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Reconstruction of a coastal raised bog development in the proximal part of the Curonian Spit, Kaliningrad Region, Russia, South-Eastern Baltic

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Abstract. The Holocene development of a peculiar coastal peatland (raised bog Svinoye), southern Curonian Spit, Russia, is reconstructed based on the analysis of taxonomic diversity of plant macrofossils and radiocarbon dating of peat and gyttja deposits. The development of the bog can be referred to the primary mire formation, which was preceded by a period of gyttja accumulation (7500–7000 cal. yr BP) in a shallow water body. The mire vegetation development started from 7000 cal. yr BP through the spread of the alder carrs and reed stretches that presumably experienced inundation during transgression events of the forming Baltic over the period 7000–6300 cal. yr BP). These habitats were successively replaced by the communities of the rich fen, transition mire and active raised bog. During the whole post-transgression period

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(6300 cal. yr BP – present time), the vegetation successions were not influenced by the sea-level oscillations but were determined by climatic and anthropogenic factors. The diagrams of the botanical composition of peat enabled to assign and describe 12 formation phases for the Svinoye bog ecosystem. In contrast to the other peatlands in the region, the stage of transition mire persisted here over a long-term period of 1200 years. The formation of a typical raised bog began around 3400 cal. yr BP. As recent as 200 years ago, the ecosystem had the characteristics of a maritime climate mire. The mean peat accumulation rate was defined for the period of the last 7000 year as having the highest values in the Late Atlantic and the Late Sub-Atlantic (1.7–2 mm/yr), while the lowest increment (0.8 mm/yr) is recorded for the whole Sub-Boreal.

Introduction

The raised bog Svinoye is a unique ecosystem within the natural complex of the Curonian Spit in the Russian south-eastern Baltic coast. Large raised bogs are not found in any other sand barrier throughout the shoreline of Baltic. Being a specific habitat, the bog Svinoye defines the peculiar landscape features in the Curonian Spit, especially in its proximal part which has a different history of origin than the rest territory of the spit.

The formation of the Curonian Spit was studied and is still under investigation of a number of researchers [*Badyukova et al.,* 2006, 2007; *Berendt,* 1869; *Dobrotin,* 2018; *Gams,* 1932; *Gaigalas et al.,* 1991; *Gudelis,* 1990, 1998; *Gudelis et al.,* 1993; *Kabailiené,* 1967, 1995; *Kharin et al.,* 2006, 2013; *Michaliukaite,* 1962; *Moe et al.,* 2005; *Paul,* 1944; *Povilanskas et al.,* 2006; *Sergeev,* 2015; *Sergeev et al.,* 2015, 2016; *Wichdorff,* 1919; etc.]. Nevertheless, there are some issues remained concerning the genesis of different parts in this specific geological body. In this respect, the investigation of peat bed and ist botanical composition in the Svinoye bog can elucidate both the questions of the proper bog development and some geological, geomorphological, palaeoclimatic, and palaeoenvironmental issues related to the Curonian Spit and adjacent areas in the Baltic Sea and the Curonian Lagoon.

The article is aimed at providing new insights into temporal development of the Svinoye bog ecosystem during the Holocene based on the analysis of plant macrofossils in peat and outcomes of radiocarbon dating of organogenic mire deposits.

The raised bog Svinoye occupies a greater part of the territory in the proximal side of the Curonian Spit (Figure 1), between the mouth channel of Trostyanka river and the Baltic Sea coast from which it is separated by 300–400 m wide zone of the black alder wet woodland. The peatland has a total area of 238 ha, comprising a 50-ha central site of the open *Sphagnum* dominated raised bog with scattered low pines and major, heavily drained, peripheral part covered by the high pine forest with *Ledum* and *Vaccinium myrtillus*.

Material and Methods

The peat bed coring and further sediment core retrieval were performed both in the central ($54^\circ57'51.4''$ N; $20^\circ31'02.8''$ E, core 1) and the peripheral ($54^\circ57'51.4''$ N; $20^\circ31'02.8''$ E, core 2) parts of the bog (Figure 1c). Successive 0.5-m long peat monoliths were sampled using the Russian peat corer (TBG-1 model). The coring was executed according to the standard technique and methodological guidelines [*Minkina,* 1939].

