ACTA SOCIETATIS
BOTANICORUM POLONIAE
Vol. XLV, nr 1—2
1976

Radioecology of *Picea excelsa* (L.) Lam.

JAN SAROSIEK and IRENA IWEN

Department of Ecology and Nature Protection, Institute of Botany, Wrocław University, Wrocław

(Received: August 6, 1975)

Abstract

Within the area of the radiation anomaly near Kowary (Sudeten Mountains) the spruce (*Picea excelsa*) occurs in habitats with natural soil gamma radiation within 0.05—1.48 mR/h. By way of detailed ecological analysis 5 stenotopic habitats of spruce development were selected differing in radiation intensity. In these habitats the intrapopulation variability, radioactivity and ecological properties of the *Picea excelsa* populations were investigated. It was demonstrated that radiation within the above mentioned range is an essential ecological limiting factor, conditioning ecotypic differences in *Picea excelsa*. The limiting influence of radiation is manifested in a high frequency of development anomalies in the spruce population.

INTRODUCTION

Up-to-date radioecological studies from the territory of the Sudeten radiation anomalies demonstrated that natural continuous low-intensity gamma radiation exerts a significant effect on the development of a number of plants (Sarosiek and Wożakowska-Natkaniec, 1967, 1968; Sarosiek, and Leonowicz-Babiakowa, 1970; Sarosiek, 1972; Sarosiek and Wożakowska-Natkaniec, 1973; Sarosiek, Koła and Orda, 1973). The subject of the present investigations were natural spruce seedling populations occurring on the area of the radiation anomaly in the Karkonosze range near Kowary. The aim of the studies was to establish: 1) within what range of natural radiation does *Picea excelsa* grow within the area of this anomaly; 2) does any relation exist between the variability of the basic morphologic and developmental characters of plants of this species and the natural continuous radiation of the substrate; 3) what influence has this radiation on the development of these plants in natural conditions. The need of radioecological investigations on plants in natural conditions is stressed among other authors by Aleksahin (1968) Tihomirov (1972) and Sarosiek (1973).

MATERIAL AND METHODS

Within the anomalous area 4 habitats were selected with developing spruce seedlings and one habitat outside the anomaly, but belonging to the same forest community. These stenotopic habitats as regards edaphic and microclimatic conditions were chosen on the basis of detailed analysis of 9 habitats with elimination from further studies of extremal ones. The selected habitats differed from one another only by the radiation intensity of the substrate. Gamma radiation of the soil surface in the *Picea excelsa* habitats was measured during the vegetation season 1972 (May 8, July 18 and Oct. 17) with a universal type UR-4M radiometer with a STS-8 counter and range from 0.005 to 10 mR/h.

Analysis of the chemical properties of the soil characteristic for these habitats was performed by routine methods (Kowaliński et al., 1959; Koter, 1954; Peterburgski, 1947). In order to reveal the differences in intrapopulation variability of the spruce plants in habitats with different radiation intensity biometric analysis was performed of 7 morphological characters of this species (for list of characters see table 3). Each population from the chosen 5 habitats was represented by 30 plants randomly chosen. The results of biometric measurements were elaborated by mathematical-statistical methods. The method of parallel analyses with 1 factor was applied (Barbacki, 1951).

Total geta-radioactivity of the plants was measured by the scintillation method in the Isotope Laboratory of the Institute of Soil Science, Cultivation and Fertilization in Laskowice Oławskie.

RESULTS

1. Characteristic of habitats

Spruce self-sown seedlings in the investigated habitats grow on mountain brown acid soil degraded by mining activities. The chemical characteristic of the soil is given in table 1. These soils of loamy-sandy type contain moderate amounts of nitrogen and phosphorus and are rich in potassium but calcium deficient. They are characterized by a relatively high uranium content (7×10^{-3} to 71×10^{-3} % uranium in the soil (Saro-

