

Chemical characteristics of soils in Scots pine forests of *Cladina* and *Vaccinium vitis-idaea* site types on coastal dunes of Baltic Sea

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Abstract. The coastal dunes of Southwest Estonia have been undergoing a process of stabilisation and are today covered predominantly with Scots pine forests. For the investigation of soils on dunes sampling sites were selected according to topographical positions and forest site types: two sites in *Cladina* and two sites in *Vaccinium vitis-idaea* site types on dunes of different heights. The prevailing soils on dunes are Gleyic Podzols, which are generally poor in humus, water and mineral nutrients. Great differences in soil chemical components were found on the foots, slopes and tops of the dunes depending on the height of the dune. The study showed that the concentration of macronutrients (N, K, Ca, Mg) in soil decreased from the foot towards the top. On the other hand, a serious decrease in the nutrient concentration from the O horizon to the BC horizon was typical of the dunes. The soils were generally acidic, with the pH of 3.4–5.5 in the studied sampling sites. The soils were more acidic on the foots of the dune and in the O and A horizons.

Key words: coastal dunes, Scots pine forest, soil, soil horizons, partitioning of nutrients in soil.

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Introduction

Dry coastal ecosystems have been important as objects of ecological research since the early days of ecology as a science. Many studies of coastal dunes have helped to construct ecological theories and to understand how ecological systems function (van der Maarel, 1993). The coastal area of Southwest Estonia, Rannametsa, is known for pine-covered dunes and other coastal forms, which have evolved in different stages of the transgression of the Baltic Sea. Through time, agriculture and forestry have modified dune landscapes but since the end of the 20th century tourism has been the most destructive human activity affecting coastal areas (van der Meulen, 1997).

Dunes create a diversity of soils and plant communities in a small area, offering thus an ideal opportunity to study soil–plant relationships and the role of soil in affecting the characteristics and evolution of the ecosystem. Soil is an essential component of ecosystems and its importance goes beyond being a substrate for plant growth. The upper mineral soil horizons are the greatest ecosystem reservoirs of organic matter and nutrients, and they influence or regulate most of the functional

processes occurring throughout the ecosystem, such as nutrient cycling, moisture retention and erosion protection (Hopmans *et al.*, 2005). Variabilities of soil pH in coastal dunes were observed by Isermann (2005), who showed that the variability in pH increased with increasing vegetation cover. Isermann (2005) found that increasing abundance of dominant species and decreasing species diversity of vegetation apparently reduce soil pH heterogeneity. However, in recent times human impact, especially tourism, has had a negative influence on the vegetation cover and relief of dunes (Olšauskas, 1996; Labuz, 2004), which may bring about serious changes in ecosystems on dunes. That is why Örd (2000) in his book *Kaitsemetsad ja nende majandamine Eestis* (Protection forests and their management in Estonia) presents recommendations for the protection, use and shaping of coastal forests. In this book and in his earlier studies (Örd, 1972, 1973, 1983, 1994) he draws attention to several problems concerning the productivity of dune forests, their soils, use for recreational purposes and forest protection.

In Estonian inland dunes the prevailing process in soil is podzolisation. Soils are generally acidic (pH_{KCl} 3.0–5.0), poor in humus and the content of Ca in the sandy parent material is low (Ratas *et al.*, 2003).

In addition to their picturesque looks, fixed dunes are important for biodiversity at species and the species community levels, and they are considered as a priority habitat by the European habitat directive (Council Directive..., 1992), hence the necessity of their study. Dune forests in Southwest Estonia have been studied by numerous scientists but still there is a shortage of information about the soil characteristics in dune systems.

The aim of the study was to provide a review of soil horizons and their nutrient content on dunes related to the height and position of sampling sites on the dunes. Attention was focused on soils in Scots pine forests of *Cladina* and *Vaccinium vitis-idaea* site types.

Material and Methods

Study area

The dune system of Rannametsa studied is situated in the Luitemaa Nature Reserve area in Southwest Estonia, along the Pärnu–Riga highway. The study area borders on the settlement of Uulu in the north and on the Rannametsa River in the south (Figure 1).

According to Pärnu weather station (Estonian Meteorological and Hydrological Institute) the main climate characteristics in 2007 when the soil analyses were made were as follows: average annual temperature 7.4 °C with maximum average of 18 °C in August and minimum average of –9.4 °C in February; total precipitation 766.7 mm, maximum 119.1 mm in January and minimum 27.9 mm in February.

