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Comparative analysis of the bryophyte floras of northwest Belarus concrete fortification and the Carpathians

Anastasia Sakovich[1] & Gennadij Rykovsky[2]

[1]Department of Botany, Faculty of Biology and Ecology, Yanka Kupala State University of Grodno, Ozheshko 22, Grodno, 230022, Republic of Belarus, e-mail: anastasia_pryaz@inbox.ru
[2]V. F. Kuprevich Institute of Experimental Botany, Belarusian National Academy of Sciences, Academic 27, Minsk, 220072, Republic of Belarus, e-mail: dr.rykovsky@yandex.by

Abstract: The detailed research of bryophyte flora, carried out in 2008-2011 on fortifications from the times of the First World War and Second World War in Grodno district, resulted in recording 101 species, of which 95 species were true mosses (Bryophyta) and 6 species were hepatics (Marchantiophyta). Because the substratum displayed certain ecological similarity with carbonate rocks, we made comparative analysis of the species list. The total of 28 rare and very rare (in Belarus scale) bryophyte species were recorded, of which 3 species were included in the Red Data Book of Belarus; 3 species had a conservation status at the European level.

Key words: bryophyte flora, concrete fortifications, carbonate rocks, comparative analysis

1. Introduction

In general, within a region, bryophyte floras retain more ancient features than vascular floras. At the same time, the mobility of bryophytes should not be undervalued. This mobility is a consequence of pioneer strategy in settling ‚vacant' places and various substrata. This strategy sharply distinguishes bryophytes from vascular plants which are characterized by greater dependence on the substratum because of the presence of developed root system. In addition, vascular plants possess well differentiated integumentary tissue and endohydric conductive tissue. The features of bryophyte organization allow their early settling of anthropogenic substrata which are usually not occupied by tracheophytes for a long time or at all. However, anthropogenic substrata are usually colonized by bryophytes after a time, when their surface undergoes some destruction, e.g. due to exposure to weather conditions, which are sufficiently unstable in Belarus owing to temperate climate. Concrete constructions, and first of all, fortifications erected to fend off enemy attack, draw a special attention in Belarus because of their bryophyte flora. These constructions occur more often in the western part of the country. Older fortifications, built before the First World War (WWI), were the most interesting to us, in particular the forts encircling Grodno town which are especially extensive. Another complex of fortifications, Molotov Line, belongs to the times before the Second World War (WWII).

2. Study area and natural conditions

Belarus is situated on the Eastern European Plain. Grodno town is in the west of Belarus (53°6' N, 23°9' E), near the Belarusian Moraine Ridge, on the Nyoman river. The Nyoman river occupies the 5th place among Belarus rivers with respect to the size of its water-collection area and the bulk of water. The lands of Grodno administrative district lie in two physiographic districts, Grodno Eminence (200-250 m a.s.l.) and Nyoman Lowland (50 m a.s.l.) (Zhmoydyak 2009). About 40% of Grodno district area is woodlands. Swamps are not very extensive and, generally, are confined to Nyoman Lowland. Among characteristic features of Grodno Eminence is its kame-moraine-erosion type of landscape

predominated by coniferous forests on sod-podzol soils. Nyoman Lowland is characterized by water-glacial, less often by lake-glacial landscapes with the predominance of mixed forests, consisting of pine, oak, birch and ash. The climate of Grodno town and Grodno district has a transitional character from marine to continental one. The study area lies in a belt of temperate climatic, with the predominance of temperate air masses, the alternation of which creates unstable type of weather, especially in winter period. Grodno district is situated in the zone of sufficient moistening, with 600-650 mm of rainfall per year. The main part of rainfalls is associated with cyclone activity. The dominance of the Atlantic air determines high relative air humidity. Mean atmospheric pressure is 1017 mm of mercury in winter and 1013 mm in summer. Average temperatures are 13 to15˚C from April to October and -2 to -3˚C from November to March (Klimat Grodno 1982). Thus, Grodno district has moderately continental climate, meeting the requirements of many bryophyte species, the evolution of which occurred in similar conditions.

