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Syntheses

Assessment and prediction of biotic risks in the forests of Ukraine

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Abstract. The approaches are suggested to evaluate the injuriousness of pests of regeneration (in Scots pine plantations up to 5–7 years old), the threat of foliage damage in closed forest stands, and the harm from xylophagous insects. The first approach gives the possibility to evaluate the effect of the damage of different organs of Scots pine transplants on survival (mortality), growth rate, and stem quality considering the damage to needles, buds and shoots, stem and branches, root collar, and roots by direct and indirect symptoms. It allows assessing the potential harm of the most common pests of unclosed pine plantations.

The crown damage by foliage browsing insects is calculated using the data on critical and actual population density, foliage phytomass per tree, and forage rate of given insect species. The phytomass of the foliage of the main forest tree species in artificial and natural stands in different natural zones of Ukraine is suggested to correct considering the health condition of the tree. So the population density of larvae to consume 100 % foliage of the healthy tree is 1.25; 2.5 and 6.25 higher than for the trees of the 2nd, 3rd, and 4th class of health condition. Examples of evaluation of critical population density and the threat of foliage damage are presented for several polyphagous insects while feeding in oak and ash.

The approach and scoring system of Mozolevskaya was used to evaluate physiological, technical, and general harm of more than 200 xylophagous species in coniferous and deciduous trees. The same pest was shown to be non-harmful or low harmful, moderately harmful, or highly harmful in different host trees, regions, and depending on population density and additional factors that weaken trees.
Keywords: pests of regeneration, foliage browsing insects, xylophagous insects, injuriousness, assessment.

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Introduction

Over the past 20 years, the area, frequency and severity of forest disturbances have increased in many regions of the world (Kukhta et al. 2014, Siitonen 2014, Bjorkman and Niemela 2015, Jaime et al. 2019, Sarvašová et al. 2020), particularly in Ukraine (Meshkova and

Davydenko 2011, Meshkova 2018, 2019).

To a great extent, the spread and severity of forest decline is connected with climate change (Forrest 2016) and anthropogenic loading, especially forest management practice (Meshkova 2019). Changing climate provides the best survival and propagation of aboriginal insects and pathogens as well as immigration and maintenance of the adventive species which are not pests in one region and are the pests in another region (Hentschel et al. 2018). Forest management practice brings to sudden changes the forest microclimate, makes the forest more vulnerable to natural disasters and more susceptible to harmful insects (Lindenmayer et al. 2012).

We can have little effect on global climate change, but we can adjust forest management activities with an emphasis on increasing the sustainability of forest stands and, if necessary, pest control. For adequate decision making, we must know what organisms, where, and when are able to be pests. Pests of cones and seeds in special plantations, the pests in nurseries, and the pests of felled trees must be controlled always if we want to obtain the production (Meshkova 2018). Other groups of pests must be monitored and regulated only when it is necessary. We consider here three groups of pests: the pests of regeneration (in pine plantations up to 5–7 years old), the foliage browsing insects, and xylophagous insects.

The pests of natural regeneration and plantations up to 5–7 years old consume different tissues and organs of plants, often at maturation feeding (Meshkova and Sokolova 2017). At an older age, such damage is not dangerous for trees but in the first years, it can cause mortality, decrease the growth rate, and stem quality. Different organs of Scots pine transplants are

Table 1 Rating scale for assessing the intensity of damage to unclosed pine plantations by direct symptoms (Meshkova 2016).

Pine organs	Intensity of damage			
	Low (1 point)	Moderate (2 points)	Considerable (3 points)	High (4 points)
Needles	up to 20% of needles damaged, discolored	21–50 % of needles damaged	51–70 % of needles damaged	over 70 % of needles damaged, often fall down
Buds and shoots	only lateral buds damaged, up to 20% of the total	– only apical bud damaged; – 20-50% of lateral buds damaged	apical bud and up to 70% of lateral buds damaged	apical bud and over 70% of lateral buds damaged
Branches and stem	1–3 branches with traces of damage, a stem is not damaged	up to 50% branches with traces of damage, 1–3 small (0.5 cm in diameter) shallow (xylem not affected) wounds that will heal later	over 50% branches are with traces of damage; 1-2 deep, but small (0.5 cm in diameter) wounds that will heal; gnawed stem	several single deep wounds (up to xylem) on the stem or several deep small merged wounds, swollen with resin, which will not heal
Root collar and roots	one small (several millimeters) wound on the root collar and thin roots	on the root collar, one small (0.5 cm in diameter) shallow (up to xylem) wound, which will later heal; bites on the roots are noticeable, but the death of the tree is possible only if there is additional damage	–	the root collar is girdled; the bark of the roots is severely gnawed, there are several deep wounds on the roots; the central root is gnawed; there are insect galleries in the roots - the tree is doomed

damaged by insects of different taxonomic and ecological groups. They move from one plant to another, which makes it difficult to assess the population density of certain insect species (Meshkova 2016, López-Villamor 2019). Therefore, it is only possible to assess their harmfulness by changes in individual plant organs.

