mosaic forests are not favorable for development of forest pathogen populations [8-11]. Fragments of heterogeneous mosaic plantings are approved in the Central Russian forest-steppe. It allows preventing sporadic mass premature dying off forest plants. As further development of forest communities in our changeable world is to claim that the forest plantings close to the natural woods will dominate. It does not mean copying of the woods of former eras, but it means that forest plantings will be freely formed under adaptive laws of the Nature. In such forests there will be no threat of excessive reproduction of harmful organisms. Innovative prerequisite of formation of the forest communities, capable to sustainable development, is the model of highly heterogeneous mosaic plantings presented as result of our research.

Methodology

The investigation is based on a comparison of values of the studied parameters in various conditions – at spontaneous and artificial cultivation of forest plantings. These researches were carried out permanently. Intensive long-term work began in about 2001. The region of researches is the Central Russian Upland, mainly in Shipov Oak Forest, Khrenovsky Pine Forest, and Usmansky forest. The general for these mainly man-made forests is insufficiency of natural renewal of the main forest forming breeds. Pure stands composed of essentially a single species dominate.

Methods

A qualitative and quantitative methods where used for a research of a viability of trees, heterogeneity of plantings, natural renewal of the breed of the main forest forming breeds.

The basic formulas of the conducted quantitative researches are the following:

$$IH = -\sum_{i=1}^{n} p_i \log_2 p_i \qquad (1)$$

It means: *IH* is index of heterogeneity, *i* is several of elements of a heterogeneity biodiversity, p_i is the probability of any element, n is number of groups of the studied elements.

$$D = \frac{\sum (n \times b)}{N \times B} 100\% \qquad (2)$$

It means: *D* is development of disease (%), *N* is total of the considered objects, *B* is the highest point on the accepted scale, *n* is number of individuals of this or that point, *b* is concrete point of this or that individual.

The inbreeding depression was measured on phonotypical level. Phonotypical coefficient of inbreeding can be expressed by means of the following formula:

$$ID_{ph} = \frac{d_1 - d_2}{d_1} \qquad (3)$$

where ID_{ph} – index of inbreeding depression (phenotypically), d_1 – development of a diseases in the conditions of open sites of plantings, d_2 – development of a diseases in the conditions of ecologically isolated sites of plantings.

Model objects

Ascomycete Erisiphe alphitoides (pathogen of oak *Quercus robur*) & basidiomycete *Heterobasidion annoum* (pathogen of pine *Pinus sylvestris*). *E. alphitoides* causes powdery mildew on oak trees. Today oak powdery mildew is one of the most common diseases in the explored region and in European forests. The pathogen weakens adult oak trees and kills oak seedlings. Oak powdery mildew is

in forests in the Europe, America. Pathogen kills trees of different species and is the most economically important forest pathogenic fungus. The problem of forest protection against *E. alphitoides and H. annosum* is very relevant. The scale of assessment of viability of trees and plantings: 5 (healthy trees), 4 (foliage coloration is used as a criterion for vitality), 3 (trees sick to the 1st degree, recovery of health of a tree is possible), 2 (trees sick to the 2st degree, recovery of health of a tree is improbable), 1 (the dying-off trees, separate elements of life still remain), 0 (the died-off trees, without signs of life).

Statistical analysis

The comparisons of the studied parameters of competition, natural selection and inbreeding were determined significant. A t-test was applied to determine if two sets of data are significantly different from each other. Quantitative estimates of the studied population mechanisms (the competition, natural selection, and inbreeding) allowed to make the conclusion of rather the studied forest ecosystems are capable to sustainable development.

Required details include specifics of the studied landscape and criterion of complexity of plantings. The environment of the Central Russian forest-steppe is exclusively favorable for development and distribution of many species of pathogenic organisms. The anthropogenic press in the explored region it big. It influence negatively on forest health. Invasive species of pathogenic organisms reduces viability of plantings of wood plants. The problem of protection of forest plantings against pathogenic organism is very relevant. In essence, decreased fitness of a plant population is to increase on genetics and environment basis.

