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Dynamics of Foredune Parameters of the Curonian Spit (Lithuanian Coast) since 1999

Algimantas M. Olšauskas, Ramunė Olšauskaitė Urbonienė
Klaipėda University, Lithuania.

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Foredune is naturally formed in the west of protective coastal dunes up to the slope of the sand transported by the Baltic Sea wave emissions and prevailing western winds. The sand up to the foot of the slope is reformed by wind to embryonic dunes, and the resulting merger is a foredune. It is described by three basic dimensions - length, width and height. In summer of 1999 from the foot of Kopgalis dune to the Lithuanian state border with the Karaliaučius region, with minor interruptions along the eastern part of the sea beach, the foredune made up a 50 km long belt. Average relative width of a foredune was 7.6 m, its absolute average width being 7.95 m, the height varied from 0.5 m to 1.85 m, while the eastern slope merged with the western dune slope. Plant projection cover was evaluated by 1-13%. On the foredune pioneer plant species *Honckenya peploides* (L.) Ehrh., *Cakile baltica* Jordan. were growing in small groups. Pobeda ex. Rootstock grasses *Ammophila arenaria* (L.) Link. and *Leymus arenarius* (L.) Hochst. dominated among the other grass on the foredune surface. Hurricane "Anatoly" which hit the Lithuanian seaside in early December of 1999 destroyed the foredune, and narrowed the top of protective dunes by 2 meters. During the observations of 2003 spring the foredune was partially recovered in some protective dunes of the western slope foot areas. Then its relative mean width was 3 m and the absolute width - 7 m. The observation repeated in 2005 spring, after the devastating storm "Ervin" showed that the relative average width of the foredune was 2.6 m, and the absolute width - 7 m. In 2006 winter storms bypassed the Lithuanian seaside, in spring the relative average width of the foredune increased up to 5 m, and the absolute average width to 8.4 m. The winter of 2007 was stormy and it greatly influenced the foredunes dimensions. In spring its relative average width was only 2 m, and the absolute average width - 5.3 m. In spring of 2008 the foredune continued to diminish, its relative average width being just 1.5 m, while its absolute average width increased up to 8 m. As observations have indicated the foredune accreted with rootstock grass species can better withstand storms, the western slope of a protective dune suffers less.. The way out of this problem is either artificial formation or natural growth of a foredune of an optimal size at the western slope foot with artificial planting of green rootstock herbaceous plant species.

Key words: *Foredune developments, Curonian spit seashore sand drift processes, waves' impact.*

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1. Introduction

Sand dunes are bordering long stretches of the European coastline. They develop wherever there is a suitable supply of water sediments moved onshore by the tide and then blown inland to form accumulations from a few metres to 30 meters or more thick. Their form has been greatly modified by man and today the dune landscapes are a product of a long history of exploitation (Doody, 1997). An extensive dune system stretches along the Baltic sea as well as the southeast coast from the Riga lagoon

till Vistula lagoon for a distance of over 1000 km. (Zawadzka, 1999, Bush et al., 2002). These dune systems include Latvian and Lithuanian mainland, Curonian and Vistula spits: coastal and parabolic dunes, dune fields and others (Balajan et al.; Kochler et al., Jansen; Piotrowska, 1995). The transition zone between the coastal line and the foot of a coastal protective dune is a dynamic area where accretion and erosion alternate in time and space (Hupper, 1978). In constructive periods primary dunes are formed and, as a rule, may become a continuous foredune. The latter can be subsequently breached and washed out by storm activity while erosion also takes place with significant sand movement. This results in a diverse relief characteristic of a natural foredune. The foredune is the first dune ridge behind the beach zone, where sand continues to accumulate (Carter et al., 1988, 1990). During 2-3 years the foredune ridge may increase in height and grasses will stabilise it within the subsequent 3-5 years (Gomes-Pinta et al.; Favennec, 2002).

On the foredune very characteristic vegetation, depending on its distance from the coast line and on its age, grows up. The very young foredune is an especially highly dynamic area (Hesp., 1984). Restoration work can rehabilitate dune vegetation and planting of *Ammophila arenaria* (L.) Link. is often used to recreate a semi-stable foredune, and given time their development to stable coastal protective dune will take place (Davidson et al.; Doing, 1991).