Methods for assessment of foliage browsing insects at different stages of development have been developed in many regions, as well as prediction of population dynamics in space and time (Kulman 1971, Austara et al. 1987, Lyytikainen-Saarenmaa and Tomppo 2002, Meshkova 2006 ab, 2013, Kosunen et al. 2017). However, evaluation of tree increment losses or health condition change as a result of damage by foliage browsing insects becomes complicated, because these parameters depend on the climate of the region, the weather of the year, ecological conditions of forest plot, growth pattern, and health condition of trees before the outbreak, as well as on the period of foliage consuming by insects, possibilities and rate of crown recover. Therefore, some improvement in the prediction of the threat from these pests is necessary.

Xylophagous insects inhabit the trees and cause their decline, contamination with pathogens, often mortality and devaluation of the harvested wood (Lieutier et al. 2004, Linnakoski et al. 2008, Six 2012). Although approaches to assessing the harmfulness of xylophages have been developed (Mozolevskaya 1974) and implemented (Meshkova and Kukina 2011, Skrylnik 2013, Kukhta et al. 2014), they need to be adjusted taking into account host trees, regions and depending on additional factors that weaken trees (Meshkova 2018, Skrylnik et al. 2019).

The aim of this paper was to present methodical approaches to assessing the injuriousness of pests of regeneration (in pine plantations up to 5–7 years old), the threat of foliage damage in closed forest stands, and the harm from xylophagous insects.

Pests in young pine plantations

Unclosed plantations.

We have developed scales that allow us to assess the intensity of damage to Scots pine transplants in unclosed plantations (up to 5–7 years old), taking into account the damaged organs of a tree by direct and indirect symptoms, the latter being especially important in case of damage to roots that cannot be examined in living plants (Meshkova 2016). When assessing the direct symptoms of plant damage, the intensity of damage to needles, buds and shoots, stem and branches, root collar, and roots is separately assessed (Table 1).

Some types of damage, for example, in the underground part of plants, can be detected by indirect symptoms. A rating scale was developed for assessing the intensity of damage to unclosed pine plantations using indirect symptoms (Table 2).

Thus, the average level of plant damage corresponds to defoliation of 31–60%, discolora-

Table 2 Rating scale for assessing the intensity of damage to unclosed pine plantations using indirect symptoms.

Parameters	Intensity of damage		
	Low (1 point)	Moderate (2 points)	High (3 points)
Defoliation	up to 30 %	30–60 %	over 60 %
Discoloration of needles	pale green needles	up to 50% of the needles are yellow, red, brown	over 50% of the needles are yellow, red, brown
Mean length of needles	over 4 cm	2–4 cm	less than 2 cm
Mean class of tree health condition	2.0–2.9	3.0–3.9	4 points and above

Table 3 Weight factors to evaluate the influence of damage of certain pine organs in unclosed plantations on tree mortality, increment, and stem quality.

Weight coefficients for influence on:	Damaged organs of pine				Total
	needles	buds and shoots	branches and stem	root collar and roots	
Mortality	1	1	1	3	6
Increment	2	2	2	2	8
Stem quality	0	3	2	0	5
Total influence on plant	3	6	5	5	19

tion of up to 50% of needles with needles 2–4 cm long, health condition class 3.0–3.9 points. A high level of insect damage corresponds to defoliation over 60%, discoloration over 50%, the length of the needles less than 2 cm, the class of the health condition of trees over 4 points.

Damage to individual pine organs in forest plantations has a different effect on plant viability (mortality rate), growth rate, and stem quality. In accordance with this, on the basis of an expert assessment, we have calculated weight factors for the assessment of the impact of individual pests on the mentioned parameters of the health condition of plantations.