Starting from the horizon 7.5 m in the core 1 and from the horizon 6.0 m in the core 2, the peat sam-

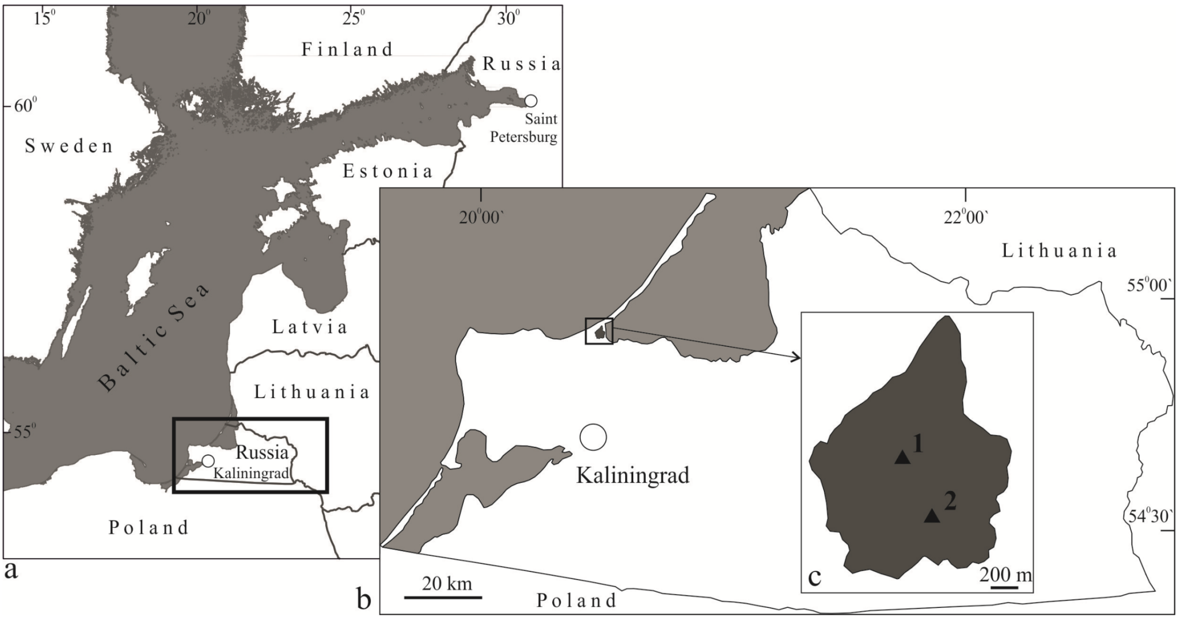

Figure 1. Sketch map of the study area (a) and the site of investigation (b, c). Locations of the boreholes for taking samples are indicated by the triangles.

ples were analysed under the microscope for taxonomic identification of plant macrofossils. The laboratory treatment of each peat sample included its cleaning, elutriation and estimation of decomposition degree [*Piavtchenko,* 1963]. The wet sample of peat was cleaned under running water on a 250-μm sieve (grid № 025K) to remove textureless humus particles. Then, the specimen of cleaned peat was examined under the microscope (Micromed-3 model) to determine the taxonomic identity of plant macrofossils and estimate the percentage ratio of different plant residues in a sample.

The identification of plant macrofossils in peat was performed using a range of identification keys and guides [*Dombrovskaya et al.,* 1959; *Katz et al.,* 1977; *Korotkina,* 1939; *Matyushenko,* 1939a, 1939b].

The species names in Latin are cited according to the *Cherepanov*'s check-list [1995] for vascular plants, and the "Check-list of mosses in Eastern Europe and Northern Asia" [*Ignatov et al.,* 2006] for bryophytes.

Four samples from the core 1 were dated using radiocarbon scintillation method in the Radiocarbon Laboratory of the Institute of Geography, Russian Academy of Sciences (Moscow, Russia), laboratory index "IGAN". Obtained radiocarbon dates were calibrated using the programme CALIB (version 7.1.0 ^{14}ChronoCentre, QueensUniversityBelfast) and the calibration curve IntCal13 [*Reimer et al.,* 2013].

As an integration of the outcomes of the macrofossil analysis [*Napreenko and Napreenko-Dorokhova,* 2019] with the estimation of peat decomposition degree and radiocarbon dating (Table 1), the summary diagrams of vegetation successions (Figure 2) have been plotted for each sediment core using C2 software (Juggins S., C2 Version 1.7.6. [Electronic resource], 2014. Mode of access: https://www.staff.ncl.ac.uk/stephen.juggins/software/C2Home.htm). The assigned stages of vegetation depict the dominating plant communities in the mire during different periods of the Holocene over the last 7300 years (Figure 2a, Figure 2b).

The age of the stages was calculated through the interpolation procedure between two known calibrated radiocarbon dates.

Results

Two sediment cores (10.0 and 6.5 m respectively) were retrieved and studied in course of investigation. The core 1 is represented by various types of peat in the upper part (8.6–0.0 m) and by a thin layer of gyttja

Table 1. Radiocarbon Dating of Peat and Gyttja Samples in the Raised Bog Svinoye

Depth of sampling, m	Lab. № (IGAN)	Radiocarbon age, (^{14}C), BP	Calibrated age interval for 1σ cal. yr BP beginning–end	probability
1.25–1.15	4801	800 ± 90	**664–796**	**0.933**
			875–892	0.067
2.55–2.45	4803	1930 ± 70	**1814–1952**	**0.894**
			1958–1987	0.106
5.70–5.60	4804	4950 ± 80	**5596–5748**	**0.954**
			5831–5843	0.046
8.95–8.85	4807	6390 ± 80	**7264–7341**	**0.540**
			7348–7417	0.460