The developing seashore (beach and dune) on the Curonian spit is a rarely encountered phenomenon on the Baltic coast. The multi-year morphology changes in the studied area show that the Curonian spit has a tendency for a slow foredune development (Olšauskas et al., 2004). The aim of this paper is to report on the part of the study dealing with the development of the foredune and its vegetation in the period of about 10 years. The novelty of this scientific work is that from the register of consequences it is moved to the analysis of causality.

2. Study area and methods

The study area is located on the Curonian spit seashore (Figure 1). This is a sandy peninsula about 100 km long and 0.4 – 4 km wide. It joins the mainland with its narrow south-end by the Sambija peninsula while in the north near Klaipeda it is separated from the mainland by the strait of Klaipeda. The spit reminds one of a scythe with its cutting edge directed against the attacking Baltic. On the eastern shore of the Curonian lagoon there are numerous bays and capers. Along the seashore, which constitutes a sandy beach, a coastal protective dune runs, for the most part it is man made and tended by human hand. In Lithuania the spit extends for 52 km from the strait of Klaipeda (Figure 1).

The coastal protective dune has been formed since the outset of the 19th century. The study area is affected primarily by western winds. The upper beach is covered by small sand. The material building the foredune contains up to 90% of fine and very small sand and not more than 10% of medium sand. Plant species growing there are typical of sand accumulation lovers such as *Ammophila arenaria* (L.) Link., *Leymus arenarius* (L.), Hochst., and lovers of salt soil – *Honckenya peploides* (L.) Ehrh., *Cakile baltica* Jord., ex Pobed, *Salsola kali* L.

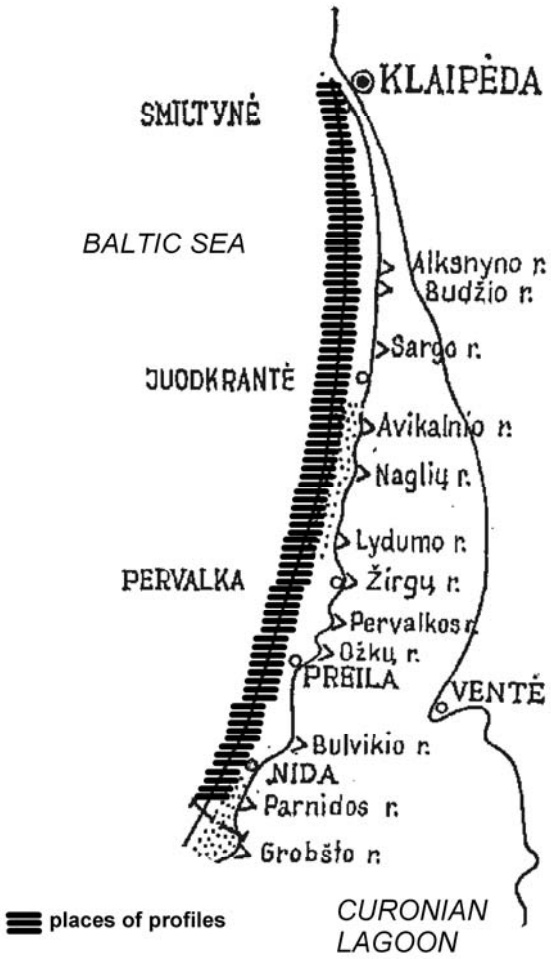

Fig.1. Study area on the Curonian spit

The study involved measuring of coastal dune and foredune relief changes, vegetation dynamics, storm surges and wind impact (Figure 2). The measurements were taken once a year, after the winter stormy period (end of May or beginning of July), after major manifestation of factors having an impact on coastal dunes and fore dunes, in particular. Relief changes were measured with a geodesic device in fixed 86 transverse profiles along the sea beach. The width of foredune was measured at the western foot to the end of the eastern slope. The height of foredune was measured from the beach surface to the ridge top. The

inclination angle of the western slope was measured at the western slope. The protection cover of herbal plants was evaluated by circular plots, whose area comprised 12.56 m^2 by gradations (percentage gradations: 0...100% of the studied area).