Thus, the effect of damage to needles, buds, and shoots on the intensity of plant mortality is assessed by a point 1, and on growth – by a point 2, the effect of damage to the buds and shoots on the stem quality – by a point 3 (Table 3). To calculate the effect of insect damage on the growth and health condition of unclosed pine plantations it was proposed to examine at least 50 plants, assessing by points the intensity of damage to needles, buds and shoots, stem and branches, root collar and roots. In this case, root damage of dead plants is determined by digging them up, and of living ones - by indirect signs (defoliation, the size of needles, etc.) (Table 2). Using the weight factors (Table 3), the effects of pest damage on growth, mortality, stem quality, and the overall effect on the plant are calculated.

Let the mean intensity of damage of needles, buds and shoots, stem and branches, and roots is 3.1, 2.3, 2.0, and 2.0 points. For each kind of damage, we multiply the mean intensity of damage by respective weight factors (Table 3): 3.1×1=3.1; 2.3×1=2.3; 2×1=2; 2×3=6 points. Then we summarize these products and divide them by the total score (3.1+2.3+2.0+6.1=13.4). The effect on mortality is 13.4/6=2.2 points. When substituting the appropriate weight factors (Table 3), we calculate the effect on growth (2.3), stem quality (2.1), and the general effect on the plant (2.3).

The approach was used to assess the potential harm of the most common pests of unclosed pine plantations in the Kharkiv and Lugansk regions. Thus, the effect of damage by *Hylobius abietis* Linnaeus, 1758, *Hylastes ater* Paykull, 1800, *Hylastes opacus* Erichson, 1836, *Hylastes angustatus* Herbst, 1793 on the mortality rate, growth and stem quality is assessed by 2, and the effect of damage by *Hylurgus ligniperda* Fabricius, 1792 on the first two features is 2, and on the stem quality - 3. The total effect on plants was 22 points for *Hylobius abietis*, 13–14 points for *Hylastes* species, and 8 points for *Pissodes castaneus* De Geer, 1775 (Meshkova and Sokolova 2017).

Foliage browsing insects

Prediction of foliage browsing insects includes an estimation of the most likely location of pest foci by forest site conditions and stand structure (Meshkova 2006 ab), the dates of seasonal development in a given place and year, and determining the necessity to use insecticides (Meshkova 2018). The criterion for the need to use insecticides is the threat of damage to more than 30% of the foliage of coniferous trees and more than 50% of the foliage of deciduous trees (Tymchenko et al. 1988).

The level of crown damage by larvae of foliage browsing insects is calculated based on data on critical and actual population density (specimens/tree). The critical density of foliage browsing insects is the number of the first instar larvae per tree, according to which they can consume 100% of foliage during the feeding period.

The critical density of foliage browsing insects is calculated according to the foliage phytomass per one tree and forage rate of given insect species. The phytomass of the foliage of the main forest tree species in artificial and natural stands is evaluated for different natural zones of Ukraine (Lakyda et al. 2011).

The forage rate of a given foliage browsing insect is the foliage mass that is consumed by one specimen for development from hatching to pupation. Since dry foliage phytomass is given in the tables of "Standards ..." (Lakyda et al. 2011), we recalculated the forage rates of larvae for the level of 50% relative humidity of foliage. However, the polyphagous insects can feed by the foliage of different tree species with different chemical composition, particularly dry matter content. Such the foliage of European ash (*Fraxinus excelsior* L.) is more humid than the foliage of English oak (*Quercus robur* L.), with dry mass content 43 and 35 % for oak and ash leaf respectively (Lakyda et al. 2011).

The feed rate of three polyphagous insects was compared at consuming the foliage of these two tree species – winter moth *Operophtera brumata* (Linnaeus, 1758): Lepidoptera, Geometridae), brown oak tortrix *Archips crataegana* (Hübner, 1799): Lepidoptera, Tortricidae) and fall webworm *Hyphantria cunea* (Drury, 1773): Lepidoptera, Arctiidae). The feed rate of *H. cunea* is 7.7 and 8.8 higher than those of *O. brumata* and *A. crataegana* respectively. At the same contents of dry mass in foliage (50 %) the feed rate of all tested insects is the same in oak and ash, and the critical population density is 2.2 higher for oak (Table 4).

Table 4 Critical population density of some polyphagous foliage browsing larvae for healthy (the Ist health condition) oak and ash trees (d = 20 cm, h = 20 m) depending on dry mass contents in the foliage (Meshkova et al. 2015) (foliage dry mass is 4.2 and 1.9 kg for oak and ash respectively (Lakyda et al. 2011).