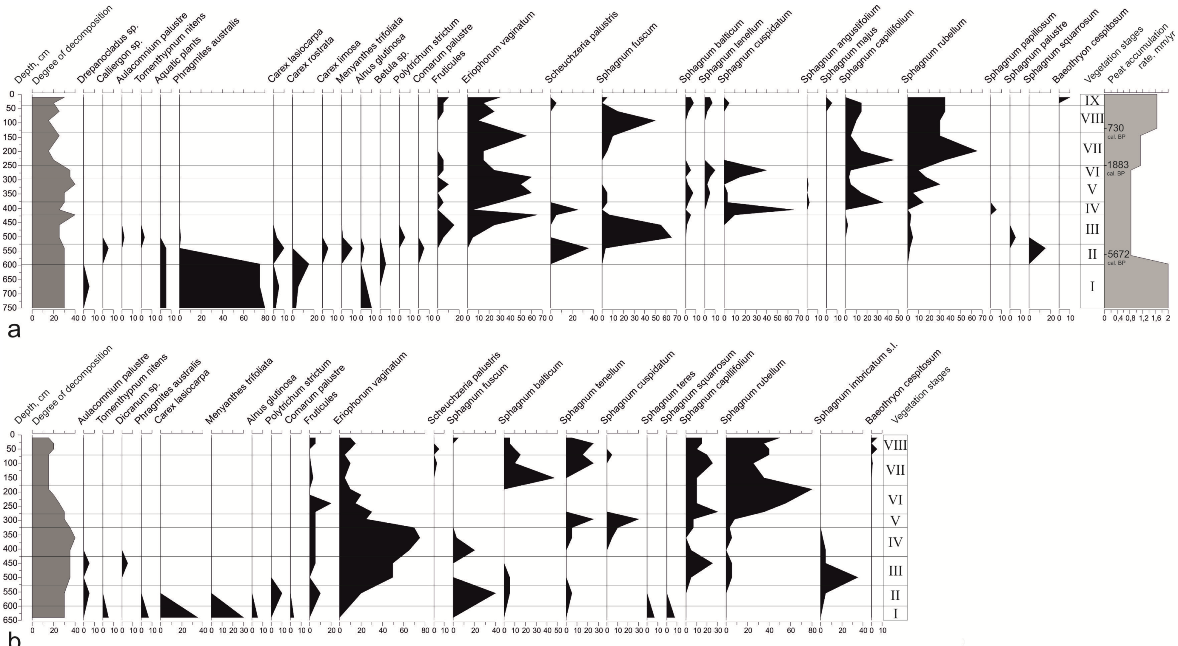

Figure 2. Botanical composition of peat and stages (successions) of vegetation on the raised bog Svinoye: a) sediment core 1, b) sediment core 2.

in the basal part (8.95–8.60 m), the lower horizons of which yielded a radiocarbon age of 7300 cal. yr BP (Table 1). The lowermost segment in the core 1 (10.0–8.95 m) is represented by clay with sand. The core 2 consists entirely of peat deposits.

The core 1 contains a 3-m thick layer of swamp and fen peat (8.6–5.0 m). The lower part of it, 8.6–7.0 m, consists of highly decomposed peat with a large number of ligneous residues (apparently, Alnus). This part of the peat bed was studied primarily in the field without the use of microscopic methods. The interlayer 7.5–7.0 is heavily water-logged, forming a peat suspension in water in some places. The upper layers (6.50–5.25 m) contain mainly herbaceous residues of *Phragmites*, *Carex* and *Scheuchzeria*, and represented by the same types of fen peat.

In the core 2, the fen peat composes only the basal 50 cm (6.50–6.00 m) and contains a very small amount of ligneous residues.

A distinct layer of the transition mire peat is recorded within the horizon 5.25–4.25 m in the core 1 and 6.00–4.25 m in the core 2. It is referred to as *Sphagnum* transition mire peat since the remnants of Sphagna dominate in its composition in both cores.

The upper part of the peat bed (4.25–0.00 m) is formed by the *Sphagnum* and *Sphagnum-Eriophorum* raised bog peat in both cores, wherein there is a clear decline of the decomposition degree for the *Sphagnum* peat from the horizon of 2.5–2.0 m. Thus, the upper part of the peat bed (the raised-bog peat bed) in the Svinoye bog is divided into two layers: the lower one with the high degree of decomposition (35–40%) and the uppermost one with the low degree (15–20%).

The uppermost surface layer (0.15–0.00 m) consists of highly decomposed *Sphagnum* peat, mineralized as a result of the bog drainage during last century.

Based on the data of the botanical composition of peat, we assigned 9 stages of vegetation (local macrofossil assemblage zones, LMAZ) for the sediment core 1 in the central part of the bog (Figure 2a).

