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SHORT-TERM CHANGES IN LANDSCAPES OF ESTONIAN SEASHORES

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Abstract. Coastal zones are probably the most dynamic environments. All over the world remarkable activation of coastal processes has been observed on the contemporary seashores during the last decades. This has brought along significant mechanical disturbances and also changes in the soils and vegetation of seashores. The biggest changes are taking place in the active shore, but they can be observed also on dying-out beaches. The changes in soils and vegetation that have occurred on the southern shore of Vesiloo and Kumari Islets in West Estonia during ten years have been given as examples.

Key words: West Estonia, activation of coastal processes, seashore, landscape.

INTRODUCTION

Estonian coasts are rich in banks and shoals and there are many bays and peninsulas. About 1500 islands can be found in the Estonian coastal sea. The length of the coastline is 3790 km. Estonia displays a large variety of contemporary shore types, which have been lithologically and stratigraphically rather well studied.

The geological history of the territory has determined the structure, dynamics, and development of the Estonian seashores. The ancient topography, Quaternary deposits, the hydrological regime of the surrounding sea, and the prevailing marine processes have affected the development of the contemporary shores. The development of Estonian coast has been greatly influenced by the uplift of the Earth's crust, which is up to 3 mm per year at present (Валлнер & Желнин, 1975). Estonian coasts were formed under the effect of wave action under the conditions of sea regression. They are classified as straightening coasts (Orviku, 1993).

The soil—vegetational differentiation evident in the belt arrangement of soil types and plant communities in the shore area and the mosaic-like cover have been examined earlier (Ratas et al., 1988; Puurmann & Ratas, 1990). The dynamics of the soil and vegetation cover on seashores is strongly influenced by coastal processes, the mechanical action of sea water (floods and surges) and hummock ice. The quickest and best observed changes occur in vegetation.

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On the seashores the development of plant communities is in most cases primary. Estonian seashores are not very strongly influenced by human activity. The human impact is more notable on seashore meadows that were used for grazing and, to a lower extent, for hay-making. At the places where human activity has stopped the shores become reedy and the species composition alters. Significant changes in seashores caused by an increased activity of the sea and a remarkable activation of coastal processes on the contemporary shores have been observed during the last decades. This can be associated with global changes in the Earth's climate. In Estonia winters have been mild during the last decades and no firm ice has formed on the coast. At the same time the seawater level has been high and strong westerly or southwesterly winds (up to 30 $\mathrm{m \cdot s^{-1}}$) have often occurred from November till February. Under such conditions the surge can reach a height of 2 m or more. In stormy periods, when breaking waves erode beaches, the strong backwash sweeps sediment offshore, whereas in calmer weather the spilling waves restore the beach profile (Raukas et al., 1994).

The influence of the sea depends on the lithology of initial deposits, characteristics of the coastal profile, exposure to wave actions, and the frequency and intensity of storms.

The changes in the seashore soils and vegetation are more expressive in areas where the surrounding sea is deeper and the breaking force of waves is stronger. Storms have caused notable damage in the soil and vegetation on active shores, especially on sandy beaches, which are

Fig. 1. Location of the studied area.

the least resistant. Wave erosion of beaches is the severest in North Estonia on the coast of the Gulf of Finland. In several places the onshore has widened and the dead part of the scarp has become active. Erosion has reduced essentially the area of several small North-Estonian islands, such as Vahekari, Põhja-Malusi, and Umblu, where the offshore is steep. Due to this, some of the plant communities have been destroyed or their development conditions have changed essentially.

Damages could also be observed on dying-out seashores, where wave action is negligible even during strong surges. The flat and gently sloping area reduces wave energy and prevents erosion. These areas are flooded by sea water several times during the vegetational period. As a result, seashore meadows on salinic littoral fluvisols are formed there. Only the narrow seashore meadow belt that borders the shoreline is subjected to abrasion.

More detailed information on the changes in soil and vegetation is available from West-Estonian small islands (Fig. 1) where some permanent study areas have been established and the changes in soil and plant cover have been studied during the last 10 years. The permanent study areas on Estonian seashores are of a high scientific value for studying the development and changes in soils and vegetation. They serve as an excellent laboratory, where natural processes and the effects of the changes going on at the boundary of land and sea can be studied.

METHODS

Permanent study areas were established on lowshores of West-Estonian small islands. The methods of large-scale mapping (1 : 500) and landscape complex profiles were used to study the landscape structure and to elucidate interdependencies of landscape components. The landscape complex profiles cross the landforms representing different soil—vegetation belts. The vegetation of different belts is described; soils, deposits, and subsurface water are studied. Geobotanical data were obtained from 2 × 2 m or 1 × 1 m squares. The species composition and coverage were fixed. Plant communities were determined by dominant species.