Those measurements provided comprehensive information on dynamics of the entire environment, for example, relief changes, vegetation dynamics, storm surges or wind impact. The following parameters of the foredune were studied:

1. Number of researched profiles;
2. Average width of foredune (in profiles);
3. Conditional width of foredune (in all profiles);
4. Height of foredune;
5. Projection cover of plants;
6. Inclination angle of a western slope of coastal dune;

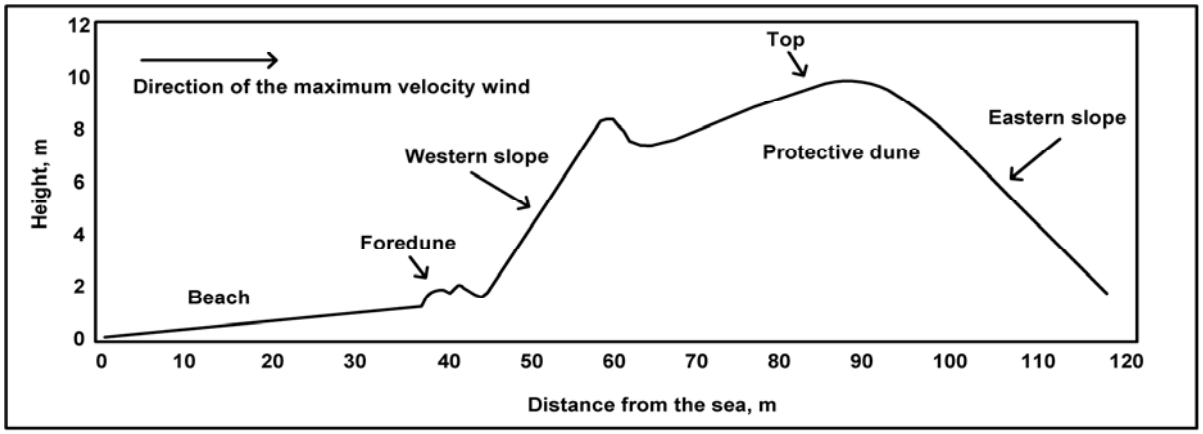

Fig 2. Ideal transverse profile of foredune and protective dune of the Curonian spit (Dubra, Grecevičius 2006)

3. Research results

At present regression caused by abrasion prevails on the Curonian spit seashore. Abrasion destroys the foredune partially or completely and it does the same to the coastal protective dune. At the end of summer of 1999, the upper beach of the Curonian spit was up to 10 – 15 m from the foot of the coastal dune, it featured numerous 0.7 to 1.8 m high drifts of sand and was vegetated by pioneer plants. The hillocks on the beach were separated from each other by deflation depressions, blowouts and organic material accumulated on their bottoms. The average width of the sea beach was about 45-75 meters. The seaward slope of the coastal dune closest to the beach has not stabilised yet. The coastal dune measured on average 5-7 meters in height. At the beginning of winter of 1999, hurricane "Anatolijus" surging by 1.75 m above the average sea level (ASL) destroyed beach's dense hillocks – foredunes, and plant habitats. It also cut the coastal protective dune off and washed it away from the whole Curonian spit seashore (Figure 3). In late spring of 2000 the surface of the beach was covered by drifting sand. The former coastal dune still showed an abraded seaward slope and in many places hurricane sequels were somehow filled up with accumulated sand. A few low sandy hillocks were seen on the coastal dune foot.