Stage I (*Phragmites – Drepanocladus*), 6300–5800 cal. yr BP. The zone is marked by a high content of rhizomes and radices of *Phragmites* (up to 80%). Among the accompanying residues found in different ratios, there are roots of sedges (*Carex* sp.) and different aquatic plants (not identified), leaves of the hydrophilic mosses (*Drepanocladus* sp.), and ligneous remnants of alder (*Alnus glutinosa*). This stage reflects the vegetation of monodominant reed stretches with the flooded sites occupied by the hydrophilic communities of mosses and minor herbaceous. Peat accumulation reaches here a maximum rate of 2 mm/yr.

Stage II (*Scheuchzeria* + *Carex* + *Menyanthes* – *Sphagnum squarrosum*), 5800–5200 cal. yr BP. This stage is defined by the dominating residues of fen species such as Rannoch-rush (*Scheuchzeria palustris*), sedges (*Carex lasiocarpa, C. rostrata, C. limosa*), buckbean (*Menyanthes trifoliata*), purple marshlocks (*Comarum palustre*), and eutrophic fen mosses (*Sphagnum squarrosum, Calliergon sp.*). The remains of birch bark (*Betula* sp.) were also found in a small amount. The stage corresponds to a rich-fen habitat with considerable herb diversity and patchy vegetation. The peat accumulation rate has more than twofold decreased – 0.8 mm/yr.

Stage III (*Eriophorum* + *Fruticules* – *Sphagnum fuscum*), 5200–4000 cal. yr BP, is characterized by the dominance of *Sphagnum fuscum* residues (up to 60–70%). There is a considerable percentage of cotton grass (*Eriophorum vaginatum*) and dwarf shrubs (Ericaceae). The bryophytes of different mire types are distinct: *Polytrichum strictum*, *Tomenthypnum nitens*, *Aulacomnium palustre, Sphagnum palustre*. The stage corresponds to phytocoenoses of the transition mire which were gradually transforming into a raised bog.

The peat accumulation remained at the same rate of 0.8 mm/yr.

Stage IV (*Scheuchzeria* – Sphagna), 4000–3400 cal. yr BP, is defined by the dominance of the hydrophilic *Sphagnum* species – *S. cuspidatum* (over 60%). The radices of *Scheuchzeria palustris* are also in abundance. A distinct component here is *Sphagnum papillosum*, a species of the flat and moist hummocks on coastal bogs. The stage reflects the herb- and *Sphagnum*-dominated vegetation of wet bog carpets and soaks. The peat accumulation rate is 0.8 mm/yr.

Stage V (*Eriophorum* + Fruticules – Sphagna), 3400–2600 cal. yr BP, is characterized by the dominance of *Eriophorum vaginatum* and hummock-forming *Sphagnum* species: *S. rubellum* and *S. capillifolium*. Dwarf shrubs and some species of moist depressions, *Sphagnum balticum, S. tenellum, S. cuspidatum*, are present in a small amount. The stage corresponds to an open raised bog occupied by numerous hummocks of *Eriophorum* and Sphagna. The peat accumulation rate is 0.8 mm/yr.

Stage VI (*Sphagnum cuspidatum* + *S. tenellum*), 2600–1900 cal. yr BP. There is a distinct predominance of the hydrophilic hollow species of Sphagna: *S. cuspidatum, S. tenellum, S. balticum*. The percentage of hummock-forming Sphagnum species and cotton grass decreased markedly. This composition matches to the vegetation cover of wet depressions on hummock-hollow bog complexes. The peat accumulation rate remains at 0.8 mm/yr, while increases at the end of the stage.

Stage VII (*Eriophorum* – Sphagna), 1900–850 cal. yr BP, is similar to the LMAZ V. *Eriophorum vaginatum, Sphagnum rubellum* and *S. capillifolium* dominate in different proportions, while the dwarf shrub percentage is insignificant. The stage corresponds to the hummock vegetation of the open raised bog. The peat accumulation rate increases up to 1.1 mm/yr.

Stage VIII (*Sphagnum rubellum + S. fuscum*), 850–200 cal. yr BP. The hummock-forming species as *Sphagnum rubellum* and *S. fuscum* dominate, while the portion of *S. capillifolium*, cotton grass and dwarf shrubs declines. The stage corresponds to phytocenoses of large and medium-size hummocks on an open raised bog. The peat accumulation rate reaches 1.7 mm/yr.

Stage IX (*Baeothryon + Scheuchzeria* – Sphagna), 200–100 cal. yr BP. *Sphagnum rubellum* continues to dominate. *S. capillifolium, S. tenellum, S. balticum, and S. cuspidatum* are recorded in a small amount. A peculiar characteristic of the stage is an appearance of an Atlantic species, the tufted bulrush (*Baeothryon cespitosum*). The amount of cotton grass and dwarf shrubs increases. The stage reflects the vegetation of an open raised bog with low hummocks and *Sphagnum* carpets natural for the coastal bogs of a maritime climate. The peat increment remains at a high rate of 1.7 mm/yr.

