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Results of cartometric investigations of dune morphodynamics on the Curonian Spit

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According to the results of a high-accuracy comparative cartometric survey, the annual aeolian sediment migration rate of the Great Curonian dune ridge crest has slowed down from 4–5 m per year in 1909–1954 to 2–3 m per year in 1954–1990. The first and primary reason of the stabilization and flattening of the shifting Curonian dunes during the second half of the 20th century is the lack of marine sand supply, supported by the active dune stabilization and forestation policy which was conducted on both the Russian and Lithuanian sides of the border. Climate warming and a decreased herd of wild and domestic animals, which was usually detaining the expansion of vegetation on dunes, also contributed to this phenomenon. Application of remote sensing data is a very effective way for tracing the sediment migration rate and changes of the morphology of dunes. The remote sensing should be performed periodically as an integrated part of environmental monitoring and state-of-environment reporting.

Key words: cartometric investigations, dune morphodynamics, Curonian Spit, aeolian transportation and sedimentation, 3D satellite images, sediment migration rate

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INTRODUCTION

Shifting dune systems usually make a significant impact on sensitive coastal ecosystems, communities and engineering infrastructure. Therefore the rate of Aeolian sediment migration and changes in the morphology of dunes are a subject of permanent monitoring.

The Great Curonian dune ridge is one of the most magnificent natural wonders of the Baltic Sea Region. It is the Europe's longest and one of the highest still active ridges of the shifting dunes. The shifting dune wilderness forms the most distinctive natural value of the spit, with the highest dunes reaching 50 meters in height.

Today there are several strips of the shifting dunes remaining within the Great Curonian dune ridge (Fig. 1). The total length of these strips of the shifting Curonian barkhans is 32.6 km, 21.9 km being on the Russian side and 10.7 km on the Lithuanian side (Povilanskas, 2004). All three southern strips of the shifting dunes – the White, Fringilla and Skilvit dunes – belong to Russia (Fig. 2).

The central strip of the dunes stretches across the Russian–Lithuanian state border and is featured by the highest peaks. The ridge on the northernmost strip of the Grey dunes, which belongs to Lithuania, is rapidly degrading and overgrowing with vegetation, but some of these dunes continue to advance towards the lagoon.