3. Material and methods

Field floristic research was carried out by the detailed route and total recording methods (Zhukova 2000) in 2008-2011, embracing 12 forts of Grodno fortress, and also 12 pillboxes of the 68th Ukrepraion (Molotov Line). The main studied materials were bryophyte samples deposited in the herbaria of Grodno State University (GRSU) and V. F. Kuprevich Institute of Experimental Botany (MSK-B). Morphology and anatomy of bryophytes were examined by means of conventional light optical devices. Specimens were identified by a widely accepted method of comparative anatomy and morphology (Ignatov & Ignatova 2003, 2004; Rykovsky & Maslovsky 2004, 2009). Species nomenclature and taxonomy followed (Ignatov *et al*. 2006) with the following modification: we did not distinguish the Polytrichopsida class, taking into account that the phylogenetical distance between Bryopsida and Polytrichopsida is sufficiently smaller than between this class and Sphagnopsida and Andreopsida (Rykovsky 2010). Geographical elements were determined following (Lazarenko 2001; Rykovsky & Maslovsky 2004, 2009). Comparisons of the studied bryophyte flora with floras of the Ukrainian and Polish Carpathians in order to find a relationship in their origin were carried out according to (Zerov & Partyka 1975; Stebel & Ochyra 2008; Stebel *et al*. 2010). The description of studied fortifications is given below.

Grodno fortress. The forts studied in this research are permanent defensive points of support an were constructed in 1912-1915. They stretch over the distance of about 60 km, which classifies the fortifications as a fortress of broad arrangement. According to the initial project, the fortress was to have consisted of 16 forts. In the subsequent plan, the number of forts was reduced to 13. The construction works were supposed to finish in 1917. Grodno was declared a fortress in August 1913, but works on the main fortress line were only beginning at that time. By the beginning of WWI, none of the forts was at least 50% ready. Construction work in the fortress did not stop almost till the evacuation in August 1915 despite the outbreak of the war and proclamation of siege. Before the retreat of the Russian army from Grodno, an order was issued to destroy all fortifications of the line which was achieved with different degree of success. Fort IV is the single completely preserved facility (Pivovarchik 2006).

Molotov Line. When the area of Western Belarus became part of the Soviet Union and the frontier moved, the building of a new fortification line started with urgency. The fortification was given an unofficial name 'Molotov Line'. The 68th Grodno Fortification Area ('Ukrepraion') was built in 1940-1941 in the vicinity of Augustów Channel. The construction was not finished by the beginning of the war, but on the 22 June, 1941 the pillboxes accepted the thrust of hostile forces. Grodno Fortification Area was the most powerful of the all fortifications erected in the west of the country. The total of 606 pillboxes along the front of 80 km of the Nyoman river, west of Sopockin and to Goniądz town was planned to be built with the defence area of 5-6 km in depth. However, by the 1st of June, 1941, only 165 constructions were erected, of which 67 were in Sopockin uezd (Pivovarchik 2006).

4. Results and discussion

These fortifications, appearing as artificial rock-like, carbonate-enriched habitats, can play a role of suitable ecotopes for settling of some mountain bryophytes in plain areas. A part of species, having mountain ecology, is historically present in flora of Belarus. But some of them could enter Belarus later, from the Ukrainian and Polish Carpathians. The latter species are of the greatest interest with respect to florogenetics. As a result of long-term effect of various natural factors on concrete fortifications, their initial characteristics underwent changes. Also the destruction of the fortifications in WWI, which led to the appearance of many microniches suitable for various species played an important part in the development of bryophyte flora. Moreover, the devastation of the surface of these constructions continues permanently. It leads to the development of semi-natural plant communities with bush and tree levels, with shadowed conditions and wetter microclimate. The surface of the constructions is being covered by tree litter, while sand and humus

are drifted here by water flows and by wind, and so pH and trophic characteristics of the substratum change.

An important factor is also the washout of carbonates from concrete constructions, indicated by the presence of stalactites and stalagmites in some constructions dated from WWI. This process should lead to decrease in substratum alkalinity. The presence of a wide range of bryophyte ecological groups, from basiphilous to acidophilous species, characterized by different attitude to humidity and trophic features of the substratum, is associated with the processes described above. Thus a wide spectrum of humidity morphs and trophic morphs of the species is observed here, along with various substrata-preference groups (epigeious, epixylous, epilithic, epiphytic and polytopic species). The specificity of concrete fortifications is underlined by the presence of calcephilic bryophytes.