During the last 100 years, the formation of raised bog Svinoe is marked by a stronger influence of anthropogenic disturbance resulted in significant drainage and essential compositional change of vegetation. The present-day bog vegetation stage is to be defined as *Calluna* + *Eriophorum* – Sphagna for the central part, and *Pinus* – *Ledum* + *Vaccinium* for the forested edge zone.

Similar to the first sediment core, there have been assigned 8 vegetation stages (LMAZ) for the core 2 from the peripheral bog zone (Figure 2b).

Stage I (*Menyanthes* + *Carex* – *Sphagnum squarrosum*) is correlated with stage II in the core I from the bog centre. Residues of *Carex lasiocarpa* and *Menyanthes trifoliata* are dominant. A distinct presence of mosses *Sphagnum squarrosum, S. teres, Tomenthypnum nitens* is also recorded. Remains of *Phragmites and Alnus* (bark) are in a small amount. The stage corresponds to a fen with rich biodiversity and patchy vegetation.

Stage II (*Eriophorum* + Fruticules – *Sphagnum fuscum*) is correlated with stage III in the core I. This local zone is defined by the dominant moss remains of *Sphagnum fuscum* (up 40%) and abundant residues of *Eriophorum vaginatum*, ericaceous dwarf shrubs, and some species of different types of mires (*Polytrichum strictum, Aulacomnium palustre, Sphagnum imbricatum* s.l.). The stage corresponds to transition mire habitats which were gradually transforming into a raised bog.

Stage III (*Eriophorum – Sphagnum imbricatum + S. capillifolium*). The dominant plant remains are cotton grass and two species of mesotrophic hummock mosses: *Sphagnum imbricatum* and *S. capillifolium* (over 60% for both). The green moss remains (*Aulacomnium palustre Dicranum* sp.) and dwarf shrubs are recorded in a small amount. The stage reflects the vegetation of transition mire dominated by cotton grass and Sphagna.

Stage IV (*Eriophorum – Sphagnum fuscum*) can be, to a certain degree, correlated with stage V in the core 1. The residues of *Eriophorum vaginatum* and *Sphagnum fuscum* distinctly prevail in this local zone. The remains of dwarf shrubs are present in a small amount. The percentage of other species is insignificant. The stage represents the vegetation of an open raised bog dominated by hummocks of *Sphagnum* and *Eriophorum*.

Stage V (*Sphagnum cuspidatum* + *S. tenellum*) completely matches stage VI in the core 1, is also defined by the prevalence of hydrophilic hollow species of Sphagna (*S. cuspidatum* and *S. tenellum*) with the distinctly fewer percentage of cotton grass remains. The stage corresponds to water-logged depressions on the raised bogs.

Stage VI (*Eriophorum – Sphagnum rubellum*) is correlated with stage VII in the core 1 and defined by the dominant moss remains of *Sphagnum rubellum* accompanied by the residues of *Eriophorum vaginatum, S. capillifolium* and dwarf shrubs. The stage corresponds to the vegetation of hummocks on an open raised bog.

Stage VII (*Sphagnum balticum* + *S. tenellum* + *S. rubellum*) with correlated stage VIII in the core 1. The dominant plant residues are remains of Sphagnum species representing different microhabitat ecology, both the hollow species – *Sphagnum balticum, S. tenellum*, and the hummock-forming ones – *S. rubellum* and *S. capillifolium*. The remains of cotton grass are in small amount. The stage represents communities of different microtopography elements on a patterned raised bog with hollow-hummock complex.

Stage VIII (*Baeothryon* + *Scheuchzeria* – Sphagna) is correlated with stage IX in the core 1. The dominant species are the same as in the previous local zone: *Sphagnum rubellum, S. tenellum, S. capillifolium*, and *S. balticum*. There is an appearance of *Baeothryon cespitosum*. The remains of *Eriophorum* and dwarf shrubs are also found in a certain amount. The stage reflects the vegetation of an open coastal patterned bog of a maritime climate with the low hummocks and *Sphagnum* carpets.

Discussion

As it is resulted from the diagrams, the vegetation stages (LMAZ) are, in general, well-correlating each other in both cores which enables to derive, based on this fact, more common development phases (periods) for the whole ecosystem of the raised bog Svinoye.

The beginning of the Svinoye bog formation is to be related with the mid-Holocene Littorina transgressions in the eastern Baltic sector. Before the Pre-Littorina time, as it is suggested from the available geological data [*Badyukova et al.,* 2007; *Gams,* 1932; *Kharin et al.,* 2013; *Sergeev,* 2015], the mire formation area was situated on a residual Pleistocene morainic hill, composed of both glacier and lacustrine clay. The latter is considered to have the Ancylus age [*Gams,* 1932; *Kunskas,* 1970].

