Conference Paper

Morphometric Measurements of Scots Pine Needles from Radioactively Contaminated Area

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Abstract

The morphometric indices of needles were investigated in chronically irradiated Scots pine (*Pinus sylvestris* L.) populations from territories that were heavily contaminated by radionuclides as a result of the Chernobyl Nuclear Power Plant accident. The variability in needle weight and length, as well as the fluctuating asymmetry indices were studied in seven contaminated and two reference populations of Scots pine in 2011, 2013, 2014 and 2016. The weight of needles in the contaminated populations was significantly higher than in the reference population; however, the dependence of this index on the level of radiation exposure was not revealed in the studied range of doses. The length of needles differed significantly from the references populations. The effect changed from decreasing to increasing in various years of observation; however, in 2016 this index decreased with the dose rate of β-radiation. The index of fluctuating asymmetry in needle length was significantly higher than at the reference sites during three years and correlated to the estimated annual absorbed dose in 2011 and 2013. No relationship was revealed between the asymmetry in weight of paired needles and radiation exposure.

Keywords: *Pinus Sylvestris* L. / chronic radiation exposure / needle / Chernobyl accident / fluctuating asymmetry

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1. Introduction

Phytotoxic effects of acute impact are well known, but the consequences of long-term chronic exposure to low pollutant concentrations are neither well understood nor adequately included in environmental assessment. The International Commission on Radiological Protection has included pine in the list of Reference Animals and Plants used for the newly developing concept of protecting the environment against radiation

[2]. The aim of this work was to estimate biological effects of chronic radiation impact for pine trees using needle indexes as test-functions.

2. Materials and methods

2.1. Study sites

Investigations were carried out in the most contaminated districts of the Bryansk region of Russia and the Gomel' region of the Republic of Belarus. For the dose rate assessment data were used on radionuclides specific activities (^{137}Cs, ^{90}Sr, ^{238}–^{241}Pu, ^{241}Am) in soil and pine cones, according to the dosimetric model previously developed for calculation of the total (internal + external) radiation dose absorbed by pine trees crowns [9]. The reference sites (Ref and Ref1) and the four impacted sites marked VIUA, SB, Z1 and Z2 are located in the Bryansk region of Russia. The three other study sites, namely Kozh, Mas and Kul, are located in the Gomel' region of Belarus, they were studied only in 2016. The level of radioactive contamination significantly varies from site to site which causes obvious differences in doses to tree crowns from α-, β-, γ-radiations (Table 1). The heavy metal contents in soils and cones are within the background levels [1]. The study sites are similar in climate characteristics, stands of trees are homogeneous.

Table 1: The study sites and estimated annual dose rate in 2016, mGy/yr.

Sites	Dγ	Dβ	Dα	Dsum
Ref	0.024	0.0038	0	0.028
Ref 1	0.219	0.0058	0	0.230
VIUA	9.93	0.090	0	10.0
SB	19.2	0.175	0	19.4
Z1	32.3	0.805	0	33.1
Z2	38.0	0.571	0	38.6
Kozh	3.82	14.2	0.7	18.7
Kul	62.6	4.0	35.1	101.7
Mas	37.4	13.5	77.6	128.5

2.2. Sampling

2-years old needles were sampled from 15 trees at every study-site; there were picked up 20, 40, 40 and 40 paired needles per tree in 2011, 2013, 2014 and 2016, respectively. Morphometric parameters (length, weight) and fluctuating asymmetry (FA) was estimated for paired needles. The length and weight of the needles were measured with an accuracy of 0.5 mm and 0.1 mg, respectively. Indices of fluctuating asymmetry was calculated from the length and weight measurements [3, 8].

2.3. Data statistical analysis

The data values were screened, and statistical outliers were excluded from the calculations. Data from all sites were checked for fitting the Gauss distribution using Shapiro-Wilk's W-test. Significance of difference in the needle length was determined using the Student's t-test. Other indices were not normally distributed, thus we used Mann-Whitney U test to compare the study sites. Correlation analysis was done using the Pearson correlation coefficient. The data are presented as «mean value ± SE». Statistical analysis was performed using MS Office Excel 2003 software and Statistica 8.0.