All in all, we recorded 101 bryophyte species on the studied fortifications. They were mostly Bryopsida (95), with only 6 species of Hepaticopsida. The dominant families comprised: Brachytheciaceae (15 species), Amblystegiaceae (9), Bryaceae (9), Orthotrichaceae (9), Pottiaceae (9), Mniaceae (6), Grimmiaceae (5) and Pylaisiaceae (5). According to the number of genera, the leading families were: Amblystegiaceae (7), Pottiaceae (7), Brachytheciaceae (7), Pylaisiaceae (4), Grimmiaceae (3), Hylocomiaceae (3). The most numerous genera included: *Orthotrichum* (9 species), *Bryum* (9), *Brachythecium* (8), *Plagiomnium* (5). The systematic list of the taxa is given in the Appendix 1.

The bryophyte flora of concrete fortifications was compared by us with the flora of the Carpathians as a probable source of settling new species in Belarus. In all, in the Carpathians we counted 583 species of Bryopsida; 372 species are known from the Western Carpathians (Stebel & Ochyra 2008; Stebel *et al.* 2010) and 461 from the Eastern Carpathians (Zerov & Partyka 1975). The similarity of the studied flora is about the same with the Western and Eastern Carpathians. From the flora of the studied fortifications, 9 species are unknown in the Western Carpathians (*Bryum algovicum*, *B. creberrimum*, *B. schleicherii*, *Campylidium sommerfeltii*, *Dicranella cerviculata*, *Mnium marginatum*, *Orthotrichum gymnostomum*, *Rhynchostegium confertum*, *Stereodon fertilis*) and 4 in the Eastern Carpathians (*Bryum klinggraeffii*, *Orthotrichum cupulatum*, *Schistidium crassipilum*, *Tortula mucronifolia*). As seen from the published data, 2 species from the list (*Bryum warneum* and *Grimmia muehlenbeckii*) are unknown in the entire Carpathians. Of the species recorded, 42 are known on carbonate substrata (limestones, concrete walls, carbonate soils) in the Western Carpathians and 58 – on carbonate substrata in the Eastern Carpathians.

The species preferring rock and stony substrata are classified as (properly) epilithic ones. First of all, they are 9 following species: *Campyliadelphus chrysophyllus*, *Didymodon rigidulus*, *Encalypta streptocarpa*, *Orthotrichum cupulatum*, *Schistidium crassipilum*, *Syntrichia virescens*, *Tortella tortuosa*, *Tortula mucronifolia*, *T. muralis*. These species are more peculiar to concrete constructions, but the species with other ecological preferences occur here, with the exception of hyperacidophilic ones. Epiphytic, epigeous and broad ecology species are found on concrete constructions as well because of the heterogeneity in ecological conditions of these habitats.

Most probably, the latitudinal migration vector to Belarus of most of these bryophyte species with mountain ecology, spreads from the Carpathians and their foothills, because it is the nearest mountain system. We believe that the defensive Molotov Line and other concrete constructions (Pivovarchik 2006) constituted a significant element in the development of mountain species migration flow from the Carpathians to the north (Belarus and Baltic states). They served as a migrational 'channel' or ecological corridor for spreading rock-inhabiting calciphilic species (first of all, bryophytes) to plains. We believe that a probable drift of mountain species of bryophytes in Belarus occurred in the following ways: (*i*) by wind flows (owing to the predominance of western winds), creating 'outposts' and 'exclaves' on the appropriate artificial substrata (an optimum condition of such substrata is that they should be long time out of human use); (*ii*) with building materials (rocks), which were used in constructing fortifications; (*iii*) by birds.

According to distribution pattern within Belarus, 48% of the species, recorded by us, had various degree of rarity; 15% of the species need different conservation measures in the country. These two groups include: exceptionally rare, very rare, rare and fairly rare species. From them, *Tortella tortuosa*, *Bryum klinggraeffii* and *B. schleicherii* are included in the Red Data Book of Belarus (2005) under CR, EN and EN categories, respectively. *Tortella tortuosa* is known in Belarus in two more localities only (Smorgon and Braslav districts); the second known locality for *Bryum klinggraeffii* is in Belovezhskaya Pushcha, and for *B. schleicheri* – in Mozyr district. We recorded the second locality in Belarus for *Schistidium crassipilum* and *Tortula mucronifolia*. The species from this study, which need preventive conservation measures, are *Orthotrichum gymnostomum* and *O. patens* (Red 2005). *Bryum warneum* was recorded by us on concrete fortifications in two localities. Earlier it was known for Belarus only from the data published a long time ago. This species should be included in the next edition of the Red Data Book of the Republic of Belarus (CR). Three species of those recoded by us belong to European red list: *Bryum warneum*, *Orthotrichum patens*, *Stereodon fertilis*

(Red 1995). The latter species is probably rare in Belarus, but has not a conservation status yet.