Dunes at Rannametsa were initially mounds of fine-grained sand and later became fixed and covered with vegetation. Rather low vegetated dunes characterize the coastal landscape, their height rarely reach 20 metres. Dunes are covered predominantly with pine forests, which belong to *Cladina*, *Calluna*, *Vaccinium vitis-idaea* and *V. myrtillus* site type. Today Rannametsa dunes form part of the Luitemaa Nature Reserve. The dune area was joined to the reserve to lessen unpropitious human impacts on them.

For the investigation of soils on dunes of different height four sampling sites were selected (Figure 1):

1. Site 1, located 58°08'23" N, 24°30'36" E and reaching 34 m in height (absolute altitudes were measured with Garmin Gpsmap 76csx), is one of the highest dunes in the area (Tornimägi). The pine stands on this dune belong to *Vaccinium vitis-idaea* site type with Gleyic Podzols. The sample points for the determination of soil horizons on the dune were located at heights of 12, 22 and 34 m a.s.l.

2. Site 2, located 58°08'20" N, 24°30'27" E and reaching up to 27 m in height; is of *Vaccinium vitis-idaea* site type with Podzols. The sample points for the determination of soil horizons on the dune were located at heights of 14, 20 and 27 m a.s.l.

3. Site 3, located 58°14'28" N, 24°31'21" E with a maximum height of 14 m, belongs to *Cladina* forest site type with Gleyic Podzols. The sample points for the determination of soil horizons on the dune were located at heights of 10, 12 and 14 m a.s.l.

4. Site 4, located 58°13'51" N, 24°30'47" E, belongs to *Cladina* forest site type with Gleyic Podzols. It was the lowest site in the present study with an absolute altitude of 9 m. The sample points for the determination of soil horizons on the dune were located at heights of 3, 5 and 9 m a.s.l.



Figure 1. Location of Rannametsa area and sampling sites 1, 2, 3 and 4.

Joonis 1. Uurimisala ja proovialade 1, 2, 3 ja 4 asukoht.

Methods

Data were collected from the four sites (dunes) in October 2007. On each dune, sample points were established on the foot, slopes and the top. Different soil horizons were distinguished to the depth of 1 m from the surface and their thickness was measured. Soil samples were taken from each horizon and put in marked plastic bags. In laboratory, the samples were air-dried and sieved through a 1 mm sifter.

From each soil sample the pH was measured ($n=5$) in a soil-water suspension (ISO/10390, 1994) using a laboratory pH-meter (Mettler Toledo MP220). The ratio of soil to water used for air-dry organic soil samples was 1:10 and for mineral soil, 1:1.25. The chemical analyses were made in the Plant Biochemistry Laboratory of the Estonian University of Life Sciences where the concentrations of macronutrients for plants (N, P, K, Ca, Mg) were determined. Standard methods of soil analysis were used: the content of P and K was determined by the Egner-Riehm double lactate method and that of Ca and Mg, by Egner-Riehm-Domingo ammonium acetate-lactate method (ISO/11260, 1995). Total N was determined by the Kjeldahl method (ISO/11261, 1995).

The data obtained were processed statistically to find relationships between the height of the dune and the concentrations of nutrients in soil. Regression analysis was used (R^2). The differences between sampling sites were evaluated using t -test with the level of significance 0.05.

Results

In Southwest Estonia dunes characteristic of southern coasts of the Baltic Sea dominate (Cramer, 1993; Ratas & Ravis, 2003). The sands of dunes have been observed to vary in the chemical and physical composition (Raukas, 1968; Martin, 1978). Analysis of the growth substrate of the dunes studied indicated significant variation in the concentration of nutrients between dunes of different height as well as at different heights of one and the same dune.

Table 1. Characteristics of soil horizons on sand dunes in Southwest Estonian coastal area in October 2007.

Tabel 1. Mullahorisontide keemilised karakteristikud Edela-Eesti rannikuala luidetel oktoobris 2007.