Insect species	Feed rate (g of dry mass) at dry mass contents, %			
	50 oak	50 ash	43 oak	35 ash
Archips crataegana	0.28	0.28	0.24	0.19
Operophtera brumata	0.32	0.32	0.28	0.22
Hyphantria cunea	2.46	2.46	2.12	1.72
	Critical population density, larvae per tree			
Archips crataegana	15000.0	6785.7	17759.0	9870.1
Operophtera brumata	13125.0	5937.5	15261.6	8482.1
Hyphantria cunea	1707.3	772.4	1985.3	1103.4

Because the larva consumes more foliage, if it contains less water, at the same dry mass contents, the critical population density of fall webworm is 7.7 and 8.8 less than those of winter moth and brown oak tortrix respectively, and critical density of all analyzed insects is 1.8 higher for oak than for ash.

We took into account that the phytomass of foliage depends on the health condition of the tree. Therefore, if the phytomass of a healthy tree is taken as a 1, then the phytomass of a weakened tree (2 class of health condition) is equal to 0.8, severely weakened tree (3 class) 0.4, and drying tree (4 class) 0.16 of the phytomass of a healthy tree of this species. So the population density of larvae to consume 100 % foliage of the healthy tree is 1.25; 2.5 and 6.25 higher than for the trees of the 2nd, 3rd, and 4th class of health condition (Table 5).

Table 5 Critical population density of foliage browsing insects (thousands of the Ist instar larvae per one tree) in oak and ash trees of different health condition (d = 20 cm, h = 20 m) (Meshkova et al. 2015) (dry mass contents in foliage is 43 and 35 % for oak and ash respectively (Lakyda et al. 2011)

Insect specieS	Class of oak health condition				Class of ash health condition			
	I	II	III	IV	I	II	III	IV
Archips crataegana	17.8	14.2	7.1	2.8	9.9	7.9	3.9	1.6
Operophtera brumata	15.3	12.2	6.1	2.4	8.5	6.8	3.4	1.4
Hyphantria cunea	2.0	1.6	0.8	0.3	1.1	0.9	0.4	0.2

To determine the level of crown damage by foliage browsing insects in a given stand, it is necessary to assess the average index of the health condition according to the assessment of at least 100 trees selected at random.

The population density of foliage browsing insects is estimated by methods adopted in forest protection and recalculated to one tree. If the insects are counted in the litter, their number is recalculated per crown projection of 1 tree. If the insects are counted on the cut model branches, the average number of individuals on one branch must be multiplied by the number of branches in one tree. If the females of geometrids are counted in the trapping belt on the stem, the average number of eggs in the abdomens and the average number of eggs per tree must be evaluated by the multiplication of these parameters.

In cases where not the 1st instar larvae are counted, but other stages, which assessment requires less time and labor, it is necessary to determine the density of the 1st instar larvae, using data on the survival of insects at certain stages of development. If the coefficients for recalculating the number of insects of the studied species, determined at different instars and stages, are not known, it should be assumed that the survival of pupae, adults, and eggs is 0.5, 0.9, and 0.8 respectively.

For species recorded at the pupa stage (eonymphs, pronymphs), it is necessary to consider the proportion of females and fertility of adults. For example, 10 pupae of winter moth were recorded per tree, the fertility of females is 50 eggs, the proportion of females is 0.6. Then the density of the 1st instar larvae is calculated as follows:

$10\times0.5\times0.6\times50\times0.9\times0.8 = 108$ 1st instar larvae/tree

To determine the threat of damage to crowns by larvae, a table is selected for the respective natural zone, tree species, stand origin (natural forest or plantations), insect species, and a class of health condition of stand and compared with observed data.

For example, if the critical (tabulated) density of the first instar larvae is 10 specimens/tree, and the observed density is 3 specimens/tree, the expected level of damage to the crowns will be: $3\times100/10 = 30\%$

Xylophagous insects

Xylophagous insects can cause physiological damage to living trees and/or technical damage to living, dead, and felled trees. The health of living trees can deteriorate if the galleries of xylophages cut off the supply of water and nutrients from the roots to the crowns, as well as in the case of significant damage to foliage, shoots, or branches at maturation feeding and if pathogenic bacteria, fungi or other harmful organisms penetrate the tree. The wood quality of living, dead and felled trees can deteriorate as a result of galleries gnawing and the spread of blue-stain and wood-destroying fungi (Lieutier et al. 2004, Six 2012, Meshkova 2018).