5. Conclusions

The detailed research of bryophyte flora carried out by us in 2008-2011 on fortifications built in the course of WWI and WWII in Grodno district, resulted in recording 101 species, of which 95 species were true mosses (Bryophyta) and 6 species were hepatics (Marchantiophyta). Because the substratum displayed certain ecological similarity with carbonate rocks, we carried out florogenetic analysis of the species list, and hypothesized probable ways of migration of a sufficient part of these species (first of all, calcium-preferring) to the study area from the Carpathians. The total of 28 rare and very rare (in Belarus scale) bryophyte species was recorded, of which 3 species were included in the Red Data Book of Belarus; 3 species obtained a conservation status at European level. Today, following our proposals, the habitats of some rare species (*Bryum klinggraeffii*, *Encalypta streptocarpa*, *Orthotrichum cupulatum*, *O. patens*, *Tortella tortuosa*) on the studied fortification objects were placed under protection.

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Appendix 1. List of species occurring in the Eastern (*) and Western (^{V}) Carpathians.

Bryobionta, Bryophyta, Bryopsida, Polytrichales, Polytrichaceae: *Polytrichum formosum* Hedw.*^{V}, *Polytrichum juniperinum* Hedw.*^{V}, *Atrichum undulatum* var. *undulatum* (Hedw.) P. Beauv.*^{V}; **Funariales, Funariaceae:** *Funaria hygrometrica* Hedw.*^{V}; **Encalyptales, Encalyptaceae:** *Encalypta streptocapra* Hedw.*^{V}; **Grimmiales, Grimmiańeaĺ:** *Grimmia muehlenbeckii* Schimp., *Grimmia pulvinata* Hedw.*, *Racomitrium canescens* Hedw.*^{V}, *Schistidium crassipilum* H. H. Blom.^{V}, *Schistidium apocaprum* Hedw.*^{V}; **Dicranales, Dicranaceae:** *Dicranella heteromalla* Hedw.*^{V}, *Dicranella cerviculata* Hedw.*, *Dicranum scoparium* Hedw.*^{V}, *Dicranum flagellare* Hedw.*^{V}, **Ditrichaceae:** *Ceratodon purpureus* Hedw.*^{V}, *Ceratodon purpureus* f. *purpureus* Hedw., **Pottiaceae:** *Barbula unquiculata* Hedw.*^{V}, *Bryoerythrophyllum recurvirostrum* Hedw.*^{V}, *Didymodon rigidulus* Hedw.*^{V}, *Tortella tortuosa* Hedw.*^{V}, *Tortula mucronifolia* Schwaegr.v, *Tortula muralis* Hedw.*^{V}, *Syntrichia virescens* De Not.*^{V}, *Syntrichia ruralis* Hedw.*^{V}, *Weissia controversa* Hedw.*^{V}, **Fissidentaceae:** *Fissidens adianthoides* Hedw.*^{V}; **Orthotrichales, Orthotrichaceae:** *Orthotrichum anomalum* Hedw.*^{V}, *Orthotrichum diaphanum* Brid.*^{V}, *Orthotrichum cupulatum* Hedw.*^{V}, *Orthotrichum obtusifolium* Brid.*^{V}, *Orthotrichum pallens* Bruch ex Brid.*^{V}, *Orthotrichum patens* Bruch ex Brid.*^{V}, *Orthotrichum pumilum* Sw.*^{V}, *Orthotrichum speciosum* Ness.*^{V}, *Orthotrichum gymnostomum* Bruch ex Brid.*; **Splachnales, Meesiaceae:** *Leptobryum pyriforme* Hedw.*^{V}; **Bryales, Bryaceae:** *Bryum argenteum* Hedw.*^{V}, *Bryum caespiticum* Hedw.*^{V}, *Bryum capillare* Hedw.*^{V}, *Bryum creberrimum* Tayl.