In order to evaluate the alteration processes and to predict the development tendencies of soil and vegetation, repeated soil sampling and detailed sketching of vegetation (1 × 1 m sample squares) on the permanent study areas were performed.

Samples from different soil horizons, seawater, and subsurface water were taken for laboratory analyses. Besides the humus content, pH_{KCl} and physical clay (the fraction <0.1 mm) as well as the content of $N\text{-}NO_3$, Na, B, Cl, and S were determined in the water extract of soils. The content of K, Cu, Ca, and Zn was determined in the 1N HCl extract.

RESULTS AND DISCUSSION

The landscape complex profile in the northern part of **Kumari Islet** (18 ha) crosses beach ridges and a shallow depression between them (Fig. 2). On the maps dating from the beginning of the last century, this area was below sea-water level. Four soil—vegetation belts where significant changes have occurred during the last ten years (1984—94) may be observed on the profile line.

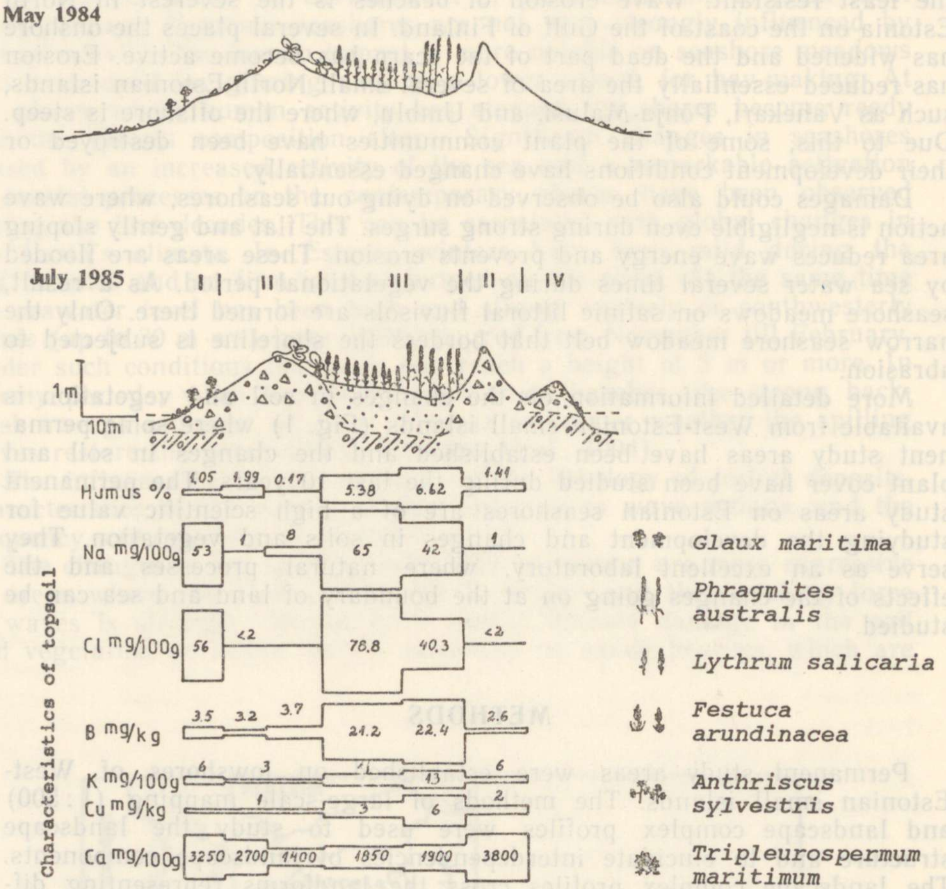

Fig. 2. Changes in the soils and vegetation on Kumari Islet.

Soil—vegetation belts: I, initial seashore meadow on primitive salinic littoral fluvisols; II, pioneer communities on primitive rendzic leptosols on coastal deposits; III, initial communities in shallow depressions on littoral gleysols; IV, plant communities on drift litter.

Differences in the topsoil along the landscape complex profile are shown in Fig. 2, which presents the content of some chemical elements in the 0—15 cm topsoil layer in June 1985. The content of some elements varies widely in the topsoil through the years and during the vegetational season. The largest differences are observed in the upper part of the raw humus horizon of salinic littoral fluvisols on coastal deposits (Ratas et al., 1988; Puurmann & Ratas, 1990).

Repeated studies (in 1984, 1985, 1987, 1994) on this profile revealed changes caused by storms during a high sea level. Continuous accumulation and abrasion of deposits prevent the formation of soil and plant cover, which are therefore fragmented.