Table 1

Chemical properties of soil from the microhabitats of *Picea excelsa*

No.	Properties	Range of values from 9 microhabitats in Kowary	Range of values from 5 selected microhabitats
1	Organic substance contents (%)	7.92—12.25	8.11—10.07
2	pH	4.5	4.5
3	Hydrolytic acidity	3.11—7.10	3.11—5.82
4	Total exchangeable acidity	0.72—9.05	4.70—8.22
5	Sum of exchangeable cations	4.15—12.08	5.04—11.47
6	Nitrogen contents (%)	0,21—0.43	0.32—0.39
7	P_2O_5 mg/100g	2.11—5.05	2,26—2,51
8	K_2O mg/100g	12,5—48.7	18.0—20.3
9	Ca mg/100g	20.7—27.3	21.3—26.5
10	Mg mg/100g	19.2—28.3	23.1—28.1
11	Mn mg/kg	28.30—78.00	31.25—37.26

siek, 1972). Gamma radiation of the soil surface is shown in table 2. Changes in radiation intensity in the vegetation period are conditioned by the periodically enhanced water circulation. Spruce seedlings in habitats within the radiation anomaly grow within the range of natural continuous low-intensity gamma radiation of the soil surface of 0.05—1.48 mR/h. They grow on open spaces forming loose groups without any contribution of competitive tree species. Habitats were selected in which spruce seedlings grow in full light, because, as demonstrated by McCormick and McJunkin (1965), shading changes the radiosensitivity of the seedlings. The community to which numerous spruce seedlings belong is composed of few species, large areas within it are occupied by bryophyte synusia (Sarosiek, 1975).

Table 2

Radioactivity levels (mR/h) of soil in microhabitats of *Picea excelsa*

Microhabitats	Spring	Summer	Autumn
I	0.05—0.22	0.04—0.18	0.05—0.20
II	0.42—0.45	0.37—0.40	0.40—0.42
III	0.60—0.86	0.52—0.76	0.58—0.80
IV	1.11—1.48	1.02—1.32	1.08—1.40

2. Analysis of ecological spruce populations

Statistical-mathematical analysis demonstrated significent differences between the *Picea excelsa* plants from habitats with different intensity natural radiation as regards morphological characters (Table 3). Even-aged seedlings in the populations from habitats with higher intensity gamma radiation are lower than those from habitats not exposed to radiation (character 1). In habitat I with lowest radiation the spruce seedlings show a reduction of growth by 25 per cent. In habitats III and IV, that is those with high-intenstiy radiation the growth of the seedlings is inhibited in more than 50 per cent. As regards the height of the plants the population from habitat I does not differ significantly from that in habitat II.

Table 3

Mean values of morphological characters of populations *Picea excelsa*

No.	Characters	Populations					Dt
		I	II	III	IV	V	
1	Height of plants, cm	31,2	26.8	20,2	18.6	41.8	2.988
2	Increase of terminal shoot between 3-th to 4-th year	2.36	1.70	1.10	1.05	3.80	0.654
3	Increase of terminal shoot between 8-th to 9-th year	4.96	4.78	1.71	1.39	4.67	1.211
4	Increase of terminal shoot in last year	2.66	2.08	1.50	1.49	2.00	0.628
5	Length of longest lateral shoot of I order in IV node	15.77	15.63	13,85	11.26	22.99	2.716
6	Number of lateral shoots of I order	28.9	28.6	29.5	19.3	34.1	4.718
7	Length of needles	0,882	0.799	0.643	0.644	1.067	0.074

A significant difference was found in extension growth of shoots between the spruce seedling populations from the habitat with normal radiation level, and the populations from habitats with enhanced radiation (character 2). It was noted that the growth increment of the leader in spruce seedlings is the smaller between the 3rd and 4th year the higher the radiation intensity of the substrate. Thus the growth limitation was highest in habitat IV with highest radiation.

Seedlings from habitats I and II with lowest radiation did not show growth inhibition of the leader between the 8th and 9th year. There seemed even to be a certain tendency to growth stimulation as compared with that of plants in the habitat with normal radiation (V).

Seedlings from populations III and II originating from habitats with the highest radiation level show a smaller growth increment between the 8th and 9th year, by about 60—70 per cent (character 3).

