Analysis of the tree stands health status in the near border area of Russia and Finland based on the regular grid of sample plots and GIS-technologies

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Abstract. During the summer field season of 2019, the state of stands in the border zone of Russia and Finland was assessed on the basis of previously established regular network of permanent sample plots (PSP) of the ICP-Forests program. The research was conducted on the territory of the Vyborg district of the Leningrad region located closely to Finnish border. PSP are arranged as a regular network with a step of 4-8 km. Each PSP is a 4-element cluster, strongly oriented to North-South and West-East, consisting of 4 subplots, on each of which evaluated the health state of 6 specially selected model trees. Also occurrence of natural damaging factors such as insects, deceases, wind withdrawals, snow and frost damage as well as manmade such as forest fires, air pollution, garbage dump was registered. Special attention was paid to assessing the availability and stock of dead wood. All collected data was put into special database and analyzed using MapInfo 10.0 Professional software to reveal spatial regularities in tree stands health status characteristics. The concept of tree stand “temperature” was used in statistical analysis of trees distribution over damage classes to interpret the tree stands health status in more holistic and transparent way.

1. Introduction

The near border forests health status is of big concern of both countries Russian Federation and Finland first of all because of potential possibilities for cross-border transport of pollutants, forest fires, pests and diseases. This area is relatively dense populated from the both sides of the border has a well developed road network and intensively used for different kinds of economic and social activities including such a sensitive to forest health status as forestry, recreation, tourism, sport, hunting, fishing, ecological farming, education and training. That is why authorities at regional and municipal levels, forest authorities of regional and local levels as well as a number of nongovernmental groups of interests representing local people are interested in the information on study area forests status.

It is reasonable to use for the tree stands health status estimations on study area the level 1 regular grid of PSP established according ICP-Forests methodologies. At least two reasons may be mentioned in favor of such a decision, first, ICP-Forests program was implemented for a long time in both countries, so approximately the same grids of sample plots are already exist in both countries from both sides of the border, second, the methodology of field inspection of sample plots is precisely the same and the results of all estimations and assessments will be comparable, which is very important for between countries comparisons and conclusions.
The spatial aspects of tree stands health status is very important for the analysis of damaging factors spreading over study area and revealing the possible reasons why they took place in particular site especially if took into account its location respectively roads network, industrial plants, settlements etc.

2. Material and methods
The research was conducted on the territory of the Vyborg district of the Leningrad region. The trial areas are arranged as a regular network with a step of 4-8 km. Each trial area (PSP) is a 4-element cluster North-South and West-East oriented, consisting of 4 subplots on each of which was evaluated the state of 6 specially selected model trees. The methods of conducting field work are described in detail in [1] and successfully were widely used in a number of other special researches [2-5].

A total of 106 locations were surveyed, 2 trial areas were surveyed twice, 2 over the past period of time were built up by dacha settlements, 1 burned, 1 cut down, 1 was in a swamp and 1 in an inaccessible place. In total, information about 99 trial areas was included in the database for further processing. In table 1 and in figure 1 data on the predominant tree species in the surveyed sample areas are given. Six species of woody plants was examined on PSP: Scots pine (Pinus sylvestris), Norway spruce (Picea abies), Birch (Betula pendula), Aspen (Populus tremula), Black alder (Alnus glutinosa) and Gray alder (Alnus incana). Four of them Scots pine, Norway spruce, Birch and Aspen occupied a dominant position on PSP while two species Black and Gray alder were presented by single trees.

![Figure 1](image1.png)

**Figure 1.** Distribution of sample plots over study area (a) and dominating species on sample plots (Scots pine – orange, Norway spruce – violet, Birch – blue, Aspen – green) (b).

| Tree species   | Number of sample plots | Percent, % |
|---------------|------------------------|------------|
| Scots pine    | 59                     | 59.6       |
| Norway spruce | 28                     | 28.3       |
| Birch         | 11                     | 11.1       |
| Aspen         | 1                      | 1.0        |
| Total         | 99                     | 100.0      |

**Table 1.** Dominating tree species on sample plots located in Vyborg district of Leningrad region.
It follows from the table 1 and figure 1 data that on study area dominates two coniferous tree species Scots pine and Norway spruce which together dominate on 87 sample pots or on 87.9% of total sample plots number.

Health status of total number of 2416 trees was estimated according to ICP-Forests methodology based on defoliation and discoloration of trees crown assessments. As a result, each model tree was attributed by health status grade: 0 - full health tree, 1 - slightly damaged, 2 - moderately damaged, 3 - severely damaged and 4 - dead tree. Species distribution of the trees is presented in the table 2.