For a quantitative assessment of the harmfulness of xylophages, a scoring system was developed about 50 years ago (Mozolevskaya 1974), which takes into account the effect of these insects on the health of living trees and on the timber quality. The calculation algorithm has been described many times (Meshkova and Kukina 2011, Kukhta et al. 2014, Meshkova 2017, Skrylnik et al. 2019), so we give it schematically.

Evaluation of harm from stem pests includes:

i) General harmfulness = technical damage × physiological damage × correction coefficient (1 – for one-generation per year, 2 – for two generations per year, and 0,5 for development during two, and more years).

ii) Physiological damage = physiological activity (ability to colonize trees of different health condition) + ability to damage the trees during maturation feeding + ability to vector the pathogens.

iii) Technical damage = general wood destruction × colonized area × damaged wood value.

iv) By the general harmfulness score, all studied xylophagous insects were referred to four groups, namely, highly harmful (the general harmfulness is 80 and more points), moderately harmful (20–79 points), low harmful (10–19 points), and non-harmful (less than 10 points) (Mozolevskaya 1974).

Thus, the harmfulness of more than 200 species of xylophagous on Norway spruce (*Picea abies* [L.] Karst) (Kukhta et al. 2014), Scots pine (*Pinus sylvestris* L.) (Skrylnik 2013) and several deciduous species, particularly English oak (*Quercus robur* L.) (Meshkova, Kukina 2011), Silver birch (*Betula pendula* Roth) (Skrylnik et al. 2019) was estimated.

At the same time, a comparison of different populations of the same species indicates a variation in some parameters in different host trees, regions, and depending on additional factors that weaken trees (Meshkova 2017, Skrylnik et al. 2019). For example, the ability to inhabit the trees of the 1st–2nd classes of health condition (healthy and weakened trees) was estimated at 10 points. Insects capable of colonizing trees of the 3rd–4th classes of health condition, coarse woody debris, and timber, obtained 1 point. Insects, capable of colonizing only trees of the 5th–6th classes of health condition (deadwood), stumps, and timber, obtained 0.1 points.

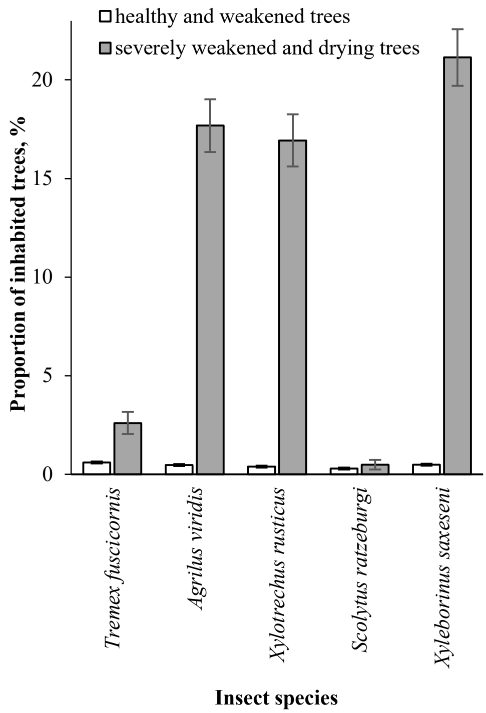

Figure 1 Proportion of silver birch trees of different health condition inhabited by xylophagous insects

Usually, xylophages that inhabit mostly dead trees are not pests. The most dangerous are xylophagous species that inhabit healthy and weakened trees, although even these species prefer severely weakened and dying up trees. Thus, the population of healthy and weakened birch trees with xylophages in the Left-bank Forest-steppe of Ukraine did not exceed 0.6% (Fig. 1), moreover, individual branches, or stem fragments were inhabited.

The frequency of colonization of severely weakened and dying up silver birch trees by rare and common species under these conditions was also low. It was 0.49% for *Scolytus ratzeburgi* Janson, 1856, and 2.6 % for *Tremex fuscicornis* (Fabricius, 1787). At the same time, the widespread insect species – *Agrilus viridis* Linnaeus, 1758, *Xylotrechus rusticus* (Linnaeus, 1758), and *Xyleborinus saxeseni*

(Ratzeburg, 1837) – inhabited about 20 % of trees with such health condition (Figure 1).