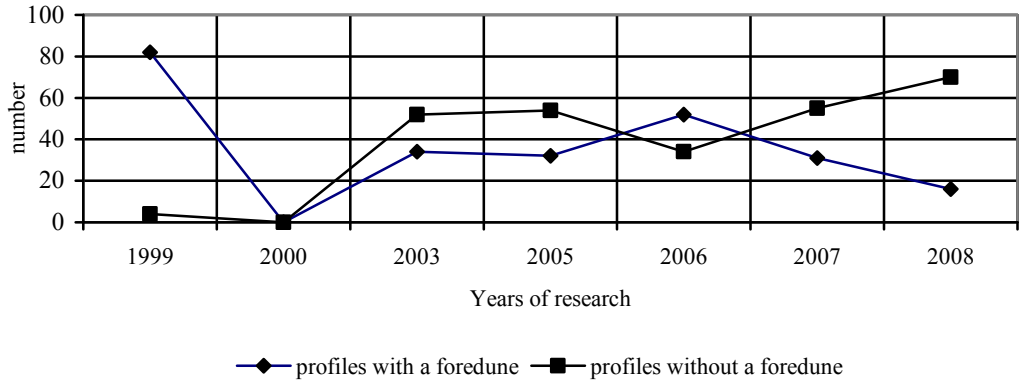

Fig 3. Dynamics of profiles number on the Curonian spit seashore

In 2003 the foredune was growing in size. In some places it joined the western (seaward) slope of the coastal dunes. The increasingly denser grass entrapped higher and higher amounts of sand. As a result of sand accumulation, the abraded seaward slope of the coastal dune became transformed into a classical form. No storms affected the seashore of the Curonian spit in winter of 2004. Narrow depressions between the foredune and coastal dune were filled with the drifting sand.

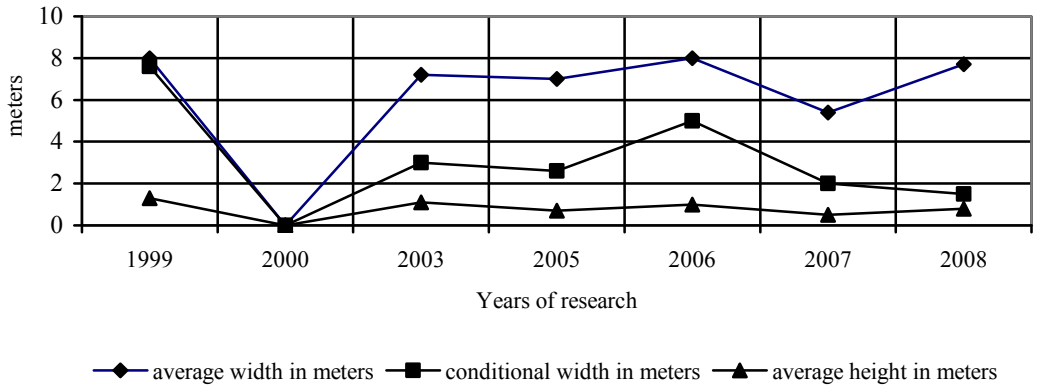

Fig. 4. *Dynamics of foredune parameters of the Curonian spit seashore*

The foredunes got linked into a dune ridge, parallel to the coastal dune, the western (seaward) slope being flat, landward slope of that ridge being steep or melted into the seaward slope of the coastal protective dune. The new foredune did not have any straight ridge along the coastal dune. It was a single ridge consisting of tops of embryo dunes joined together. Ridges of embryo dunes ran transverse to the new foredune ridge. Those ridges reached up to 1.5 – 2 meters. In front of them the accumulation process and plant growth started again. (Figure 4).

In winter of 2005 a heavy storm damaged the foredune and a seaward slope of the coastal dune. Intensive waves raised by the storm washed down the foredune into some profiles in the study area.

No storms affected the foredune in winter of 2006. In spring of that year the sand accumulation process started filling all the gaps and gates in the foredune and a seaward slope of coastal dunes. Some heavy storms (water level to 1.5 meter above ASL) damaged the foredune and destroyed the plant cover in 2007.

The foredune was washed down and on a seaward slope of the coastal dune many storm gaps appeared. The coastal dune was cut off and allowed sea waves incursions on to the seaward slope. In early spring of 2007, sand transport from the beach surface towards the coastal dune foot started, and in summer the foredune was already 1.2 – 1.5 meters high. During that season, an intensive colonization by cereal grasses was observed (Figure 5). During that spring the beach was 25 – 50 meters wide.