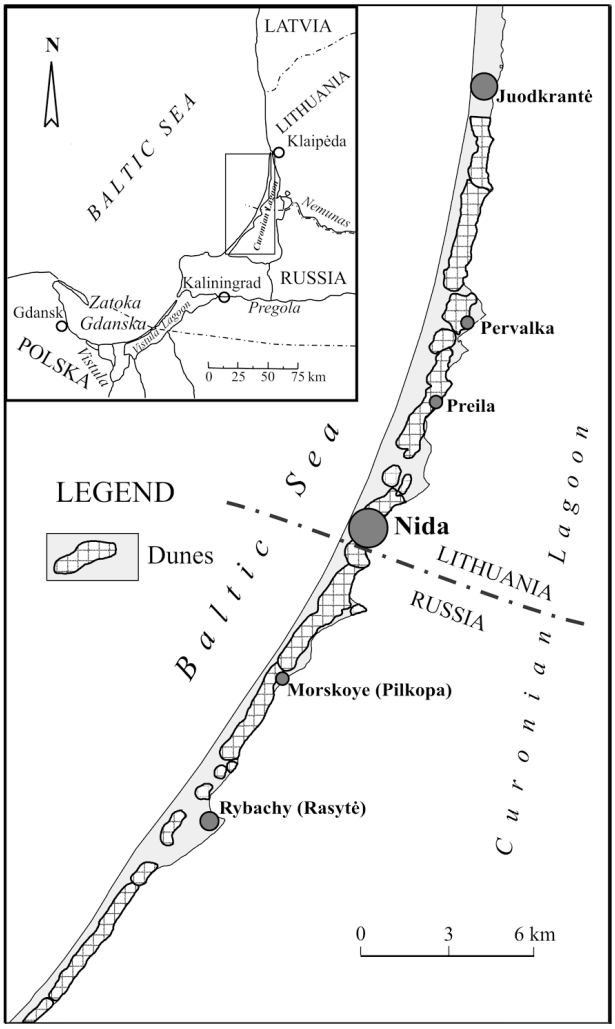

Fig. 1. Location of the surveyed shifting dune ridge strips on the Curonian Spit

1 pav. Tirtų pustomo kopagūbrio ruožų vieta Kuršių nerijoje

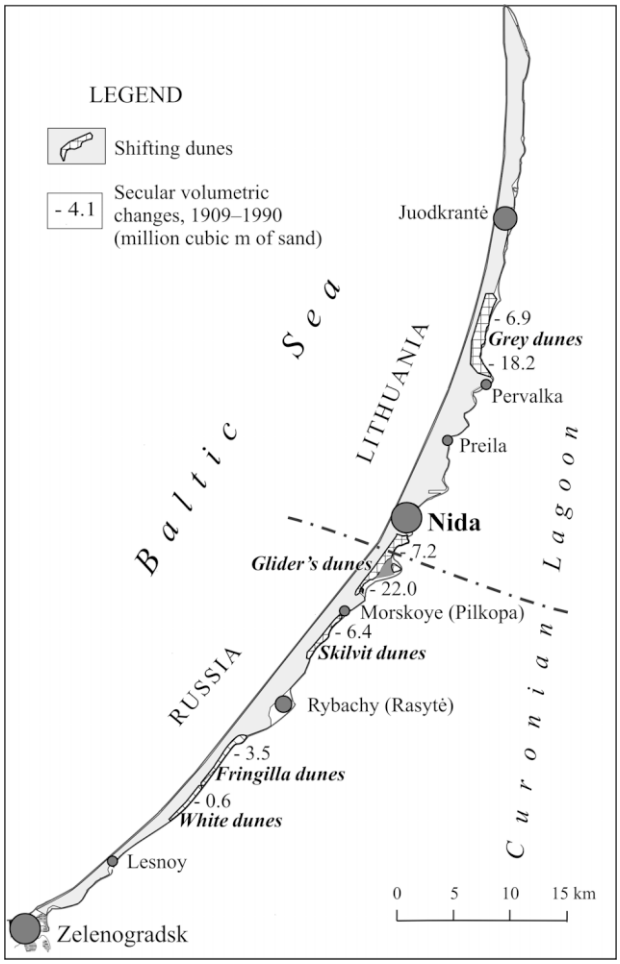

Fig. 2. Morphodynamic changes on various strips of the shifting dunes on the Curonian Spit

2. pav. Įvairių Kuršių nerijos pustomo kopagūbrio ruožų morfodinaminiai pokyčiai

METHODS

Quite a few comparative cartometric surveys have been carried out to measure the development of the Great Curonian aeolian dune ridge since the pioneering studies of Berendt (1869) and Hess von Wichdorf (1919). Particularly, cartometric surveys from various periods in the second half of the 20th century should be noted, which documented a slow degradation and flattening of the drifting Curonian dunes (Michaliukaitė, 1967; Мардосене, Вайнаускас, 1984; Гудялис, Казакевичюс, 1988).

The previous studies were dealing with variuos parts of the Curonian Spit. The present research was conducted for the entire area of the Curonian Spit with the first application of remote sensing technologies.

The cartographic materials used for this comparative survey and the verification of the results included topographic maps and 3D satellite images of the Curonian Spit from different years (Table 1).

All these cartographic information sources were digitized, transformed and compared in the UTM geographical reference system, WGS84 projection. The net volume changes in the drifting dunes during the periods 1909–1953 and 1953–1990/1993 were assessed using the SURFER 7 program. The minimal accuracy of the comparative cartometric analysis was limited by the accuracy of the historic geodetic measurements of the dune height ($d_y = \pm 0.5$ m) and by the accuracy of the original topographic maps at a scale of 1:25,000 ($d_x = \pm 10$ m). 3D satellite images of the Curonian dune areas from 1999 and 2003 were used to verify the calculation results.

RESULTS AND DISCUSSION

Without a steady supply of sand from the seashore, the annual migration rate of the Great Curonian dune ridge crest has slowed down from 4–5 m per year in 1909–1954 to 2–3 m per year in 1954–1990. During the latter period the migration rate of the dune crest in the southernmost strip of the shifting dunes (White dunes) was 3–4 m, whereas in the northernmost (Pervalka–Avikalnis) strip it was only 1–2 m per year.