On the western shore of the island, which is more exposed to wave action, the *Glaux maritima* community spreads initially in narrow strips or patches on primitive salinic littoral fluvisols (I). In these areas the shore has a gradient 4—7 $cm \cdot m^{-1}$. Here abrasion occurs during storms and gravelly loamy sand is cast on shore. These processes interfere with the development of closed plant communities. The storms of the recent years have destroyed the *Glaux maritima* community on primitive salinic littoral fluvisols.

On the eastern shore the drift litter, mainly seaweeds, carried by the sea is of great importance in the changes of plant communities. Only pioneer communities can develop here (IV).

In the shallow depression sea water affects soils and vegetation mainly through subsurface water. Here initial communities on littoral gleysols (III) occur. When the water level is high, sea water (salinity *c.* 7‰) floods the shallow depression between beach ridges. This causes extinction of some plant species. For example, *Lythrum salicaria,* which shows some tolerance to sea water spray and to salty subsurface water conditions and can survive under quite high levels of Na (67 $mg \cdot 100\ g^{-1}$) and Cl (79 $mg \cdot 100\ g^{-1}$) in the soil, does not tolerate occasional inundation by sea water.

On active shingle beach ridges pioneer communities on rendzic leptosols (II) develop. The development stage of the soil and the species composition of the plant communities on beach ridges differ greatly, since the soil and vegetation pattern may change from year to year due to storms.

One of the permanent study areas for ecological monitoring was established on **Vesiloo Islet** (14 ha) off the western coast of Saaremaa in 1981 (Остров Вилсанди..., 1988). The permanent study area is situated on the southern shore of the islet (Fig. 3).

Geologically this area is connected with the Silurian or West-Estonian Klint, which is composed of hard biohermic dolomite of the Jaagarahu stage. These rocks are covered with highly calcareous till.

The shore on Vesiloo is formed mainly by wave processes and carries an open seashore plant community. The most widespread soils on the seashore are salinic littoral fluviosols. The soil profile has a simple structure, consisting of A- and D-horizons. As a rule, the topsoil is only 5—15 cm thick and composed of a mixture of clay, silt, sand, and organic matter.

In 1981, a seashore strip of *c.* 25 × 200 m was mapped (Fig. 4). At the time of the initial description of the permanent area distinct vegetation belts were evident. Named after the dominant species, the communities were *Tripolium vulgare* *, *Juncus gerardii*, and *Alopecurus arundinaceus* on primitive salinic littoral fluvisols on the flat shore, and *Crambe maritima* on the shingle beach ridge.

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* *Tripolium vulgare* = *Aster tripolium* in the nomenclature by *Flora Europaea.* Vols. 1—5. Cambridge University Press, 1964—1980.