Results and discussion

Results of long-term researches are presented in the following items (3.1, 3.2, and 3.3). The studied mechanisms of ecosystem regulation of pathogenic processes in forest ecosystems can separately operate, but their joint simultaneous action is especially effective. 3.1 Competition as process of formation of a biocenosis happens at all levels of formation of forest plantings. Survival, dying off, growth and development, origin of posterity and its safety depend on the competition. A high density of trees encourages competition in forest plantings. The first step in a research of the competition in communities of trees is the determination of the minimum size on which the index of heterogeneity of plantings is stabilized (Figure 1).

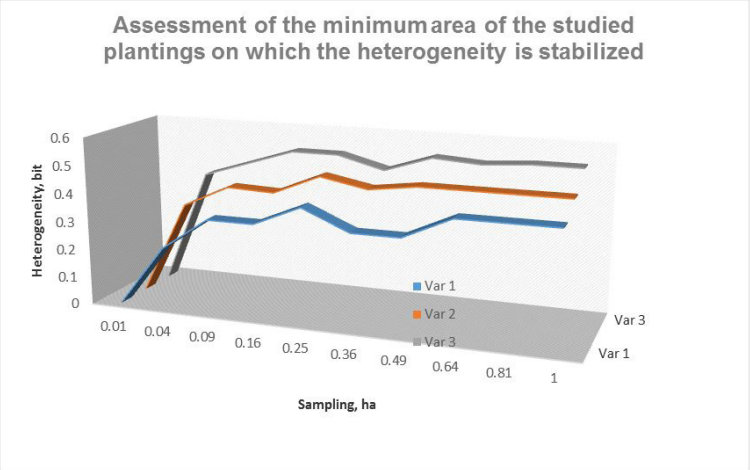


Figure 1: Dynamics of the variables heterogeneity index in the studied plantings depending on the size of sampling

Apparently on graphic (Figure 1), the index of heterogeneity (*IH*) of the studied plantings is stabilized at minimum sampling of 25000 m^2. An optimal area of forests for research of the self-regulation, is basic condition for ecosystem regulation of pathogenesis in forest plants. Optimal area of forests is a basis for spontaneous development of plantings. The recommended land area in the Central Russian forest-steppe of Russia is 25000 m^2 and more. In other regions and in hard plantings the minim area for ecosystem researches can be another. Policy is to ensure forest and environmental stability and maintenance of ecological balance. Transformation of the plant complexes in the pathogen center in result of free competition is presented in (Table 1).

Resulting plantings	Plant complexes				General Heterogeneit, bit
	Forest stand	Subgr-owth	Under-brush	Grassy cover	
Natural overgrowing of mixed plants	1,68	1,84	1,91	1,36	6,97
Monocultures of the pine (*P. sylvestris*)	0,72	0	0	0,92	1,64

Table 1: Heterogeneity of the plant complexes in the center of the pathogen (*Heterobasidion annosum*) under the influence of free competition and of monocultures of the pine (*Pinus sylvestris*)

As a result of natural overgrowing of the center planting with higher level of heterogeneity is formed (Table 1). Such plantings have high resilience to adverse factors. In essence, in them are formed the plantings close to the natural woods. Natural integration processes in such plantings are rather active. Internal adaptive mechanisms freely act. Monocultures of the *P. sylvestris* as pure

stands composed of essentially a single species are preferred for pathogens. Integration processes cannot be fully shown here. In populations of pathogens the stabilizing selection dominates. The probability of mass biotic damages of plantings is high. Thus, from ecological and forest protection positions natural overgrowing of the centers is preferable. 3.2 Natural selection as a key mechanism of adaptation of a population over generations. Search of key mechanisms of adaptation in forest ecosystems is especially relevant in the always changeable world. Phonotypical selection forms forest ecosystems through change by generation. Natural selection acts stabilizing, disruptive or directional selection. The second stage is investigation of optimal species composition and structure for spontaneous development. Depending on the nature of plantings this or that type of natural selection dominates. In the Central Russian forest-steppe disruptive selection is most relevant. Disruptive selection corresponds to the central concept in modern biology concept of biodiversity. Disruptive selection (diversifying selection) is understood here as two or more two outstanding genotypes dominate. This phenomenon is used for increase in stability of the protected plantings. Thus natural selection is one of the most important biological processes for sustainable development of plantings. *Directional selection* phenomenon is usually seen in environments that have changed over time. Changes in climate or food availability can lead to directional selection. A directional selection in forest plantings is a force in that causes populations to evolve towards one end of a trait spectrum. This natural process happens in populations of both wood plants, and their pathogens. The forest tree populations influence sustainable development of forest ecosystems. It is necessary to provide freedom of choice, freedom of action to natural biotic mechanisms.