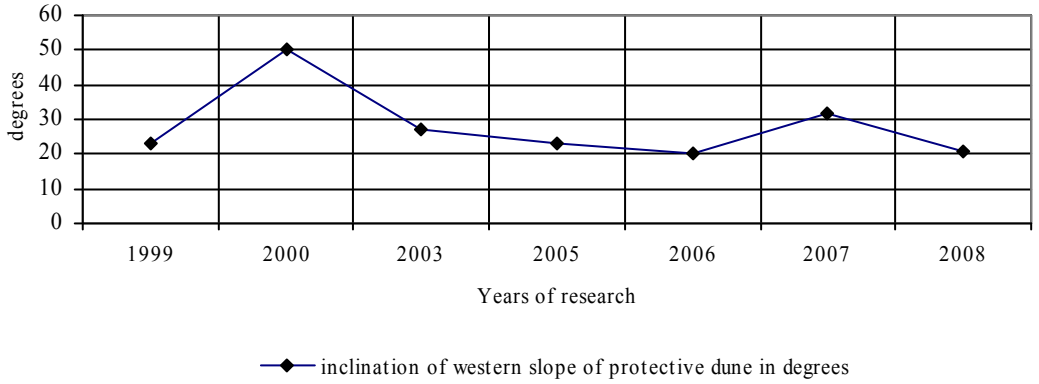

Fig. 5. *Dynamics of inclination of western slope of protective dune on the Curonian spit seashore*

Sand transport from the beach surface towards the foredune and coastal dune started in spring, 2008. At the end of that summer the foredune in some profiles was 1.5 – 2 meters high and 5 – 12 meters wide. The foredune was not continuous, it had opening places and was thinly covered with grass at a density comparable to that observed in 1999 (Figure 6).

Foredunes play a noticeable role in coastal dune protection. They act as a resilient barrier to the destructive forces of waves and wind, absorbing the impact of storms, preventing invasion of water at the foot of a western slope of the protective dune, nevertheless, the loss of vegetation that traps and holds sand makes foredunes more susceptible to wind and water erosion.

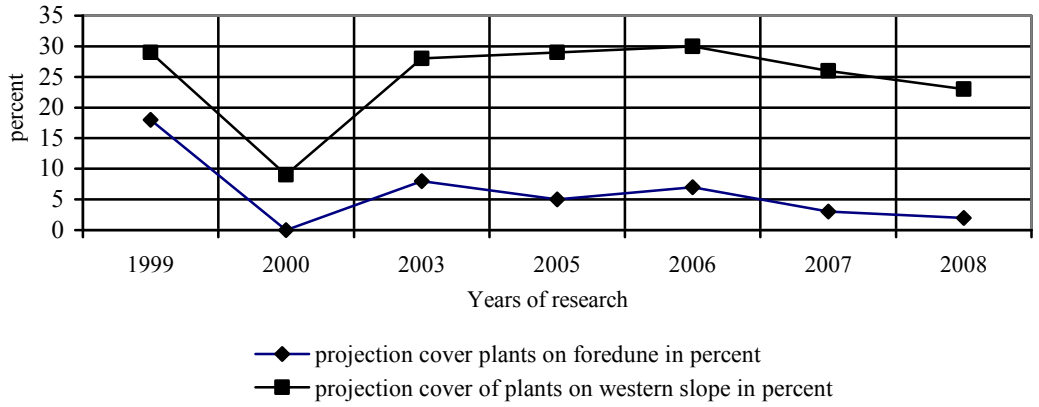

Fig. 6. *Dynamics of projection cover of plants on foredune and on western slope of coastal dune of the Curonian spit seashore*

4. Conclusions

The foredune and a western (seaward) slope of the coastal protective dune on the Curonian spit seashore were completely destroyed and washed off by hurricane "Anatoly" in December, 1999. At present this foredune has been not sufficiently stabilised by grass and is not resistant to withstand heavy storms. At the foot of the western slope of the coastal dune a new foredune was being raised and colonised by herbal plants in spring of 2001. The former foredune has emerged on the seashore area in the period of 2000 - 2008 and its formation is continuing. The winter season in the Curonian spit may feature numerous storms (as in winters of 2004 – 2005; 2006 – 2007). Hurricanes and storm surges cause abrasion of both foredune and coastal protective dune and make the sand layer on the beach surface thin. Absence of mass recreation leads to natural foredune development on the seashore of the Curonian spit.

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Dr. Algimantas M. Olšauskas – prof. at Department of Recreational and Landscape Architecture., Klaipėda University
Main research areas: anthropogenic influence of the vegetation in Lithuanian seaside (protective dune, fore dune).
Address: Klaipeda University,
H. Manto str. 84,
LT – 92294, Klaipeda, Lithuania.
Tel.: +370–63–98830
Fax.: +370-63-98835
E-mail: rpc.gmmf@ku.lt

MSc. Ramunė Olšauskaitė Urbonienė –Department of Recreational and Landscape Architecture, Klaipeda University.
Main research areas: dynamics of the vegetation scatter of the protective dune, dynamics of seaside, recreational influence of the protective dune.
Address: Klaipeda University,
H. Manto str. 84,
LT – 92294, Klaipeda, Lithuania.
Tel.: +370–63–98830
Fax.: +370-63-98835
E-mail: rpc.gmmf@ku.lt

Prieškopės matmenų dinamika Lietuvos Kuršių nerijos jūriniame krante nuo 1999 m.