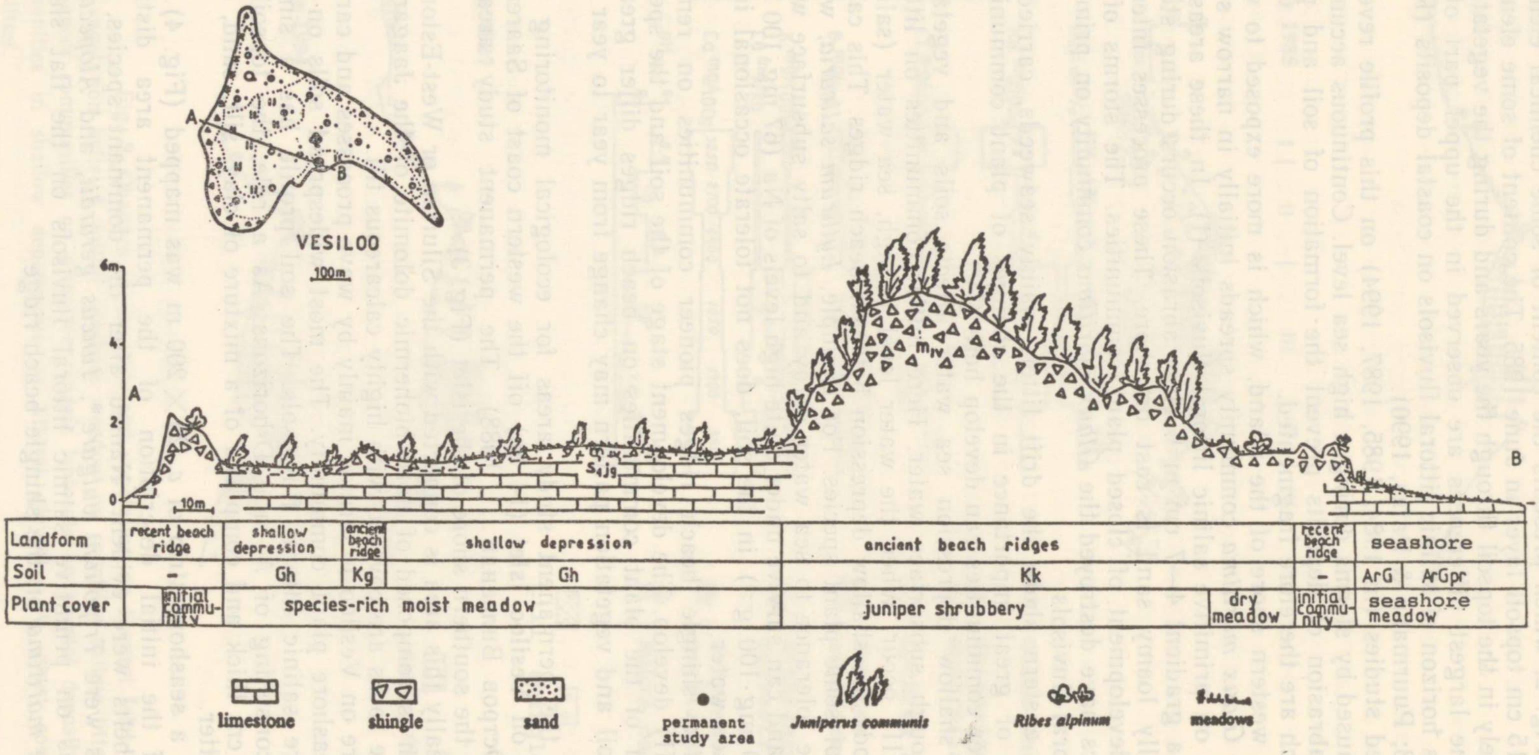

Fig. 3. The landscape complex profile of Vesiloo Islet.
Soil types: Gh, rendzic gleysols on limestone; Kg, gleyic rendzic leptosols on coastal deposits; Kk, rendzic leptosols on coastal deposits; ArG, salinic littoral fluvisols on coastal deposits; ArGpr, primitive salinic littoral fluvisols on coastal deposits.