Table 1. **Cartographic materials applied to analyze the dynamics of the Curonian dunes from 1909 to 1990**
1 lentelė. **1909–1990 metų kartografiniai duomenys, panaudoti Kuršių nerijos kopų kaitos analizei**

No.	Source of information	Year of mapping	Executive agency	Scale
1.	Topographic map of the entire Curonian Spit	1909	German Cartographic Survey	1:25,000
2.	Topographic map of the entire Curonian Spit	1953	Agency for Geodesy and Cartography of the USSR	1:25,000
3.	Topographic map of the Lithuanian part of the Curonian Spit	1990	Lithuanian Aerogeodetic institute	1:10,000
4.	Topographic map of the Russian part of the Curonian Spit	1993	Russian Geodetic Survey	1:25,000
5.	3D satellite image of the Lithuanian part of the Curonian Spit	1999	Lithuanian Aerogeodetic institute	1:10,000
6.	3D satellite image of the Russian part of the Curonian Spit	2003	Euro Space Imaging Ltd	1:25,000

Dynamics of the White dunes

The degradation of the White dunes reached a dramatic scale in 1954–1990: the dunes lost 53% of the sand volume (or 0.6 million cubic metres) and about half of the area became covered with mugo pine and *Scots* pine plantations as well as by the proliferation of natural bush vegetation. The dunes became very much fragmented with many sand blowouts and gullies intersecting the dune surface. The altitude of the White dune peak had decreased from 35 m in 1909 and 1954 to mere 15 m in 1990.

Dynamics of Fringilla dunes

The Fringilla dune area (to the north of the White dunes) experienced a relatively robust development during the 20th century. The first half of the 20th century witnessed a further accumulation of sand in the shifting dunes which were still in the growing phase: the Lotmi□kis dune peak experienced a 5 m increase from 50 m in 1909 to 55 m in 1954. The total sand volume remained relatively stable and the area covered by the shifting sand increased at the expense of the coastal sand plain.

In the second half of the 20th century, a slow degradation of the Fringilla dune strip started, as the dunes had not received any additional sand input. In 1954–1990, the Fringilla dunes have lost ~7% of their total sand volume, which was a rather big amount in absolute terms: the total loss was 3.1 Mio. m^3 of sand (or ~9 thousand m^3 of annual sand loss per 1 km of the dune front). This means that in the period 1954–1990 the degradation was much faster than in 1909–1954.

The height of the Lotmiškis dune – the highest shifting dune in Fringilla area – has declined from 55 m in 1954 to 53 m in 1994 (a very small decline compared with all other shifting dune peaks on the Curonian Spit in the second half of the 20th century).

Although in the meantime the foresters have planted vast mugo pine and Scots pine plantations in the adjacent dune areas (*e.g.*, White dunes to the south and the Matrosov dune to the north), but the acreage of the shifting sand remained relatively stable in the Fringilla dunes and the proliferation of psammophilic forbs, herbs, bushes and trees in this area was minimal during 1954 to 1990.

Dynamics of Skilvit dunes

The highest Central shifting dune reviers could be split into two very distinctive parts: the southern dune area (Skilvit) showed relative robustness throughout the 20th century, whereas the central and the highest cross-border area of the shifting dunes (Gliders' dunes) experienced a very dramatic change in the dune development trend during the last quarter of the 20th century.

During the entire measurement period of 1909–1990 Skilvit dunes have lost 7.44% of their initial volume of drifting sand, which in absolute terms is a relatively huge amount: ~6.4 Mio. m^3 of sand, or 16.3 thousand m^3 per annum per 1 km of dune ridge length.

The height of the highest dune in that revier, Senkaimis, did not change in 1909–1954 and remained at 60 m. Then, within 36 years till 1990, the area experienced a rapid flattening of the shifting dune surface (probably due to the increasing frequency of westerly storms).

The height of the Senkaimis dune decreased to mere 38 m in 1990, whereas the area covered with shifting sand increased by 50 hectares during the same period. Also, the dune ridge experienced erosion and fragmentation of its surface with numerous valleys and remnants of eroded dunes appearing on the surface of the windward side of the dune crest.

Dynamics of the Gliders' dunes

Meanwhile, the latest history of the Gliders' dunes (named after Lithuanian and German gliders' schools,