Algimantas M. Olšauskas, Ramunė Olšauskaitė Urbonienė
Klaipėdos universitetas

(gauta 2008 m gegužės mėn.; atiduota spaudai 2009 m. birželio mėn.)

Prieškopė natūraliai formuojasi pajūrio apsauginės kopos vakarinio (priešjūrinio) šlaito papėdėje iš Baltijos jūros bangų išmetamo ir vyraujančių vakarų krypčių vėjų pernešamo smėlio. Smėlis šlaito papėdėje vėjo yra performuojamas į užuomazgines kopas, o joms susijungus susidaro naujas darinys – prieškopė. Ji apibūdinama trimis pagrindiniais matmenimis – ilgiu, pločiu ir aukščiu. 1999 m. vasarą prieškopė nuo Kopgalio iki Lietuvos valstybinės sienos su Karaliaučiaus kraštu su nedideliais pertrūkiais išilgai jūros paplūdimio rytinio pakraščio apsauginės kopos papėdėje driekėsi apie 50 km ilgio juosta.

Santykinis vidutinis prieškopės plotis buvo 7,6 m, o absoliutus vidutinis plotis – 7,95 m aukštis keitėsi nuo 0,5 m iki 1,85 m, o rytinis (pavėjinis) šlaitas susiliejo su vakariniu kopos šlaitu. Augalų projekcinis padengimas buvo įvertintas 1–13 %. Nedidelėmis grupelėmis ant prieškopės augo pionierinės augalų rūšys: sultingoji jūrasmiltė (*Honckenya peploides* (L.) Ehrh.) ir baltijinė stoklė (*Cakile baltica* Jord. ex Pobed.). Šakniastiebinės varpinės žolės pajūrinė smiltlendrė (*Ammophila arenaria* (L.) Link) ir smiltyninė rugiaveidė (*Leymus arenarius* (L.) Hochst.) vyravo prieškopės paviršiuje, susiformavusiame kovos komplekso žolių sąžalyne.

Uraganas Anatolijus, Lietuvos pajūriu praūžęs 1999 m. gruodžio pradžioje, ištisai sunaikino prieškopę ir 2 metrais susiaurino apsauginės kopos viršūnę. Atliekant stebėjimą, 2003 m. pavasarį prieškopė kai kuriose apsauginės kopos vakarinio šlaito papėdės vietose buvo iš dalies atsikūrusi: jos santykinis vidutinis plotis buvo 3 m, o absoliutus plotis – 7 m. Stebėjimas pakartotas 2005 m. pavasarį praūžus stipriai audrai Ervinas. Prieškopės santykinis vidutinis plotis buvo 2,6 m, o absoliutus plotis – 7 m. 2006 m. žiemą audros Lietuvos pajūrį aplenkė, todėl pavasarį prieškopės santykinis vidutinis plotis padidėjo iki 5 m, o absoliutus vidutinis plotis siekė 8,4 m. Pasitaikė audringa 2007 m. žiema, kuri gerokai paveikė prieškopės matmenis. Jos santykinis vidutinis plotis pavasarį tebuvo 2 m, o absoliutus vidutinis plotis – 5,3 m. 2008 m. pavasarį prieškopė dar labiau sumenko, o jos santykinis vidutinis plotis tesiekė 1,5 m, nors absoliutus vidutinis plotis padidėjo iki 8 m.

Kaip rodo stebėjimų duomenys, prieškopė, apaugusi šakniastiebinėmis žolių rūšimis, geriau atlaiko audras ir mažiau nukenčia apsauginės kopos vakarinis šlaitas. Išeitis – kopos vakarinio šlaito papėdėje dirbtinai suformuoti arba natūraliu būdu užauginti optimalių matmenų prieškopę ir dirbtinai apželdinti šakniastiebinėmis žolinių augalų rūšimis.