The spruce seedling population from habitats with the lowest radiation differs from that outside the anomaly by a greater growth increment of the leader in the last year (character 4). Populations from habitats with the highest radiation intensity show inhibitation of growth of the leader.

The longest I order lateral shoots in the 4th whorl distinguish the seedling population from the habitat where radiation is not enhanced. Analogous shoots of mean length are characteristic for the population from habitats with the lowest radiation (I and II), whereas the shortest shoots were observed in the population from the habitat with highest radiation (IV).

The largest number of lateral shoots (character 6) was found in the population growing outside the anomalous area. The population in the habitat with highest radiation intensity showed the lowest number of lateral shoots. Populations from habitats I, II and III had a number of lateral shoots lower by 14.7 per cent.

Spruce seedling populations from the anomalous area were characterized by a reduced length of the needles. This reduction of needle length is the greater the higher the radiation intensity of the substrate in the habitat (character 7).

3. Developmental anomalies of *Picea excelsa* seedlings

In the spruce seedlings from all habitats on the area of the radiation anomaly in Kowary morphological modifications were found, mainly of the type of anomalous development (table 4). The most conspicuous anomaly of these seedlings was a distinct inhibition of growth, and in extreme cases dwarfism. Limitation of growth was noted in 100 per cent of the

Table 4

Frequency of the developmental anomalies of the seedlings *Picea excelsa* from the area anomaly radiation express of all the plants

No.	Developmental anomalies of plants	% of all the plants	Populations I	II	III	IV
			in percentage			
1	Limith of growth	100	100	100	100	100
2	Dwarfing	27	—	—	25	92
3	Suppression apical dominance of the terminal shoot	21	—	—	11	16
4	Accessorial shoots	46	8	24	28	4
5	Fasciate shoots	10	—	5	6	8
6	Dichotomous of terminal shoots	2.5	—	—	—	2.5
7	Swedlling of needles	94	52	79	100	100
8	Deformations of needles	38	8	8	76	100
9	Adventitious roots	5	—	—	5	2.5

plants examined, whereas dwarfism appeared in only 27 per cent, being most frequent in the habitats with highest radiation intensity. Abolition of apical dominance in the main shoot was observed in 21 per cent of the plants. This inhibition with strong branching and increase of number of lateral shoots of II and III order changes the habitus of the whole plants which form crowns quite different from the average shape. The widest diameter of crowns in anomalously developing plants is shifted towards the apex. The habitus is also affected by the irregular development of I order lateral shoots, their stronger development on one side or unproportional development of shoots from neighbouring whorls. In 46 per cent of the spruce seedlings growing within the radiation anomaly secondary development of accessory shoots from the main shoot was observed, usually very weak and thin ones ending their development within one vegetation season. Ten per cent of the spruce seedlings exhibited fasciation of lateral shoots of various orders. In the habitat with highest radiation intensity one seedling exhibited a dichotomous leader. This branching had its origin in the root neck. Anomalous thickening of the needles and their reduced size showed an incidence of 94 per cent in all the seedlings from the anomalous area. Irregular thicking and deformation of the needles were found in 38 per cent of the plants. These deformations were the more pronounced the higher was radiation in the given habitat. In only as few 5 per cent of the plants and only in habitat III was development of adventitious roots noted from the main shoot without damage of the latter.

4. Radioactivity of spruce needles

Analysis of total beta-radioactivity of needle ash from the investigated seedlings demonstrated that the spruce populations from the area of anomalous radiation exhibit a high beta-activity, on the average 909.69

Table 5

Total beta-radioactivity of the needles *Picea excelsa*

Populations	beta-activity in pC/g ash	
from radiation anomaly		
I	763.75 ± 33.35	
II	$884,25 \pm 43.12$	mean
III	1038.40 ± 35.26	value
IV	952.38 ± 37.90	909.69
without radiation anomaly		
V	439.08 ± 20.45	

pC/g of ash (Table 5). The population from beyond the anomaly, thus beyond the aureola of primary uranium dispersion in the substrate shows a much lower beta-radioactivity of 439.08 to 20.45 pC/g of needle ash.