Sampling site Forest site type Height of dune, m a.s.l.	Position and height (m a.s.l.) of sample points on dune	Soil hori- zon	pH _{H₂O} <i>n</i> = 5	N, %	P	K	Ca	Mg
					mg kg ⁻¹			
Site No. 1 <i>Vaccinium vitis-ideae</i> 34 m	Foot (12 m)	O	4.086	1.670	133.14	684.10	942	326.06
		A	3.726	0.623	59.76	226.46	804	224.50
		E	4.570	0.014	13.27	10.11	57	1.19
		BC	5.426	0.005	91.76	6.35	47	0.11
	Slope (22 m)	O	4.078	1.166	64.24	239.99	1117	244.58
		E	5.372	0.011	9.42	5.93	48	0.10
		BC	5.128	0.009	53.15	5.11	37	1.43
	Top (34 m)	O	4.348	0.786	76.18	164.88	606	95.32
		E	4.772	0.011	20.61	7.60	44	0.20
		BC	5.552	0.006	30.86	5.09	44	0.83
Site No. 2 <i>Vaccinium vitis-ideae</i> 27 m	Foot (14 m)	O	4.074	1.402	30.32	157.38	707	381.65
		A	4.524	0.020	4.24	10.12	97	9.57
		E	4.834	0.007	9.12	5.09	49	1.07
		BC	5.194	0.010	70.45	5.12	39	2.07
	Slope (20 m)	O	4.342	0.771	41.20	156.12	1048	294.70
		E	4.660	0.014	8.94	8.01	58	1.00
		BC	5.284	0.006	46.44	4.68	36	0.46
	Top (27 m)	O	3.988	0.318	93.57	136.80	1159	210.37
		E	4.652	0.010	7.18	8.85	51	0.15
		BC	5.246	0.009	74.93	4.69	43	0.07
Site No. 3 <i>Cladina</i> 14 m	Foot (10 m)	O	3.848	1.731	51.40	468.79	888	389.39
		A	3.400	0.558	9.79	23.46	55	14.17
		E	4.436	0.037	4.41	4.71	38	0.60
		BC	4.736	0.015	4.81	4.72	40	0.63
	Slope (12 m)	O	4.180	0.826	39.42	200.39	776	289.27
		E	4.588	0.018	10.64	7.22	40	1.76
		BC	4.974	0.015	14.72	7.27	38	0.45
	Top (14 m)	O	4.180	0.704	44.08	164.49	785	199.49
		E	4.538	0.019	8.09	10.53	55	0.66
		BC	5.188	0.016	23.34	6.38	37	0.24
Site No. 4 <i>Cladina</i> 9 m	Foot (3 m)	O	3.784	1.309	63.36	425.40	1107	308.22
		A	4.416	0.025	4.59	13.51	59	0.16
		E	4.438	0.008	4.99	7.17	39	0.11
		BC	4.666	0.013	14.07	5.95	37	1.09
	Slope (5 m)	O	3.97	0.957	78.75	380.88	803	247.75
		E	4.344	0.021	7.65	10.53	59	0.45
		BC	5.03	0.008	14.10	5.10	36	0.89
	Top (9 m)	O	3.984	0.751	74.39	352.08	681	235.33
		E	4.276	0.012	5.86	10.94	47	0.30
		BC	4.686	0.011	16.13	5.54	38	0.21

The results obtained revealed several differences in soil structures between the sampling sites studied. Although different site types may often occur on one and the same dune at different heights (Örd, 1972; Mandre, 2000, 2003), for our study sites with certain forest site types were selected. The *Vaccinium vitis-idaea* site type of pine forests occurs on sampling sites 1 and 2 and *Cladina* site type on sampling sites 3 and 4. Gleyic Podzols, which prevailed on the dunes, are generally poor in humus, water and mineral nutrients. Great differences were established in soil chemical components on the foot, slopes and the top of a dune depending on the height of the dune. It was found that soils on the foot of the dunes were rich in nutrients (Table 1). Waters flowing down the dune and decomposition of organic plant material accumulating at the foot of the dune enrich this area with nutrients. The concentration of nutrients decreased upwards, and a sharp shortage occurred on the tops of the dunes.

In general, primitive sandy soils (Podzols) have a thin humus horizon. We found it only on the foot of the dunes. Humus horizons were lacking on the slopes and on the tops of the dunes (Figure 2). The thickness of the humus horizons on the foots varied on the dunes studied in the range 2–20 cm. The litter horizon was also relatively thin being 4–30 cm on the foots and significantly thinner on the slopes and on the tops of the dunes (5–10 cm).