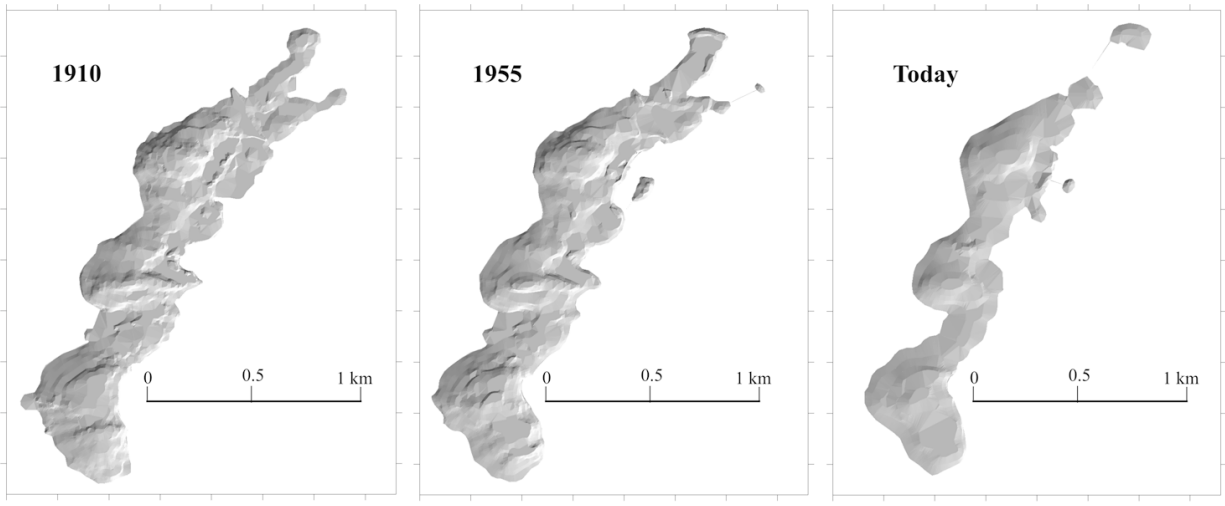

Fig. 3. Degradation of Parnidis and adjacent shifting dunes in the XX century
3 pav. Parnidžio ir gretimų pustomų kopų nykimas XX a

which functioned in that dune revier on both sides of the Lithuanian–German border in 1930) was completely different from the neighbouring Epha–Skilvit dunes.

In the first two thirds of the 20th century the highest Curonian dunes were steadily growing and rapidly advancing eastwards – the dunes were reaching their maturity. The southern peak of the Gilders' dune reached 68.3 m height in 1967, which made it the highest contemporary dune in the Baltic Sea region. A rapid advance of the Gliders' dunes left a wide belt of hummocks behind on the windward slope of the shifting dunes (Paul, 1944–1953).

Unfortunately, the policy of dune forestation, which prevailed on the Curonian Spit after World War II, and particularly throughout 1970–1980, speeded up degradation, fragmentation, sylvanization and flattening of the Gliders' dunes, particularly their southern (Dune Krasnaya) and northern (Dune Parnidis) fringes (Fig. 3).

Hence, the height of the highest peak of the Gliders' dune rapidly declined from 68.3 m in 1967 to 53.1 m in 1983. In 1954–1990, the Gliders' dune ridge lost 141.8 hectares (16.66%) of its original acreage of shifting sand to vegetation.

Aparticularly large shifting dune degradation in the late 20th century occurred in the northern part of the Gliders' dune strip – at the Parnidis dune and Parnidis cape, which had lost 89.1 hectares (24.39%) of its original acreage of shifting sand to vegetation, mainly to mugo pine and Scots pine plantations. After an intensive forestation program, the dune became void of any local sand supply sources and rapidly degraded. In 1954–1990, the height of the shifting part of the Parnidis dune declined from 55 m to 43 m. The total loss of sand in this strip is estimated to as much as 22.0 Mio. m^3.

Dynamics of the Grey dunes

The northernmost strip of the shifting Curonian dunes (Grey dunes) wasn't directly affected by the active forestation policies throughout the last century. However, due to sylvanization of the accumulative sand plain and secular fluctuations of the groundwater level, these shifting dunes reached maturity and started to degrade already in the first half of the 20th century.

Thus, a total deflated sand volume was 19.97 Mio. m^3 in 1909–1954 (~60 thousand m^3 per annum per 1 km of the dune front). Meanwhile, in 1954–1990 the deflated sand volume was only 5.18 Mio. m^3 (~19.4 thousand m^3).

However, regarding the acreage of the shifting sand area, which was lost to proliferating vegetation, the picture is reverse: 39.24 hectares (5.3%) of the total surface of the dune ridge turned from the bare sand dunes to the vegetated ones during 1909–1954, while during 1954–1990 this figure was 83.49 hectares (11.92%). The explanation for this discrepancy is rather simple. In the first half of the 20th century the modern Grey dunes were degrading, their flattening, deflation and the development of gullies and ravines being the prevailing processes. Meanwhile, in the second half of the century, immediately after the groundwater table appeared closer to the ground surface as a result of dune erosion, the proliferation of vegetation took the full speed.

The secular dynamism of the Grey dunes and a long-term contact among the dunes, waves and ice as major coastal development agents has resulted in very interesting and diverse interaction processes between the leeward dune slope and the coastal zone of the Grey dunes.