*, *Bryum klinggraeffii* Schimp.^{V}, *Bryum warneum* Roehl., *Bryum schleicheri* DC.*, *Bryum moravicum* Podp.*^{V}, *Bryum algovicum* Sendtn. ex Muell. Hal.*, **Mielichhoferiaceae:** *Pohlia nutans* Hedw.*^{V}, **Mniaceae:** *Mnium marginatum* Dicks.*, *Plagiomnium affine* Bland.*^{V}, *Plagiomnium cuspidatum* T. J. Kop.*^{V}, *Plagiomnium elatum* Bruch *et al.*^{V}, *Plagiomnium ellipticum* Brid.*^{V}, *Plagiomnium undulatum* Hedw.*^{V}; **Hedwigiales, Hedwigiaceae:** *Hedwigia ciliata* (Hedw.) P. Beauv.*v; **Hypnales, Leucodontaceae:** *Leucodon sciuroides* Hedw.*^{V}, **Hypnaceae:** *Hypnum cupressiforme* Hedw.*^{V}, **Pylaisiaceae:** *Stereodon fertilis* Sendth.*, *Stereodon pallescens* Hedw.*^{V}, *Pylaisia polyantha* Hedw.*^{V}, *Calliergonella cuspidata* Hedw.*^{V}, *Callicladium haldanianum* (Grev.) H. A. Crum*^{V}, **Neckeraceae:** *Homalia trichomanoides* Hedw.*^{V}, **Leskeaceae:** *Leskea polycarpa* Hedw.*^{V}, **Pseudoleskeellaceae:** *Pseudoleskeella nervosa* Brid.*^{V}, **Thuidiaceae:** *Abietinella abietina* Hedw.*^{V}, *Thuidium assimile* Mitt.*^{V}, **Plagiotheciaceae:** *Plagiothecium laetum* Bruch *et al.*^{V}, **Amblystegiaceae:** *Campylium stellatum* Hedw.*^{V}, *Campyliadelphus chrysophyllum* Brid.*^{V}, *Campylidium sommerfeltii* Myrin.*, *Amblystegium serpens* Hedw.*^{V}, *Hygroamblystegium varium* Hedw.*^{V}, *Hygroamblystegium juratzkanum* Schimp.*^{V}, *Dreponacladus polycarpus* Hedw.*^{V}, *Serpoleskea subtilis* Hedw.^{V}, **Plagiotheciaceae:** *Plagiothecium laetum* Bruch *et al.*^{V}, **Scorpidiaceae:** *Sanionia uncinata* Hedw.*^{V}, **Brachytheciaceae:** *Brachytheciastrum velutinum* (Hedw.) Ignatov & Huttunen*^{V}, *Brachythecium rivulare* Bruch *et al.*^{V}, *Brachythecium campestre* Muell. Hal.*^{V}, *Brachythecium salebrosum* F. Weber & D. Mohr*^{V}, *Brachythecium rutabulum* Hedw.*^{V}, *Brachythecium albicans* Hedw. (Schimp.)*^{V}, *Brachythecium mildeanum* Schimp.*^{V}, *Brachythecium starkei* Brid.^{V}, *Sciuro-hypnum populeum* (Hedw.) Ignatov & Huttenen*^{V}, *Sciuro-hypnum oedipodium* (Mitt.) Ignatov & Huttunen *^{V}, *Homalothecium lutescens* Hedw.*^{V}, *Homalothecium sericeum* Hedw.*^{V}, *Oxyrrhynchium hians* Hedw. Loeske*^{V}, *Eurhynchium angustirete* (Broth.) T. J. Kop.*^{V}, *Rhynchostegium confertum* (Dicks.) Schimp.*, **Hylocomiaceae:** *Pleurozium schreberi* Brid.*^{V}, *Hylocomium splendens* Hedw.*^{V}, *Rhytidiadelphus squarrosus* Hedw.*^{V}, *Rhytidiadelphus triquetrus* Hedw.*^{V}, **Climaciaceae:** *Climacium dendroides* Hedw.*^{V}; **Marchantiophyta, Marchantiophytina, Marchantiopsida, Marchantiales, Conocephalaceae:** *Conocephalum conicum* L., **Marchantiaceae:** *Marńhantia polymorpha* L.; **Jungermanniopsida, Jungermanniales, Lophocoleaceae:** *Chiloscyphus latifolius* (Nees) J. J. Engel *et* R. M. Schust., *Chilosńóphus polyanthus* L., **Plagiocchilaceae:** *Plagiochila porelloides* (Torrel ex Ness) Lindenb., *Radula complanata* L.