A linear relationship was found between the soil pH and the height of the sample point on the dune at statistical significance $p < 0.05$ ($R^2 = 0.634$) (Figure 2, Table 1). An increase in the pH from 4.07 in the O horizon to 5.09 in the BC horizon was typical of the soils on the dunes. A linear decrease in the concentrations of N, K, Ca and Mg from the O to the BC horizon and from the foot of the dune to its top was established. Only some increase in the P concentration could be observed in the deeper BC horizon of soil and on the top of the dune in both *Vaccinium vitis-idaea* and *Cladina* forest site type. Regression analysis revealed a linear dependence between the average con-

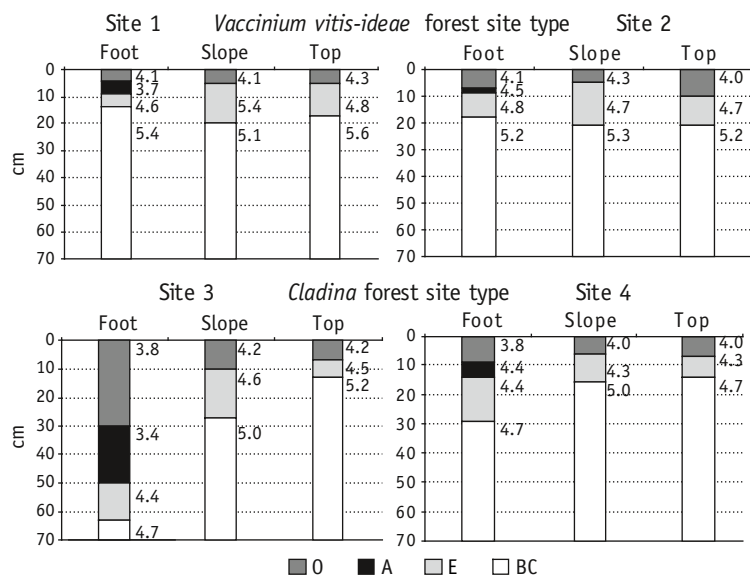


Figure 2. Thickness and pH value of soil horizons on fixed sand dunes sampled from foots, slopes and tops.

Joonis 2. Mullahorisontide tüsedus ja pH väärtused luite jalami, nõlva ja harja proovipunktides 4 proovialal.

centrations of mineral elements N, K, Ca and Mg in the O horizons of the soils and the heights (location) of the sample points on the dunes (foot, slope, top) for both forest site types ($R^2_N = 0.577$; $R^2_K = 0.676$; $R^2_{Ca} = 0.459$; $R^2_{Mg} = 0.793$) but not for P. Some statistical differences were revealed in the dependences between chemical characteristics of different horizons of soils on different positions of sample points for different forest site types (Table 2). Relationships of soil chemical components were found to be stronger for higher dunes and for the O horizon. Differences (*t*-test) between sampling sites of *Vaccinium vitis-idaea* and *Cladina* forest site type in the average concentration of nutrients in soil (O, E, BC horizons; no A horizons occurred in the soils of higher sample points) were revealed at significance level $p < 0.05$.

It is known that the availability of water to trees falls and the soil temperature rises towards the top of a dune (Wojterski, 1993). According to Örd (1972), the water content in different soil layers of dunes varies significantly, being 1.7–4.5% of absolutely dry weight at a depth of 4–8 cm, 8.8–12.4% at 8–18 cm and 2.1–2.8% at 20–26 cm. The water content depends significantly on the amount of precipitation. In addition, it depends on the location of the sample point on the dune. On the top of a dune, where the sun and winds have an intensive drying effect, the water content in the O horizon may be 4.5 times lower than on the slope or 6 times lower than on the foot of the dune (Örd, 1972).

Table 2. Dependence of soil horizons chemical characteristics of height of sample points on dune in different forest site types. Regression coefficients (R^2) at $p < 0.05$.

Tabel 2. Mulla keemiliste omaduste sõltuvus proovipunktide kõrgusest luitel erinevate metsatüüpide männikutest. Regressioonkoefitsiendid (R^2) $p < 0.05$ olulisuse juures.