**Table 2.** Species distribution of the trees estimated on the grid of sample plots.

| Tree species    | Number of trees | Percent, % |
|-----------------|-----------------|------------|
| Scots pine      | 1329            | 55.0       |
| Norway spruce   | 668             | 27.6       |
| Birch           | 383             | 15.9       |
| Aspen           | 31              | 1.3        |
| Gray alder      | 3               | 0.1        |
| Black alder     | 2               | 0.1        |
| **Total**       | **2416**        | **100**    |

Table 2 data also shows the strong prevailing of Scots pine and Norway spruce in total number of model trees assessed on study area in Vyborg district of Leningrad region.

At each PSP on the area of circle of 100 meters in radius from central tree was done registration of some additional characteristics related with tree stands health and vitality: occurrence of infrastructural elements (roads, pipe lines, electric power lines), clear or selective cuttings, thinning, forest fires footprints, wind withdrawals, snow and frost damage to trees, garbage dumps, recreation footprints (fire places, campfire, walking trail).

Mean damage class for all sample plots was calculated as a quantitative measure of forest health status at tree stands level and as an initial data for special GIS layer for spatial analysis. MapInfo 10.0 Professional software was used to reveal spatial regularities in tree stands health status characteristics meanwhile Statgraphics 18-X64 for statistical analysis of the collected field data [6-8].

**3. Results and discussion**

Mean damage class of tree stands dominating by Scots pine, Norway spruce and Birch as a measure of its health status is presented in table 3 and spatial distribution of sample plots with different mean damage class is shown on figure 2.

**Table 3.** Mean damage class of the main forest species and groups of species on the surveyed sample areas.

| Tree species or group of species | Mean damage class |
|---------------------------------|-------------------|
| Scots pine                      | 0.69              |
| Norway spruce                   | 0.40              |
| Coniferous                      | 0.59              |
| Birch                           | 0.28              |
| Broadleaves                     | 0.28              |
| All species                     | 0.54              |
In order to interpret the table 3 data the following scale was used: full healthy tree stands were those with a mean damage class in the range of 0-0.5, slightly damaged 0.51-1.50, moderately 1.51-2.50, severely damaged 2.51-3.50, dying and dead 3.51-4.00. Table 3 data say that stands of all breeds are either healthy (spruce, birch) or slightly damaged (pine), broadleaves are in better condition than coniferous ones, and pine stands are most damaged. In general, the state of stands in the border zone of Russian Federation and Finland on the part of Russia, in the Vyborg district of the Leningrad region, can be assessed as good: 56 sample plots were assessed as completely healthy and 43 as slightly damaged.

![Figure 2](image)

**Figure 2.** Location of sample plots in accordance with the mean damage class (dark green indicates full healthy stands, light green slightly damaged) (a) and sample plots with forest fires footprints of different age (b).

Figure 2 (a) shows that the weakened stands are located mainly in the middle part of the surveyed territory (delineated by red line), the reasons for such placement of weakened tree stands will be investigated further, from a first view the more dense population of that area may be considered as a possible reason of damage to tree stands. On 9 sample plots the footprints of forest fires of different age was detected and mapped on Figure 2 (b), the share of damaged by fires in former time sample plots is as much as 9.1%, main part of them 7 or 77.8% located near roads and settlements, which suggests that the human factor is the cause of fires. During field inspection of sample plots on 16 sites or 16.2% of sample plots total number the slight damage to trees from pests, insects and deceases was detected.

For a more detailed description of the state of stands, the distribution of trees by damage classes was studied and modeled. The distribution of trees by damage class was determined for pine, spruce, birch, and all breeds together. In all cases, an exponential distribution was obtained with high level of accuracy, the coefficient of determination varied from 0.74 to 0.93 (see figure 3). The exponential distribution of trees by damage classes is typical for healthy, weakly or moderately damaged tree stands and allows them to be ranked by an indicator that is conventionally called the "temperature" of tree stands [1]. The inverse of the exponent is the "temperature" of the stand:

$$y = \text{const} \cdot e^{-\frac{1}{T} \cdot x}$$

(1)

here, $y$ is the percentage of trees that have a state score of $x$.

The concept of tree stand “temperature” implemented in the statistical analysis of trees distribution over damage classes offer a possibility to interpret the tree stands health status in more holistic and transparent way using the analogy with assessment of human’s health state and them possible illness by measure of the body temperature. The results of such a specific statistical analysis are presented in the table 4.

Standard or etalon distribution of trees over damage classes also was used to determine and more detailed describe the health state of inspected tree stands. It was shown that in full health tree stands at
least 65% of trees may be healthy, 24% slightly damaged, 8% moderately damaged and 3% severely damaged or dead. On figure 3 the results of statistical analysis of trees distribution over damage classes are presented.

![Figure 3](image)

**Figure 3.** Distribution of the trees over damage classes (a) Scots pine, (b) Norway spruce, (c) Birch and (d) All species. Green colour – field data, red – standard distribution for full healthy tree stands, gray – exponential curve.