Applied conclusion from stated is that linear placement of trees such opportunity is not provided. Group placement of trees is necessary. Relative smaller patches and cohorts of trees are not healthy for the pathogenic populations. Natural selection in group plantings is well differentiates on participation in ecosystem life. *Stabilizing* selection commonly uses in forest plantings. Population favors the intermediate variants phenotypes. This situation is fair for forest plantings of various ages. During the stabilizing process most extreme phenotypes are removed. This process happens not only in populations of wood plants, but also in populations of their pathogens. In long-term biotic struggle of a host wood plant against pathogens almost always pathogens win because of a huge difference in frequencies of changes of generation: wood plants have a long-term generative cycle, on the contrary pathogenic organisms have usually one-year or even double generation. As a result mass reproduction of pathogenic organisms sporadically develops. Mass reproduction of pathogenic organisms can be regulated by planting. This phenomenon was investigated by us on the example of fungus which causes powdery mildew on oak on trees. In homogeneous, heterogeneous oak plantings within uniform population of *E. alphitoides* (Table 2).

Plantings	Infection, %
Homogeneous (one-species, one-aged/ ten-year-old, linear)	83,6
Heterogeneous (mixed-species, uneven-ageв, group-shaped)	12,7

Table 2: Infection of *Erisiphe alphitoides* in homogeneous and heterogeneous oak plantings

As visible in (Table 2), the degree of infection in heterogeneous oak plantings is much less, than in Homogeneous oak plantings. We see an explanation for this fact that heterogeneous plantings are adverse for development of a pathogen. In the conclusion it is possible to generalize that natural selection is daily and hourly in forest ecosystems. 3.3 Inbreeding as the pathogenesis regulator in forest plantings. Inbreeding as closely related sexual reproduction of organisms, is usual in the wild nature and used. As a result of inbreeding in the habitat the homozygosity of populations increases, the fitness, the viability of population's decreases. The purpose of the researches a phenomenon a depression organisms. Effect of an inbreeding depression is reached through splitting populations of pathogens into rather limited subpopulations. Splitting populations into subpopulations is reached through ecological barriers. As ecological barriers plantings of various tree species are used. Researches were conducted in a forest-steppe oak grove of the Central Russian forest-steppe in 2016. Model object is the pathogen *Erisiphe alphitoides*. For oak the high susceptibility to powdery mildew is typical. The leaves disease is the main cause of partial or complete failures. Development of a pathogen in the conditions of open plantings and on limited (≈ 0,25 ha) sites of plantings of an oak was compared (Table 3).

Plantings	Development of the disease, %	Sizes of konidiya, μм		Parameters of kleystotetia	
		Length	Width	Diameter, μm	Frequency, n/cm²
Open	78	32	18	99	64
Ecologically isolated	16	24	13	74	8