Before the onset of the Littorina transgressions, the study area was not likely to be exposed to inundation, although it was the region where the mouths of palaeorivers – Pra-Deima, Pra-Matrosovka, and Pra-Kurovka [*Badyukova et al.,* 2007; *Kharin et al.,* 2013; *Sergeev,* 2015] – were located and, according to palaeomaps [*Sergeev,* 2015], have fragmented the morainic plain onto separate upper sites.

The first Littorina transgression in the South-Eastern Baltic region (L1, 8300–8000 cal. yr BP) is often considered to have resulted into a fast sea level rise [*Badyukova et al.,* 2007; *Damušyté,* 2011] and formation of a range of bays along the coast between Sambian Peninsula and Rybachy Plateau [*Sergeev,* 2015]. Nevertheless, these events have not led to flooding the study area, as well as the most territory of today's Curonian Lagoon and Neman Delta [*Damušyté,* 2011]. This is in agreement with our data – the very first layers of gyttja are dated 7300 cal. yr BP, i.e. they are already correlated with the period of the second Littorina transgression.

Thus, before the onset of the second Littorina transgression (7500 cal. yr BP), the territory of the study area (today's bog Svinoye and surrounding sites) was located within the terrestrial environment without traits of mire formation.

The period of a shallow water body with gyttja accumulation (7500–7000 cal. yr BP).

During the second Littorina transgression (L_2, 7500–7000 cal. yr BP), the sea level rise is likely to have led to the inundation of the vast region covering today's area of Curonian Lagoon and some territories adjacent to its southern and eastern coast. The palaeomaps of this region [*Damušyté,* 2011; *Sergeev,* 2015] demonstrate the shoreline exceeding 3 to 8 m its present-day position. It implies that the study area (territory of the bog Svinoye) was covered with a shallow water body, where the accumulation of gyttja deposits occurred during that time (7500–7000 cal. yr BP). The character of these deposits was, apparently, affected by the abrasion of the morainic remnants and relief leveling [*Badyukova et al.,* 2007]. Our samples of sandy gyttja from the depth 8.95–8.6 m in the core 1, which corresponds to the indicated age, implicitly confirms these theses.

The layers of sandy gyttja became probably a substrate for primary mire vegetation development on the study area during the regression of the Littorina basin (7000–6600 cal. yr BP). The widespread mire development was recorded during that time on a vast coastal area adjacent to the recently formed brackish lagoon [*Kunskas,* 1970; *Bitinas et al.,* 2002]. The same conclusion is confirmed by our data concerning the onset of the Bolshoye Mokhovoye bog formation in the southern part of the Neman Delta [*Napreenko-Dorokhova and Napreenko,* 2018].

The period of alder carrs (7000–6300 cal. yr BP).

The first mire communities on the study area of the Svinye bog were the wet black alder carrs with the dense herb layer of *Phragmites*. Having likely to be experienced an inundation of the area during the regular sea-level rise of the Littorina basin, these communities died, forming a half-meter layer of heavily water-logged ligneous peat. This peat is well defined and visible on a horizon 7.5–7.0 m in the core 1 of the Svinoye bog deposits. Through interpolation, we date this event in the interval 6600–6300 cal. yr BP that may have been related to one other peak of the second Littorina transgression, the exact time frame of which is still under discussion [*Badyukova et al.,* 2007], despite the interval 7500–7000 cal. yr BP adopted by many authors.

According to the point of view stated already by *Gams* [1932], the waterlogging of peat was caused by the isostatic submersion of ligneous and *Phragmites* peat layers into underlying gyttja deposits. Nevertheless, we recorded the similar water-logged layers of ligneous peat and ligneous reed peat, dated the same age, in the lower part of the Bol'shoye Mokhovoye bog, whereas, the deposits of gyttja were not found there.

Thus, the formation of the water-logged layers of fen peat, both on the western (Sviniye bog) and the eastern (Bol'shoye Mokhovoye bog) coast of Pre-Curonian Lagoon, was more likely a consequence of sea-level rise during the Littorina basin transgression, or there has been a small-scale isostatic submersion of a whole southern coast of the lagoon in this area. The probability of the glacio-isostatic processes in this region is suggested in some recent investigations [*Uscinowicz,* 2003; *Badyukova et al.,* 2007; *Sergeev,* 2015]; the first paper also refers to a possible transgression in the Neman Delta at 6000 cal. yr BP.

The period of reed stretches (6300–5800 cal. yr BP).

As evident from the analysis of peat structure for the horizons lying above 7.0 m (6300 cal. yr BP), there had been no further inundation on the area of Svinoye bog formation. The areas of the vanished alder carrs were colonised by the monodominant stretches of the common reed (*Phragmites*) that had been existing here for 500 years. Among the reed stands, there were more inundated sites occupied with the hydrophilic riparian herbs and aquatic mosses. The warm and humid climate of the mid-Holocene favoured, apparently, to the intensive growth of tall herbaceous, while the hydrophilic environment prevented decomposition of the fast accumulating biomass in these habitats, therefore the peat increment reached here the very high rate of 2 mm/yr. The 1.5-m layer of rapidly formed fen reed peat became a substrate for the development of new vegetation stages.