DISCUSSION

The common spruce is a species with a wide ecological scale. Therefore, according to Aichinger (1967), on the basis of soil characteristic (Table 1) the habitats of the population examined could be considered as stenotopic, differing from one another only be the intensity of gamma radiation. The significant differences found in the morphological characters of the plants of the particular populations may only be ascribed to the raised chronic low-intensity gamma radiation of the substrate within the anomalous radiation area within the limits of 0.05 to 1.48 mR/h (Table 2). Confirmation of this view may be found in the papers of McCormick and Cotter (1964), Kowalsky, Worotniskaya and Lekarev (1967), Sarosiek and Wożakowska-Natkaniec (1967). Investigations of these authors demonstrated that continuous low-intensity gamma radiation within the above mentioned range is a significant ecological factor. Evidence of the effect of radiation on the spruce seedlings within the anomalous radiation area is found in the above described developmental anomalies of the seedlings with an incidence of 20—100 per cent of all plants (Table 4), whereas outside the anomalous territory development disturbances in the seedlings manifest in their morphology do not reach a frequency of 2 per cent.

Spruce seedlings from the anomalous radiation area exhibit a growth limitation which, according to Gunckel (1965), is a typical reaction of plants to radiation. According to this author, the physiological mechanism of this phenomenon has so far not been unequivocally elucidated. Probably radiation inactivates auxins. Medvediev (1970) believes that this is the consequence of an increase of growth inhibitor content in the plants. The inhibition of seedling growth is the greater the higher the radiation in the substrate. Such a relation has been experimentally established in various plants, among others in *Antirrhinum* by Schneck (Gunckel, 1965).

In the investigated habitats with lower radiation intensity (0.05—0.45 mR/h) larger growth increments of the leaders of spruce seedlings were noted than in the habitat outside the radiation anomaly. This may be the effect of growth stimulation due to natural radiation. The phenomenon of plant growth stimulation by low-intensity radiation in natural or experimental conditions is known among other plants in *Tradescantia paludosa* (Gunckel et al. 1953), *Sedum pulchellum* (McCormick and

Rushing, 1964), *Marchantia polymorpha* (Sarosiek and Wożakowska-Natkaniec, 1967, 1968).

Intensive branching of spruce seedlings in habitats with high natural radiation as the consequence of restriction of apical dominance of the leader may, according to Gunckel (1965), be considered as a typical modification due to radiation. Modification of this type evoked by low-intensity continuous radiation of the substrate in natural conditions in *Erigeron canadensis* has been described by Woodwell and Oosting (1965) and in *Symphytum officinale* by Sarosiek and Leonowicz-Babiakowa (1970).

Reduction of leaf size and their thickening are frequent changes caused by radiation (Gunckel and Sparrow, 1961). The decreases in size and thickening of spruce needles are the more pronounced the higher is the continuous low-intensity radiation in the habitat. This was also noted in *Pinus rigida* by Sparrow, Schairer and Woodwell (1964).

Total beta activity of spruce needles from the area of anomalous radiation was higher than the same value for seedlings from outside it. It was also higher than the mean value of normal beta-radioactivity reported by Grodziński (1965) for gymnosperms (700 pC/g of ash). This stresses the ecological diversity of the habitats of spruce within the radiation anomaly area.

CONCLUSIONS

1. Ecological *Picea excelsa* seedling populations from the anomalous area of low-intensity gamma radiation in the substrate within the range of 0.01 to 1.48 mR/h significantly differ from seedling populations from outside the anomaly by their length, habitus, high frequency of developmental anomalies and enhanced beta-radioactivity of ash reaching an average of 909.69 pC/g.

2. Continuous low-intensity substrate radiation within the above mentioned range limits in natural conditions growth of spruce seedlings by 25 to 50 per cent, abolishes apical dominance, stimulates development of accessory shoots and adventitious roots at the base of the main shoot, causes dwarfism of the seedlings and their intensive branching as well as flatness of the shoots and dichotomy with decrease in size, thickening and deformation of the needles.