3. Results

The needle length and weight ranged from 56 to 80 mm and from 18 to 31 mg, correspondingly. Statistically confident correlation of needle length in 2016 was revealed with the dose rate of β-radiation ($r = -0.68$; $p < 0.05$) and the activity concentrations of ^{90}Sr radionuclide in cones ($r = -0.70$, $p < 0.05$). The needle weight on all sites in 2013 and some sites in 2011 and 2016 was significantly higher than at least in one of the reference sites (Fig. 1). The data combined for 4 years showed no correlation of the needle weight with the level of radiation exposure. At that the needle weight in 2013 correlated with 2014 ($r = 0.95$; $p < 0.01$) and 2016 ($r = 0.73$; $p < 0.05$).

In 2014, the FA of needle length was significantly lower than in the reference populations at the VIUA and SB sites. The FA of needle length at the most polluted sites in 2011, 2013, 2016 was significantly higher than at the reference sites (Fig. 2).

Also, the FA of needle length in 2011 correlated with the annual absorbed dose ($r = 0.87$; $p < 0.05$), Dγ ($r = 0.87$; $p < 0.05$), and Dβ ($r = 0.91$, $p < 0.05$). In 2013 this index had a tendency to increase along with the annual absorbed dose ($r = 0.79$; $p = 0.06$)

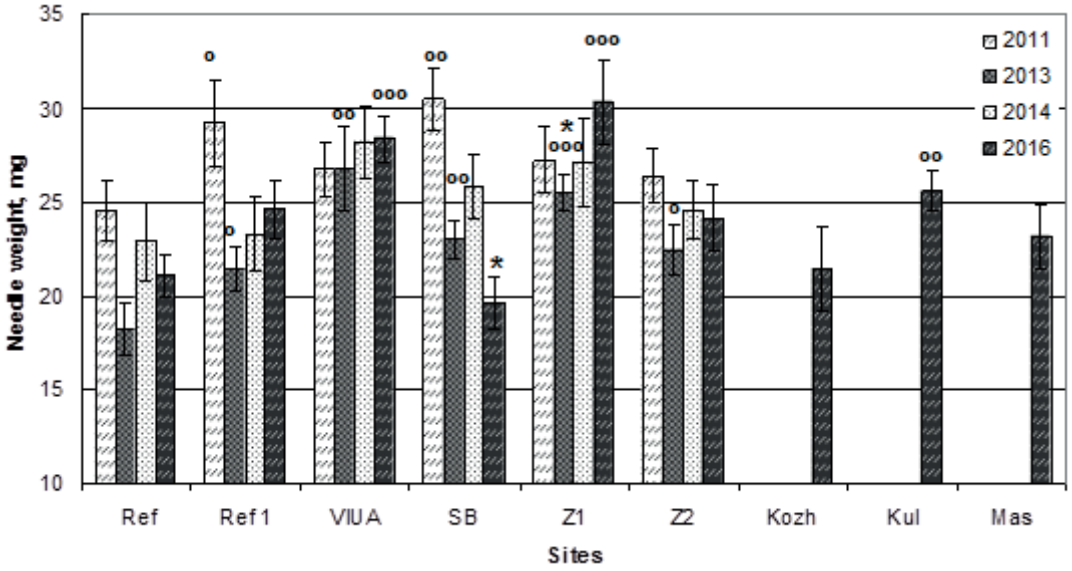

Figure 1: Needle weight in relation to the study sites. Significant difference from Ref: ∘ $p < 5\%$; ∘∘ $p<1\%$; ∘∘∘ $p < 0.1\%$; significant difference from Ref1: * $p < 5\%$.