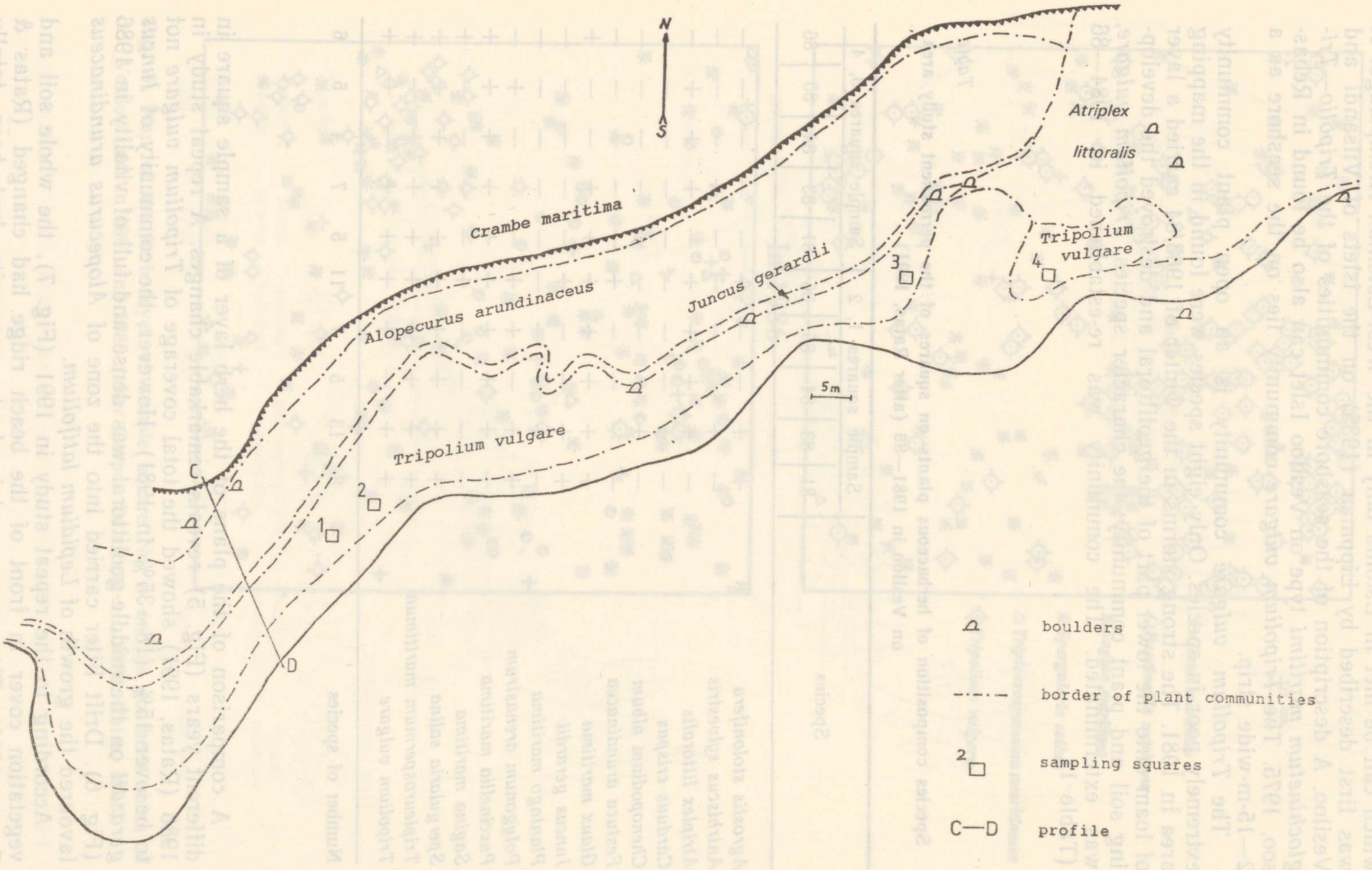

Fig. 4. Vegetation scheme of the permanent study area on the southern shore of Vesiloo Islet in 1981 (after Остров Вилсанди . . ., 1988).

Special attention was paid to the *Tripolium vulgare* community, which can be met in Estonia only in the West-Estonian Archipelago. It was first described by Lippmaa (1935) on the islets of Vilsandi and Vesiloo. A description of the seashore communities of the *Tripolio—Triglochinetum maritimi* type on Vesiloo Islet can also be found in Rebassoo, 1975. The *Tripolium vulgare* community lies on the seashore as a 2—15-m-wide strip.

The *Tripolium vulgare* community is an open plant community extremely poor in species. Only eight species were found in the mapping area in 1981. The strong storms in the winter of 1983/84 carried a layer of loam onto the lower part of the geolittoral and destroyed the developing soil and plant community: the character species, *Tripolium vulgare,* was exterminated. The community was re-established in 1984—86 (Table 1).

Table 1

Species composition of herbaceous plants on squares of the permanent study area on Vesiloo in 1981—86 (after Ratas, 1991)

Species	Sample squares 1, 2					Sample squares 3, 4				
	81	83	84	85	86	81	83	84	85	86
Agrostis stolonifera	+	+	—	—	+	—	—	—	—	—
Antrhiscus sylvestris	—	+	—	—	—	—	—	—	—	—
Atriplex littoralis	—	+	+	+	+	—	+	+	+	—
Carduus crispus	—	+	—	—	—	—	—	—	—	—
Chenopodium album	—	+	—	—	—	—	—	—	—	—
Festuca arundinacea	—	—	—	—	+	—	—	—	—	—
Glaux maritima	+	+	+	+	+	+	+	—	—	+
Juncus gerardii	+	+	—	—	+	—	—	—	—	—
Plantago maritima	—	+	—	—	—	—	—	—	—	—
Polygonum arenastrum	+	+	—	+	+	—	—	—	+	—
Puccinellia maritima	+	+	+	+	+	+	+	+	+	+
Sagina maritima	—	—	—	—	+	—	—	—	—	+
Spergularia salina	+	+	+	+	+	+	+	+	+	+
Tripleurospermum maritimum	+	+	+	+	+	+	+	+	—	+
Tripolium vulgare	+	+	—	+	+	+	+	—	+	+
Number of species	8	13	5	7	11	5	7	4	5	6

A comparison of the plans of the herb layer of a sample square in different years (Fig. 5) reveals remarkable changes. A repeat study in 1986 (Ratas, 1991) showed the total coverage of *Tripolium vulgare* not to be over 15% (18—35% in 1981). However, the community of *Juncus gerardii* on the middle-geolittoral was dense and full of vitality in 1986 (Fig. 6). Drift litter carried into the zone of *Alopecurus arundinaceus* favoured the growth of *Lepidium latifolium.*

According to the repeat study in 1991 (Fig. 7), the whole soil and vegetation cover in front of the beach ridge had changed (Ratas & Truus, 1993). The open coastal plant community had been totally destroyed by the mechanical destructive action during winter storms.