3. Growth limitation and incidence of developmental anomalies are the greater the higher the radiation intensity. All reactions of spruce seedlings to continuous low-intensity radiation are most pronounced in habitats with radiation intensity of 0.52 to 1.48 mR/h.

4. Radiation within the limits of 0.05 to 0.20 mR/h stimulates in natural conditions spruce seedling growth between the 8th and 10th year of their life.

REFERENCES

Aichinger E., 1967. Pflanzen als forstliche Standortsanzeiger. Österreichischer Agrarverlag Wien, 367 pp.

Aleksakhin P. M., 1968. Sovremiennoie sostoianiie i zadachi radiacionnoi biogeoconologii. Voprosy Radioekologii, 8—31, Atomizdat, Moskva.

Barbacki S., 1951. Doświadczenia kombinowane. PWRiL, Warszawa p. 1—36.

Grodziński D. M., 1965. Estiestviennaya radioaktivnost rastienii i pochv. Izd. Naukova Dumka, Kiew, p. 216.

Gunckel J. E., 1965. Modyfication of plant growth and development induced by ionizing radiations. Encyclopedia of Plant Physiology. 15 (2): 365—367. Springer--Verlag, Berlin-Göttingen — Heidelberg.

Gunckel J. E. and Sparrow A. H., 1961. Extermal factors, affecting growth and development. Encyclopedia of Plant Physiology, 16: 555—611, Springer-Verlag, Berlin—Göttingen—Heidelberg.

Gunckel J. E., Sparrow A. H., Morrow J. B. and Christensen E., 1953. Vegetative and floral development of irradiated and non-irradiated plants of *Tradescantia paludosa*. Am. Jour. Bot. 40: 317—332.

Koter M., 1954. Gleba jako środowisko wzrostu i rozwoju roślin. PWN, Warszawa—Olsztyn, p. 279.

Kowaliński St. et al., 1959. Ćwiczenia z gleboznawstwa i podstaw mineralogii z petrografią (Skrypt s. 317). Wyd. W.Sz.R. we Wrocławiu.

Kowalsky V. V., Worotniskaya I. E. and Lekarev S. V., 1967. Biogeochemical food chains of uranium in aquatic and terraneous organisms. Radioecol. Conc. Processes — Proc. Intern. Symp. Stockholm, 5: 329—333.

McCormick J. F. and Cotter D. J., 1964. Radioactivity on southeastern granite outcrops. The Bull. of the Georgia Acad. of Science 22 (1): 1—9.

McCormick J. F. and McJunkin R. E., 1965. Health Phys. 12 (1467).

McCormick J. F. and Rushing Wm. N., 1964. Differential radiation sensitivities of races of *Sedum pulchellum* Michx., a useful method of plant identification. Radiation Botany 4: 247—251.

Medvediev A. I., 1970. O wliyanii ioniziruiushchei radiacii na sodierzhanie inhibitorov rosta v rastieniakh. Materialy I Vsiesoj. Simp. po Radiobiol. Rast. Organizma, p: 75—76, Izd. Naukova Dumka, Kiew.

Peterburgski A., 1947. Praktikum po agrochimii. 274 p. Moskwa.

Sarosiek J., 1972. Radioekologia *Marchantia polymorpha* L. w Sudetach. Monographiae Botanicae 28: 161—203.

Sarosiek J., 1973. Z dotychczasowych badań radioekologicznych w Sudetach. Materiały III Zjazdu Pol. Tow. Badań Radiacyjnych Łódź, p: 86—87.

Sarosiek J., 1975. Wpływ naturalnego promieniowania na roślinność hałd pouranowych w Sudetach. Referat na Symp. Radioekologii w Katowicach (in press).

Sarosiek J., Koła W. and Orda A., 1973. The radioecology of *Pogonatum urnigerum* (L.) Pal. Beauv. Acta Soc. Bot. Pol. 42 (2): 241—252.

Sarosiek J. and Leonowicz-Babiakowa K., 1970. The effect of a chronic gamma radiation upon *Symphytum officinale* L. under natural conditions. Ekologia Polska 18 (22): 453—464.