Forest site type	Parameter	Soil horizon		
		O	E	BC
<i>Vaccinium vitis-idaea</i>	pH	0,551	0,012	0,138
	N	0,588	0,606	0,009
	Mg	0,918	0,678	0,032
	K	0,623	0,413	0,301
	P	0,001	0,219	0,515
<i>Cladina</i>	pH	0,619	0,088	0,270
	N	0,122	0,003	0,463
	Mg	0,487	0,148	0,736
	K	0,322	0,013	0,181
	P	0,555	0,011	0,123

Conclusions

The unique coastal dune landscapes in Estonia are popular recreation and protected areas. They have attracted scientists' attention as due to their mosaic character these landscapes offer ecosystems with rich and varying biota. Landscapes in coastal areas are distinguished on the basis of relief and of soil-vegetation complexes.

Research has revealed a large variation in the growth conditions for forest on dunes. The present study of pine forests on dunes was carried out in areas of *Vaccinium vitis-idaea* and *Cladina* forest site type, which are predominant and typical site types of the coastal landscape. The prevailing soils on dunes are Gleyic Podzols, which are generally poor in humus, water and mineral nutrients. Great differences were found in soil chemical components on the foot, slopes and the top of a dune

depending on the height of the dune. The study showed that the concentration of macronutrients (N, K, Ca, Mg) for the growth of forest trees in soil decreased from the foot towards the top. On the other hand, a serious decrease in the nutrient concentration from the O horizon to the BC horizon is typical of dunes. The soils were generally acidic; the soil pH was 3.4–5.5 in the studied sample points, the foot of the dune and the O and A horizons being more acidic. Although the forests are quite fragile due to their slow growth and low productivity (Kõresaar, 2003), they are of great importance for soil protection on dunes (Ratas & Rivis, 2003).

There is an urgent need to study the bioresources of ecosystems on dunes to promote their conservation, rehabilitation and optimum utilisation. Based on such studies, concepts for sustainable use of forest bioresources can be developed and understanding the nature of tolerance of tree species in stress conditions on dunes will be improved.

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Mulla iseärasused luitemännikutes *Cladina* ja *Vaccinium vitis-ideae* kasvukohatüübis

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Kokkuvõte

Edela-Eesti rannikumaastikule on iseloomulikud pärast viimast jääaega jääliustiku sulamise setetest moodustunud luited ja rannavallid. Luitemaa looduskaitseala on loodud Antsülusjärve ja Litoriinamere rannaluidete ja nende ümber kujunenud koosluste, aga ka rannaniitude ning ohustatud ja haruldaste liikide elupaikade kaitseks.

Luidetel on kujunenud omapärane mullastik ja universaalsed taimekooslused. Käesoleva töö eesmärgiks on anda uusi teadmisi luidete mullahorisonetidest ja toitainete sisaldusest seotuna luite kõrguse ja prooviaala asukohaga ning põhitähelepanu oli pööratud muldadele *Cladina* ja *Vaccinium vitis-ideae* kasvukohatüüpides.

Rannametsa piirkonnas valiti 4 luidet, igal luitel 3 proovipunkti: jalamil, nõlva keskosas ja luite harjal. Kaks prooviaala (kõrgustega 34 ja 27 m ü.m.p.) asuvad *Vaccinium vitis-ideae* ja kaks (14 ja 9 meetrit ü.m.p.) *Cladina* kasvukohatüübis.

Proovipunktides määrati erinevad mullahorisondid ja nende tüsedus, igast horisondist võeti proovid pH ja makrotoitainete määramiseks.

Luitemuldadele on iseloomulik õhuke huumushorison (A), mida võis leida ainult luidete jalamil paiknevates proovipunktides, horisondi tüsedus varieerus 2–20 sentimeetrini. Kõduhorison (O) oli õhuke, vähenedes 4–30 sentimeetrilt luite jalamil 5–10 sentimeetrini luite harjal.

Tulemustes ilmnesis olulised erinevused luite jalami, nõlva keskosas ja luite harja mullaproovide keemilises koostises sõltuvalt luite kõrgusest. N, K, Ca ja Mg sisaldus väheneb oluliselt liikudes luite jalamilt harjale. Samuti on luidetele iseloomulik toitainete kontsentratsiooni vähenemine O horisondist BC horisondini. Mullad on tavaliselt happelised (pH 3,4–5,5), kusjuures happelisemad on jalamil paiknevate proovipunktide mullad ning O ja A horisonidid.

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