For instance, the Grey dunes are the only place on the Curonian Spit where sand slumps occur on the lagoon coast, including disastrous ones, like in 1922 (Mager, 1938). Development of the slumps and suffusion gullies is directly related to a relatively high groundwater level in that part of the spit. The groundwater discharges at the leeward foot of the grey dune and carries out sand particles to the coast. This pro-

cess makes the leeward dune slope steeper, which promotes the creation of the slumps and gullies (Povilanskas, Chubarenko, 2000).

INTERPRETATION AND CONCLUSIONS

As discussed in the previous chapter, the first and primary reason of the accelerated sylvanization and flattening of the shifting sandy dunes during the second half of the 20th century is the lack of marine sand supply enhanced by the active dune stabilization and forestation policy which was conducted on both the Russian and the Lithuanian sides of the border. As determined during this study, the dynamics of sand migration can be evaluated by the rate of migration of the Great Curonian dune ridge crest which slowed down from 4–5 m per year in 1909–1954 to 2–3 m per year in 1954–1990, implying that sand deflation generally was prevailing over accumulation. Forest acreage on the spit was steadily increasing in 1950–2000. Climate warming and a decreased herd of wild and domestic animals, which usually was detaining the expansion of vegetation on dunes may also have contributed to this phenomenon. On the Lithuanian side the percentage of the forested areas on the spit increased from 61% in 1963 to 74% in 2001, while on the Russian side from 43% in 1953 to 65% in 2003 (Povilanskas, 2004). The results of this research confirm the conclusions of previous investigations (Michaliukaitė, 1967; Мардосене, Зайнаускас, 1984; Гудялис, Казакевичюс, 1988) performed on separate dunes.

This study points out that application of remote sensing data could be a very effective method for cartometric studies tracing the migration rate and morphology changes of dunes. Remote sensing should be performed periodically as an integrated part of environmental monitoring and state-of-environment reporting.

A radical shift in the dune-handling paradigm – from forestation to the removal of pine plantations and enhancement of dune dynamism – should be introduced on the Curonian Spit, reflecting a greater appreciation of the importance of dynamics to the dune-handling (Doody, 1998; Doody, 2004).

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KURŠIŲ NERIJOS KOPŲ KARTOMETRINIŲ TYRIMŲ REZULTATAI

Santrauka

Remiantis labai tikslios lyginamosios kartometrinės analizės rezultatais, nustatyta, kad metinis Kuršių nerijos didžiojo kopagūbrio smėlio kopų slinkimo greitis sumažėjo nuo 4–5 m per metus 1909–1954 m. iki 2–3 m per metus 1954–1990 metais. Pirmoji ir svarbiausioji pustomų Kuršių nerijos kopų stabilizacijos ir lėkštėjimo priežastis – jūrinio smėlio prietakos nebuvimas. Pustomų kopų degradavimą dar labiau skatina aktyvios kopų stabilizavimo ir apželdinimo priemonės, kurios buvo vykdomos XX a. antrojoje pusėje tiek Lietuvai, tiek Rusijai priklausančiose Kuršių nerijos dalyse. Tam įtakos turėjo

ir klimato atšilimas bei žemėnaudos pokyčiai: Kuršių nerijoje sumažėjo naminių ir laukinių gyvūnų bandos, kurios sulaikydavo natūralų augmenijos plitimą kopose. Satelitiniai duomenys padeda sekti kopų smėlio migracijos greitį, jų morfologijos pokyčius. Būtini nuolatiniai kopų kaitos satelitiniai tyrimai kaip sudėtinė aplinkos monitoringo ir būklės vertinimo darbų dalis.

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ÐÅÇÓËÜÒÀÒÛ ÊÀÐÒÎÃÐÀÔÈ×ÅÑÊÎÃÎ ÈÇÓ×ÅÍÈß ÌÎÐÔÎÄÈÍÀÌÈÊÈ ÄÞÍ ÍÀ ÊÓÐØÑÊÎÉ ÊÎÑÅ

Резюме

Результаты сравнительного картометрического анализа свидетельствуют об уменьшении результирующей скорости движения странствующих песчаных ооловых дюн Куршской косы с 4–5 м в год в 1909–1954 гг. до 2–3 м в год в 1954–1990 гг. На всех участках развеивание, ополаживание и облесение странствующих дюн достигли катастрофических масштабов из-за отсутствия поступления песка с морского берега, а также из-за потепления климата и сокращения стада диких и домашних животных на Куршской косе, которые сдерживали естественное распространение и прорастание леса на дюнах.