At the same time, many xylophages usually inhabit severely weakened trees, but after fire or hurricane they increase their numbers and also inhabit healthy trees, that is, the physiological harmfulness is not 0.1, but 10 points.

Insects which are capable to be a vector of the pathogens were evaluated as 3 points, to be a vector of the wood-destroying fungi as 2 points, to be a vector of the blue stain fungi as 1 point, and score 0 was given to insects that cannot be the vector of a pathogen. In fact, all xylophages passively carry pathogens. Therefore, apart from species inhabiting only dead trees, all others can be rated as 2 or 3 points, depending on the presence of the corresponding pathogens in the habitat.

The technical damage was evaluated as a product of points of an overall score of destruction, colonized area, and damaged wood value (the last coefficient considers the price of timber of given species comparing to other tree species). When assessing the technical harmfulness, the depth of gallery location, their diameter, the colonized surface of the sapwood, as well as inhabited stem part are taken into account. Particularly, the harm of insects, colonizing the stem parts with thick, transitional and thin bark is evaluated by 1.5, 1.3 and 1 points. At the same time, with a high population density of xylophages, they colonize a living tree outside the usual part of the stem, and even more so their location moves on felled trees.

General damage score may be affected by the number of generations (1 point – for one-year generation, 2 points – for two generations per year, and 0.5 points– for two-year development). In a changing climate, many species

Table 6 Injuriousness of some xylophagous insects (min/ max, in points)

Insect species	Host plant	Physiological injuriousness, points	Technical injuriousness, points	Number of generations	General injuriousness, points	Level of harm
Xyleborinus saxesenii (Ratzeburg, 1837)	oak	2	25.2	1 / 2	25.2 / 50.3	moderately harmful
	pine	3	11.2	1	33.5	moderately harmful
	birch	5/14	8.6	1	42.9/120.1	moderately harmful / highly harmful
Agrilus viridis Linnaeus, 1758	birch	4/14	2.0	1	8.1 / 28.3	low harmful / moderately harmful
Mesosa curculionoides (Linnaeus, 1761)	oak	1	8.1	0.5 /1	4.1 / 8.1	non-harmful
	birch	0.1 / 1	2.7	1	0.3 / 2.7	non-harmful
Monochamus galloprovincialis (Olivier, 1795)	pine	4 / 15	12 / 13.8	1 / 1	48 / 207	moderately harmful / highly harmful
Ips acuminatus (Gyllenhal, 1827)	pine	4 / 5	2,8 / 3.6	1 / 2.5	11.2 / 28	low harmful / moderately harmful
Ips sexdentatus (Boerner, 1767)	pine	4 / 5	3.9 / 4.5	1 / 2.5	15.6 / 39	low harmful / moderately harmful

Note: the general harmfulness of highly harmful xylophagous insects is 80 and more points, of moderately harmful species – 20–79 points, of low harmful species – 10–19 points, and of non-harmful species – less than 10 points.

accelerate development, completing a cycle in one year instead of the usual two, or complete the development of additional generation and/or sister broods.

Analysis of the assessment of harmfulness of xylophages shows that some species remain non-harmful on different host trees, for example, *Mesosa curculionoides* (Linnaeus, 1761) (Table 6). *Monochamus galloprovincialis* can be moderately harmful or highly harmful, and *Ips acuminatus* or *Ips sexdentatus* can be low harmful or moderately harmful. *Xyleborinus saxesenii* is moderately harmful to oak and pine, but can be highly harmful to birch.

Conclusions

The injuriousness of regeneration pests in Scots pine plantations up to 5–7 years old is suggested to evaluate by the potential effect on mortality, growth rate, and stem quality considering the damage to needles, buds and shoots, stem and branches, root collar, and roots by direct and indirect symptoms, using respective scores and weight factors.

The crown damage by foliage browsing insects is suggested to evaluate using the data on critical and actual population density, foliage phytomass per tree, and forage rate of given insect species. The phytomass of the foliage of the main forest tree species in artificial and natural stands in different natural zones of Ukraine is suggested to correct considering the health condition of the tree.

The approach and scoring system of Mozolevskaya was used to evaluate physiological, technical, and general harm of more than 200 xylophagous species in coniferous and deciduous trees. The same pest was shown to be non-harmful or low harmful, moderately harmful, or highly harmful in different host trees, regions, and depending on population density and additional factors that weaken trees.

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