The period of a herb-dominated rich fen (5800–5200 cal. yr BP).

The next ecosystem change on a forming mire approximately coincides with the boundary of the Holocene climatic periods, the Atlantic and the Sub-Boreal (5731 cal. yr BP). In the study area, the communities of *Phragmites* disappeared, having been replaced by the rich-fens with the polydominant short-grass patchy vegetation. The most widespread (and peat-forming) species are *Scheuchzeria palustris, Carex lasiocarpa, C. rostrata, C. limosa, Menyanthes trifoliata, Comarum palustre*. Despite the lowland location of the territory and the hydrophilic biotope character, the productivity of the mire communities decreased, and the peat accumulation rate had more than two times declined (0.8 mm/yr). This change may have been related both to the size of peat-forming plants and overall climate change in the Sub-Boreal towards lower humidity.

The period of a Sphagnum-dominated transition mire (5200–4000 cal. yr BP).

The stage of the transition mire existed in the study area for a rather long-term period, 1200 years. Based on the plotted diagrams, during this phase, the whole mire area was covered by the communities of moderately dry hummocks dominated by *Sphagnum fuscum*, by *Polytrichum strictum*, by *Eriophorum vaginatum* and ericaceous dwarf shrubs. Nevertheless, these phytocenoses included a range of bryophyte species typical for the mesotrophic habitats: *Tomenthypnum nitens, Aulacomnium palustre, Sphagnum palustre, S. imbricatum* s.l. Their occurrence and presence of sedges confirm the transition character of mire during that period. It is noteworthy that there was no pine which is usually a characteristic element for similar peatlands. In spite of the wide distribution of Sphagna, the hummock productivity was quite low on the relatively dry transition mire habitats, thus the peat accumulation rate did not change as compared with the previous stage (0.8 mm/yr).

The period of Scheuchzeria-Sphagnum lawns in the bog centre and transition mire communities in the edge zone (4000–3400 cal. yr BP).

This ecosystem change also occurred on a boundary of two periods of the Holocene – the Early and the Late Sub-Boreal (4041 cal. yr BP). There had been a formation of the wet lawns of *Sphagnum cuspidatum*, *S. papillosum and Scheuchzeria palustris* in the central part of the bog that may indicate the common climate humidification. The marginal part of the bog had been still occupied by the transition mire communities which were similar to those of the previous stage. Such differentiation of the vegetation cover is most likely to be the evidence of the oligotrophic conditions in the mire centre, which usually leads to a formation of the dome-shaped peat surface of the bog.

The period of a raised bog with the emerging micro- and mesotopography (3400–2600 cal. yr BP

During this period, there had been the development of a typical raised bog in the central part of the peatland which involved the formation of the vegetation community complexes and had led to a microtopography differentiation onto large drier elevations (hummocks) and small wetter depressions (pockets). The dominant elements in community composition were already the typical species of the coastal bogs, *Sphagnum rubellum* and *S. capillifolium*. The marginal and sub-marginal sites of the bog were dominated by hummocks of *Eriophorum vaginatum* and *Sphagnum fuscum*, though the mesotrophic transition mire species has vanished from their composition. Through this process, the whole mire graded into a raised-bog stage and was likely to become a dome-shaped peatland. The peat accumulation rate remained the same as in the previous three periods (0.8 mm/yr).

The period of hollow complexes (2600–1900 cal. yr BP).

The transition to this phase coincided with the beginning of the last climatic period of the Holocene, the Sub-Atlantic (2592 cal. yr BP), characterised by humid and cool climate. Through the increase of precipitation in the coastal region, this climatic change has, apparently, led to the formation of large water-logged hollows dominated by hydrophilic Sphagna – *S. cuspidatum, S. tenellum* and *S. balticum*. The coverage of hummocks and abundance of ecologically-related species of drier habitats have decreased. The hollow complexes are suggested to occupy the major part of the bog during that phase. The peat accumulation rate began to increase since the second half of the period.

The period of an active raised bog (generative complex phase) (1900–850 cal. yr BP).

During that period, the formation of the raised-bog generative complex occurred in the study peatland as a vegetation community complex of vigorously growing *Sphagnum*-dominated hummocks with *Eriophorum vaginatum* and dwarf shrubs. The hollow complexes became, in contrast, much less abundant. The cause of such changes is still unclear. The major peat-forming species was *Sphagnum rubellum*, which is peculiar as producing a considerable peat mass increment. This is considered to have led to an increase of peat accumulation rate (1.1 mm/yr) and more intensive growth of the mire peat bed.