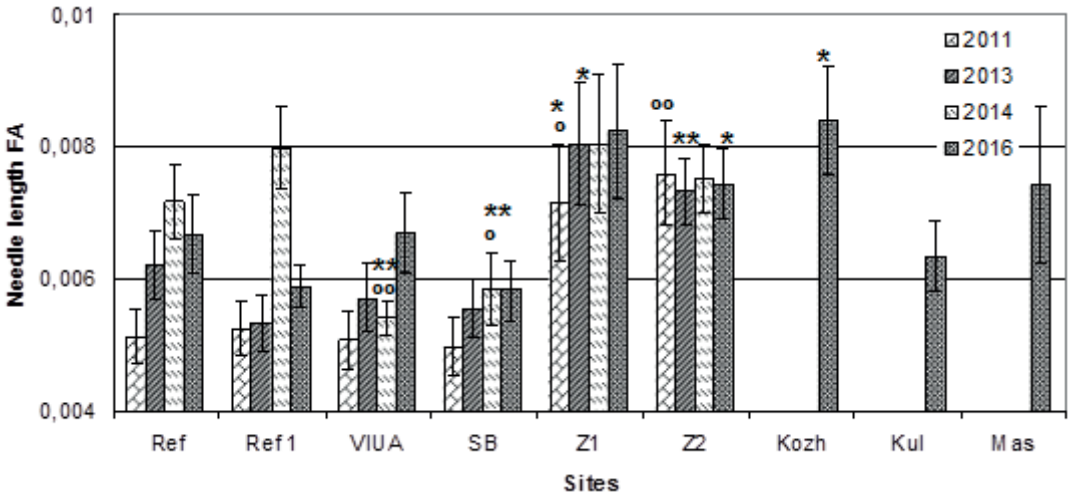

Figure 2: FA index estimated from needle length measurements in relation to the study sites; significant difference from Ref: ∘ $p < 5\%$; ∘∘ $p < 1\%$; significant difference from Ref1: * $p < 5\%$; ** $p < 1\%$.

and Dγ (r = 0.78; p = 0.07), as well as it statistically significantly correlated with Dβ (r = 0.93, $p < 0.01$). The studied parameter increased with the specific activity of ^{137}Cs in soil at the depths of 0–5 cm (r = 0.94, $p < 0.01$ and r = 0.83, $p < 0.05$), ^{137}Cs in the cones (r = 0.91, $p < 0.05$ and r = 0.95, $p < 0.01$) in 2011 and 2013, respectively. The FA of needle length correlated significantly between years of observations: 2011 and 2013 (r = 0.90; $p < 0.05$), 2011 and 2016 (r = 0.83; $p < 0.05$), 2013 and 2016 (r = 0.96; $p < 0.01$). No relationship between the asymmetry in weight of paired needles and radiation exposure were revealed.

4. Discussion

As shown by Kozubov and Taskaev [4], at high doses of 0.7–1 Gy the needle weight could increase up to 153% of the control level. The formation of thickened and shortened needles may be due to a decrease in the auxin synthesis. Auxins are the only group of phytohormones that controls the directional growth motions of plants, as well as the asymmetry of embryonic cell division. The basic auxin functions include cell-cycle control, cell-growth stimulation on the basis of cell elongation, the control of the polarity of plantbody development, photo- and gravitropic reactions, the stimulation of the initiation of lateral and additional roots, and the stimulation of the initiation and development of lateral organs in the shoot apical meristem [5].

The fluctuating asymmetry is defined as non-directional variation between the left and right sides of a bilateral trait, and it may arise as a result of an inability to control development under genetic and environmental stress [6]. The significant correlation between the fluctuating asymmetry of leaves and density of ^{137}Cs contamination was observed [7] for three plant species – *Robinia pseudoacacia*, *Sorbus aucuparia* and *Matricaria perforate* at the radioactively contaminated area with radiation background at least 0.2 μGy/h in 1994. Near the Chernobyl Exclusion Zone, all three species demonstrated levels of developmental instability three to four times higher than in uncontaminated territories away from the Chernobyl area.

5. Conclusions

Thus, significant effects may be observed at the organ level in Scots pine populations experiencing chronic radiation exposure. The increase of the needle weight with the decrease of length and the increase of needle length asymmetry were noticed at the radioactively contaminated areas.

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