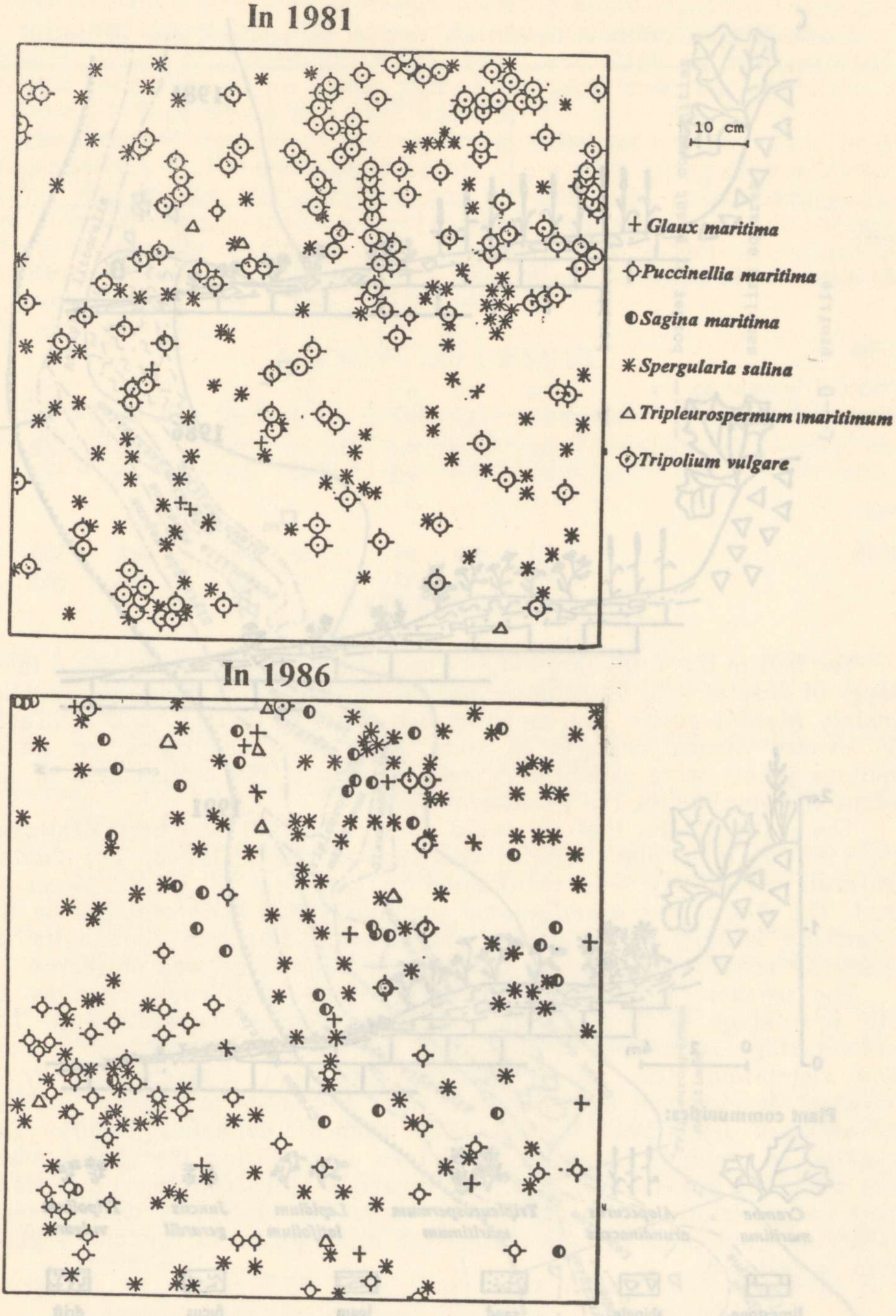

Fig. 5. Plan of the herb layer of sample square No. 4 on the southern shore of Vesiloo Islet in 1981 and 1986 (after Остров Вилсанди ..., 1988; Ratas, 1991).