Sarosiek J. and Wożakowska-Natkaniec H., 1967. Response of *Marchantia polymorpha* L. to chronic gamma radiation under natural conditions. Acta Soc. Bot. Pol. 36 (1): 187—197.

Sarosiek J. and Wożakowska-Natkaniec H., 1968. The effect of low--level acute gamma radiation on the growth of *Marchantia polymorpha* L.

originating from various ecological populations. Acta Soc. Bot. Pol. 37 (2): 241—252.

Sarosiek J. i Wożakowska-Natkaniec H., 1973. Konkurencja między gatunkami *Drepanocladus uncinatus* i *Mnium pseudopunctatum* przy różnych poziomach ciągłego promieniowania w warunkach naturalnych. Materiały III Zjazdu Pol. Tow. Badań Radiacyjnych, Łódź, pp: 84—85.

Sparrow A. H., Schairer L. A. and Woodwell G. M., 1964. Tolerance of *Pinus rigida* trees to a ten-year exposure to chronic gamma irradiation from cobalt-60. Radiation Botany 5: 7—22.

Tihomirow F. A., 1972. Dejstwie ionizirujushchikh izłuchenii na ekologicheskie sistemy. Atomizdat, Moskwa pp. 174.

Woodwell G. M. and Oosting J. K., 1965. Effects of chronic gamma irradiation on the development of old plant communities. Radiation Botany 5 (3): 205—222.

Authors address:
Doc. dr Jan Sarosiek
dr Irena Iwen
Institute of Botany of Wrocław University
Kanonia 6/8; 50-328 Wrocław; Poland

Radioekologia Pice excelsa (L.) Lam.

Streszczenie

W obrębie anomalii radiacyjnej koło Kowar w Sudetach świerk *Picea excelsa* występuje w siedliskach o naturalnym promieniowaniu gamma podłoża w granicy od 0,05 do 1,48 mR/h. Na podstawie szczegółowej analizy ekologicznej wybrano 5 stenotopowych siedlisk rozwoju świerka różniących się między sobą poziomem ciągłego promieniowania gamma podłoża (tabele 1 i 2). Populacje 10-letnich siewek świerka z wybranych siedlisk poddano analizie biometrycznej (tabela 3). Analiza statystyczno-matematyczna wykazała istotne różnice między populacjami siewek świerka z terenu anomalii radiacyjnej a populacją spoza anomalii. Populacje siewek świerka z terenu anomalii radiacyjnej różnią się istotnie od populacji spoza anomalii wzrostem, pokrojem, dużą frekwencją anomalii rozwojowych (tabela 4) i zwiększoną beta-radioaktywnością (tabela 5). Ich ogólna beta-radioaktywność wynosi średnio 909,69 pC/g popiołu igieł, gdy tymczasem beta-aktywność siewek spoza anomalii wynosi tylko 439,08 pC/g popiołu igieł.

Ciągłe, niskopoziomowe promieniowanie podłoża o podanym zakresie w naturalnych warunkach ogranicza wzrost siewek świerka od 25 do 50%, znosi apikalną dominację pędu głównego, pobudza do rozwoju pędy akcesoryczne i przybyszowe korzenie u nasady pędu głównego, powoduje skarlenie siewek, deformację ich koron, silniejsze ich rozkrzewienie, ponadto wywołuje staśmienia i dichotomię pędu oraz pomniejszenie, zgrubienie i deformacje igieł.

Ograniczenie wzrostu i częstotliwość anomalii rozwojowych siewek świerka są tym większe, im wyższe jest promieniowanie podłoża. Wszystkie reakcje siewek świerka na ciągłe, niskopoziomowe promieniowanie najdobitniej manifestują się dliskach o promieniowaniu podłoża w zakresie od 0,52 do 1,48 mR/h.

Promieniowanie w granicy od 0,05 do 0,20 mR/h w warunkach naturalnych stymuluje wzrost siewek świerka między 8 a 10 rokiem życia.