From figure 3 we may learn that the healthiest are Birch trees, next Norway spruce and last Scots pine which appear to be slightly damaged. From the last figure 3 also evident the more share of full healthy trees the more high health status of analyzed tree stand. Further analysis of the relationship between the temperature of plantings and the proportion of healthy trees in them is given in table 4.

**Table 4.** “Temperature” of tree stands and the share of full health trees.

| Tree species   | Exponent parameter, $1/T$ | Tree stand “Temperature”, $T$ | Share of healthy trees |
|----------------|---------------------------|-------------------------------|------------------------|
| Scots pine     | 1.595                     | 0.63                          | 0.47                   |
| Norway spruce  | 2.072                     | 0.48                          | 0.68                   |
| Birch          | 3.217                     | 0.31                          | 0.79                   |
| All species    | 1.611                     | 0.62                          | 0.58                   |
From the data table 4 it follows that the "temperature" of stands is inversely related to the proportion of healthy trees in their composition, the fewer healthy trees, the higher the "temperature" of stands, which means that their life condition is worse.

4. Conclusion
As a result of conducted study in the near border forests between Russian Federation and Finland on Russian side forest conditions appears to be quite good. The forested area was sampled according ICP-Forests methodology using regular grid of sample plots which provides the reliable and representative data on tree stands health state for further comparative analysis. As an additional advantage of data collection method applied is the international compatibility of the data for Russian Federation and Finland urgently because forests from both sides of the border are included into the study area. Application of GIS-technologies offers a possibility for spatial analysis of the collected data and help in revealing of possible reasons for forest fires and damage to tree stands which took place on specific sites.

Data collected on trees health status demonstrates that the forests on Russian side of the border are in good shape, Scots pine trees appears to be slightly damaged meanwhile Norway spruce and Birch are healthy, all other species Aspen, Alder gray and Alder black was presented by few trees. The statistical analyses of collected data on distribution of the trees over damage classes allows introducing the concept of tree stands “temperature” which gives more deep insight in tree stands health status and represent it in more holistic and transparent way. Such a concept if will be widely implemented may be especially useful for different kind of comparisons of tree stands health as well as damages between tree species, sites, regions and countries in different kinds of sustainability analysis [9-10].

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References
[1] Eichhorn J et al 2016 Visual Assessment of Crown Condition and Damaging Agents Manual Part IV [In: UNECE ICP Forests Programme Coordinating Centre (ed.): Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests] (Eberswalde: Thünen Institute of Forest Ecosystems) p 54
[2] Alekseev A 2003 Forest Ecosystems Monitoring Text Book 2nd ed. [in Russian – Monitoring lesnykh ekosistem 2-ye izdaniye (Uchebnoye posobiye)] (Saint-Petersburg: Saint-Petersburg State Forest Technical Academy Publishing) p 116
[3] Iacopetti G, Bussotti F, Selvia F, Maggino F and Pollastrini M 2019 Forest ecological heterogeneity determines contrasting relationships between crown defoliation and tree diversity Forest Ecology and Management 448 321-329
[4] Tikhonova E, Tikhonov G, Shevchenko N, Knyazeva S, Plotnikova A, Lukina N and Shashkov M 2017 Tree diversity patterns along the latitudinal gradient in the northwestern Russia Forest Ecosystems 4 27 10.1186/s40663-017-0114-y
[5] Alekseev A 2018 Assessment and Inventory of Forest Ecosystems Biodiversity: Case Study for Karelian Isthmus of Leningrad Region, Russia Open Journal of Ecology 8 305-323
[6] Hansen M, Potapov P, Moore R, Hancher M, Turubanova S, Tyukavina A, Thau D, Stehman S, Goetz S, Loveland T et al 2013 High-Resolution Global Maps of 21st-Century Forest Cover Change Science 342 850-853
[7] Sonti SH 2015 Application of Geographic Information System (GIS) in Forest Management Journal of Geography & Natural Disasters 145 10.4172/2167-0587.1000145
[8] Alekseev A and Nikiforov A 2014 Effects of Topography on the Structure and Productivity of
Forest Landscapes Using 3D Modeling in Terms of the Linsinsky Educational and Experimental Forest *Contemporary problems of ecology* 7 7 816-827

[9] Sheil D and Bongers F 2020 Interpreting forest diversity-productivity relationships: volume values, disturbance histories and alternative inferences *Forest Ecosystems* 7 6 10.1186/s40663-020-0215-x

[10] Karvonen J, Halder P, Kangas J and Leskinen P 2017 Indicators and tools for assessing sustainability impacts of the forest bioeconomy *Forest Ecosystems* 4 2 10.1186/s40663-017-0089-8