The period of a raised bog with continental features (850–200 cal. yr BP).

The beginning of the period occurred in the Late Sub-Atlantic and approximately coincided in time with the onset of the Little Ice Age, usually associated with the cooler environment and a certain increase in continentality. Perhaps, this climatic change explains the secondary widespread distribution of *Sphagnum fuscum* in the Svinoye bog. Being an edificator species in the continental regions in Eurasia, it provides the highest peat increment as well as *S. rubellum*. Both species are dominant during this phase of mire development, having affected to the very high rate of the peat bed increase. The dominant vegetation community complex consisted of large and high *Sphagnum* hummocks. The abundance of cotton grass and dwarf shrubs declined. The peat accumulation rate reached 1.7 mm/yr.

The period of a maritime climate raised bog (200–100 cal. yr BP).

The beginning of the phase corresponds to the end of the Little Ice Age and some mildening of the climate. The communities of low hummocks and *Sphagnum* carpets became the most widespread in the Svinoye bog. The indicator elements in their composition were the Atlantic species typical for the coastal mires in the oceanic and suboceanic regions with a considerable degree of precipitation. Among them are *Baeothryon cespitosum, Odontoschisma sphagni, Sphagnum molle, S. imbricatum* s.l. The hydrophilic species of mosses, *S. tenellum, S. balticum and S. cuspidatum*, became again very common. The peat accumulation remained at a rather high rate of 1.7 mm/yr.

Despite the differences in species composition and structural peculiarities of the bog communities during the last four phases, it is required to be taken into account that different bog microtopography forms can usually alternate each other as mire development occurs. Although the environmental properties in these sites of the bog are also getting changed, the general structure of the bog ecosystem remains stable. In this respect, the last four phases of the Svinoye bog development can be combined into one general phase – the period of a patterned dome-shaped active raised bog.

The period of a settled forested peatland (100 cal. yr BP – present time).

Having experienced a considerable anthropogenic disturbance during the last 100 years, the Svinoye mire has lost up to this moment its structure of the dome-shaped active raised bog and graded into a settled, densely forested peatland. The peat increment has significantly slowed down in the central part of the bog, or completely ceased in the marginal and sub-marginal zone.

It is noteworthy to underline that, as it is evident from our research, the genesis of the Svinoye bog is not related to succession on any terrestrial or lacustrine ecosystem existed prior to the onset of the mire formation. Having regard to a specific character of the initial stages of the Svinoye bog evolution, the way of its development is to be referred to a primary mire formation, which is assigned – together with terrestrialisation and paludification – as a separate type of mire evolution in the coastal areas experiencing isostatic fluctuations and transgression effects [*Sjörs,* 1983; *Succow and Joosten,* 2001].

Conclusions

Based on the results of macrofossil analysis for two cores taken from organogenic deposits of the Svinoye raised bog and taking into account radiocarbon dating for a range of samples, the following conclusions were made.

1. The initial stages of the Svinoye raised bog formation – a coastal mire in the proximal part of the Curonian Spit – were closely related with the transgression events in the Pre-Baltic basin (Littorina Sea) during the period 7500–6300 cal. yr BP.

2. During the period 6300–100 cal. yr BP, the vege-

tation development in the mire ecosystem was determined mainly by the climatic factors and did not experience the impact of marine and lagoon waters.

3. In the last 100 years, a considerable change in the bog structure was caused by intensive human disturbance.

4. The development of the whole mire ecosystem included 12 periods (phases):

   – the period of a shallow water body with the gyttja accumulation as a substrate for the primary mire vegetation (7500–7000 cal. yr BP);

   – the period of alder carrs (7000–6300 cal. yr BP);

   – the period of reed stretches (6300–5800 cal. yr BP);

   – the period of a herb-dominated rich fen (5800–5200 cal. yr BP);

   – the period of a *Sphagnum*-dominated transition mire (5200–4000 cal. yr BP);

   – the period of *Scheuchzeria-Sphagnum* lawns in the bog centre and transition mire communities in the edge zone (4000–3400 cal. yr BP);

   – the period of a raised bog with the emerging micro- and mesotopography (3400–2600 cal. yr BP);

– the period of hollow complexes (2600–1900 cal. yr BP);

– the period of an active raised bog (generative complex phase) (1900–850 cal. yr BP);

– the period of a raised bog with continental features (850–200 cal. yr BP);

– the period of a maritime climate raised bog (200–100 cal. yr BP);

– the period of a settled forested peatland (100 cal. yr BP – present time).

5. The initial stages of the Svinoye bog evolution are to be referred to a primary mire formation.

6. The peat accumulation rate was the highest (1.7–2.0 mm/yr) in the Late Atlantic, during the presumable influence of transgression events, and during the Sub-Atlantic. The least peat increment (0.8 mm/yr) was recorded during the whole Sub-Boreal.

7. The assigned mire development periods (phases) are in good agreement with the change of climatic periods during the Holocene.

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