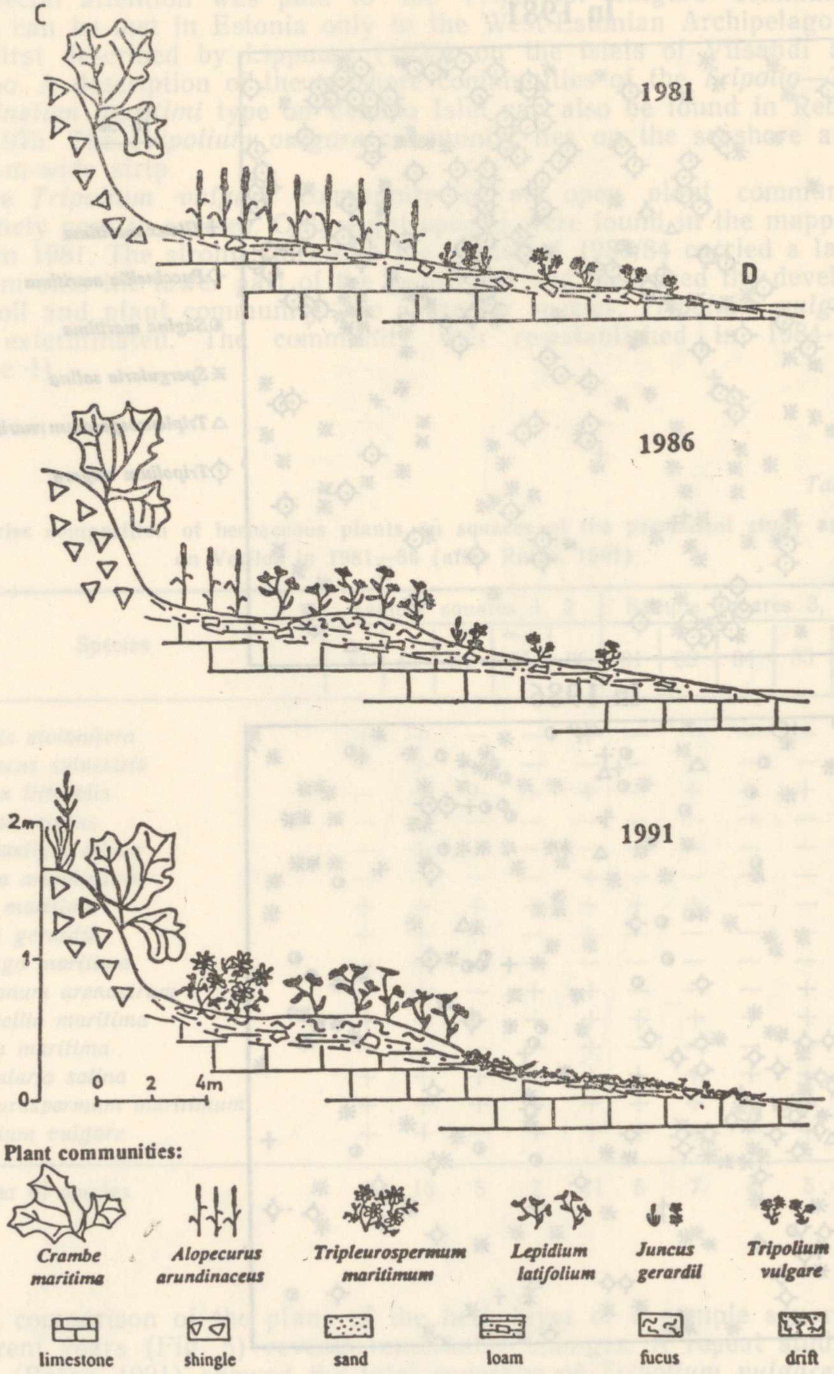

Fig. 6. Changes in the soils and vegetation on the southern shore of Vesiloo Islet.