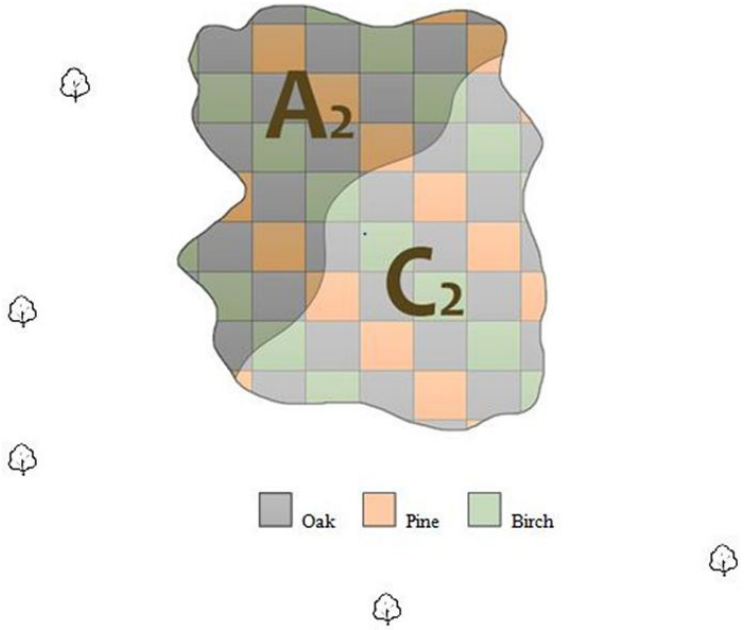
Table 3: Development of powdery mildew on oak trees in open and ecologically isolated plantings

As appears from (Table 3), the development of the oak powdery mildew in ecologically isolated plantings more than 3 times less than in the open plantings. This fact demonstrates weakening of subpopulation of a pathogen in the conditions of the small areas. The analysis of morphological fragments of a pathogen leads to the same interpretation of the phenomenon. Received results revealed that forest resistance could be achieved throw ecologically isolated plantings. Index of phenotypical inbreeding depression (ID_{ph}) in experiment is 250000 m².The results adding the values of statistical significance demonstrate reliability of the received results of a research. The offered model of mosaic highly heterogeneous planting can be a basis of self-control of pathogenic processes in the protected ecological systems of forest plants. The most critical question in forest protection is the comparative high fitness of its consumers. In essence, we need the close to nature silviculture, where nature's properties are safegarded. This will become a challenge in the future to forestry protection science and technology.

Conclusion

Our investigations as well as analyses of data from the literature yielded the following conclusion. Ecosystem regulation of pathogenic processes in forest plantings in essence according the principle of the free choice of the Nature in forest ecosystems. It means formation of plantings close to natural forests. It does not mean that it is necessary to copy forest plantings of last centuries, but it is necessary to give freedom of action to natural mechanisms of formation when forming modern forest plantings. The created forest plantings have to be auto adjustable, rich and vital. There are three main reasons for that: namely biological, economical and ethical reasons.

Management of self-regulating pathogenic processes in forest plantings: formation of highly heterogeneous forest mosaic ecosystems Forest planting is formed according to the specific scheme (Figure 2).



A_2 and C_2 – These symbols designate various conditions of growth:
A_2 - poorer, C_2 - richer.
Figure 2: General scheme of highly heterogeneous forest mosaic planting
Tumber 2 means average degree of poverty or wealth.

Structure of highly heterogeneous mosaic planting
1. General model of forest planting includes two various types of conditions of growth: A_2 and C_2.
2. Forest planting includes three sections: pine section, oak section, and birch section.
3. Each section consists of an uncertain set of sites. Each site has the approximate size 50×50 of m.
4. Within each site planting is created by crops of seeds of the corresponding species of a tree.

Elementary structures of highly heterogeneous mosaic planting are groups of plants of unit species (pines, or a birch). As an example group of a pine (Figure 3).

Figure 3: Group of pine (*Pinus sylvestris*), As elementary unit of planting
Plants have to be placed in planting not on one and not in ranks, but in groups

In groups of plants there is a competition and selection on resistance to pathogens. Each site of one species of plants is an ecological barrier to the site of other species of plants (Figure 4).

Figure 4: Coniferous /deciduous ecotone as ecological barrier for many pathogens

Types of harmful organisms are specific on the relation to plants-host; therefore change of plantings of one look in relation to other look is barrier. The network of ecological barriers it optimizes the size of sites in protected plantings and forms a basis for inbreeding in pathogenic populations. Conclusions for Management of self-regulating pathogenic processes created on the basis of the given criteria highly heterogeneous forest mosaic ecosystems are capable to self-control of pathogenesis.

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