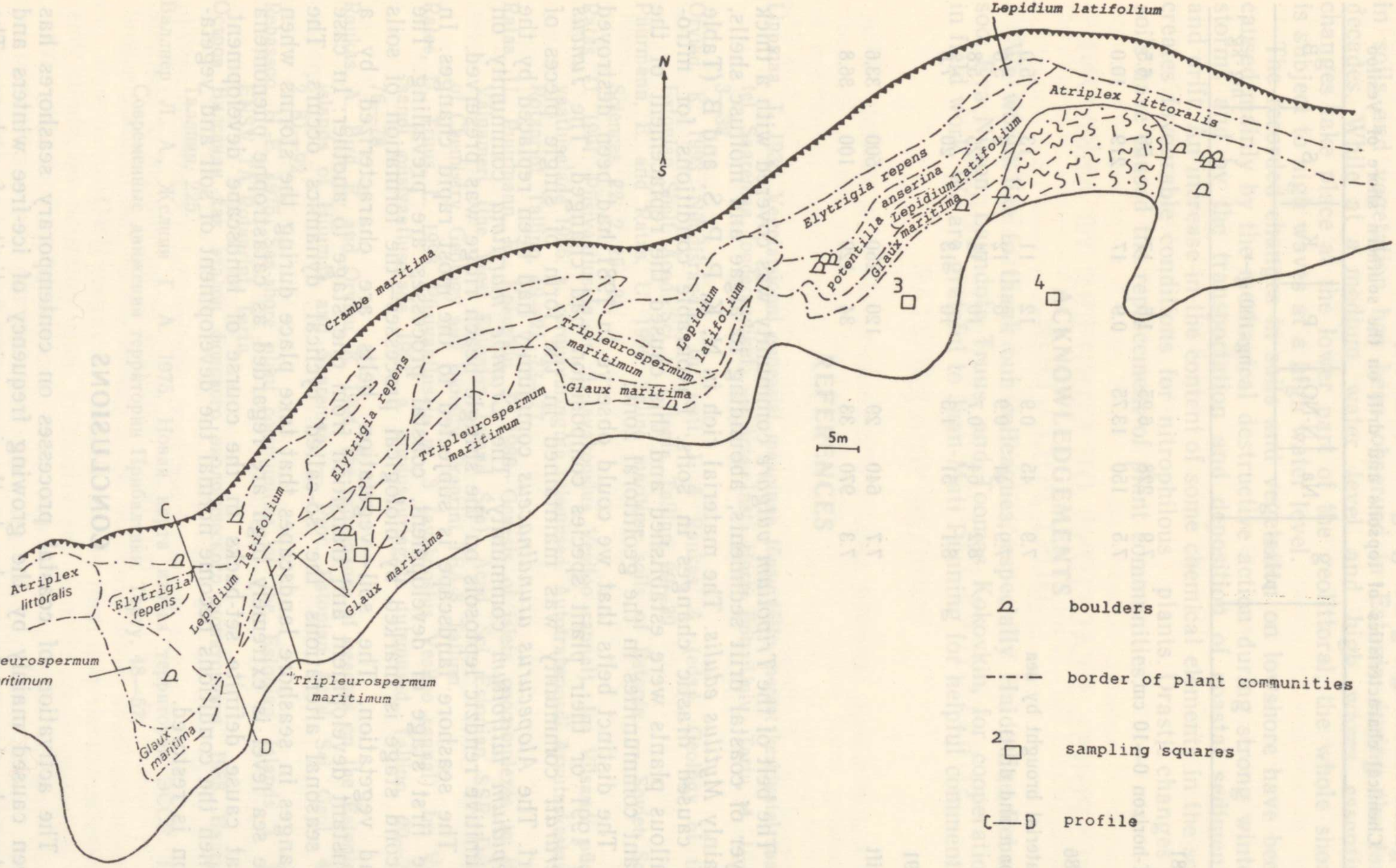

Fig. 7. Vegetation scheme of the permanent study area on the southern shore of Vesiloo Islet in 1991 (after Ratas & Truus, 1993).

Table 2

Chemical characteristics of topsoils and drift on the southern shore of Vesiloo

	pH_{KCl}	Na	$N\text{-}NO_3$	P	K	S	B
		mg·100 g^{-1}					mg·kg^{-1}
1981							
AT-horizon 0—10 cm	7.9	228	6.25	1.5	17	50	6.5
	7.5	150	13.75	0.9	17	219	10.0
1986							
Material brought by sea (loam and drift)	7.9	45	0.9	12	11	13	5.0
	7.9	41	0.9	6	12	5	5.6
	8.2	54	0.7	10	15	25	5.8
	8.1	51	1.3	10	13	20	7.6
1991							
Drift	7.7	640	29	120	250	500	33.6
	7.3	970	33	34	129	100	36.8

The belt of the *Tripolium vulgare* community was covered with a thick layer of coastal drift sediments, abounding in algae and mollusc shells, mainly *Mytilus edulis*. The material rich in N, K, P, P, S, and B (Table 2) caused drastic changes in soils. Favourable conditions for nitrophilous plants were established and this caused the replacement of the plant communities in the geolittoral zone.

The distinct belts that we could observe in 1981 had been destroyed by 1991 or their plant species composition had changed. The *Juncus gerardii* community was maintained in the form of single pieces of turf. The *Alopecurus arundinaceus* community had been replaced by the *Lepidium latifolium* community. The *Crambe maritima* community on primitive rendzic leptosols on the shingle beach ridge was preserved.

The seashore landscape is subjected to the most rapid changes. In the first stage of development, coastal processes are prevailing. The second stage is marked by biological processes—the formation of soils and vegetation. The soil—vegetation belts are characterized by a constant development and transition from one stage to another. In case of seasonal alterations the so-called cyclical dynamics occurs. The changes in seashore landscapes that take place during the storms when the sea level is extremely high are regarded as catastrophe phenomena that cause definite set-backs in the course of landscape development. When the conditions become normal the development of soil and vegetation is restored.

CONCLUSIONS

The activation of coastal processes on contemporary seashores has been caused mainly by the growing frequency of ice-free winters and extremely strong storms due to the increasing activity of cyclones. The rise of the World Sea level is of minor importance in this case, since on Estonian seashores the uplift of the Earth's crust can compensate for the water level rise.

An activation of coastal processes bringing along significant changes in soils and vegetation has been observed in Estonia during the last decades. While at a medium water level and high waves essential changes take place at the lower part of the geolittoral, the whole shore is subject to high waves at a high water level.

The recorded changes in soils and vegetation on lowshore have been caused mainly by the mechanical destructive action during strong winter storms and by the transportation and deposition of coastal sediments and drift. An increase in the content of some chemical elements in the soil creates favourable conditions for nitrophilous plants. Drastic changes in soils have caused the replacement of plant communities.

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