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RELATION OF THE COVERAGE OF THE EPIPHYTIC LICHEN *HYPOGYMNIA PHYSODES* TO BARK CHEMISTRY OF SCOTS PINE

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Abstract. Field responses of the coverage of *Hypogymnia physodes*, the most common pine-inhabiting lichen, to the pollution-influenced bark chemistry of Scots pine were studied in North Estonia. The coverage of *H. physodes* was best correlated with bark pH. Elevated levels of nitrate were found to be positively and those of sulphate negatively related to the coverage of *H. physodes* at bark pH interval of 3.3—6.1. The relations of the other chemical variables studied were not expressive.

Key words: bark chemistry, *Hypogymnia physodes*, isoquanta models, North Estonia, Scots pine.

INTRODUCTION

Hypogymnia physodes (L.) Nyl. is the most common and widespread epiphytic lichen growing on conifers in the boreal and nemoral forest zones. Quantitative evidence of this has been provided for Finland (Halonen et al., 1991; Hyvärinen et al., 1992), Sweden (Esseen, 1981), Norway (Bruteig, 1993; Hilmo, 1994), and for Estonia (Sõmermaa, 1972).

On a transect through the middle boreal subzone in Finland at latitude 65° N *H. physodes* favours pine more than spruce and has higher coverage in western localities (Halonen et al., 1991). In Norway it has an ecological optimum in the southern parts of the country, in the areas with high evapotranspiration and temperature sum and in rather dense forests of the high productivity class. In the Detrended Correspondence Analysis ordination space *H. physodes* was best correlated with precipitation and bark pH (Bruteig, 1993).

In Estonia its climatic preferences were not investigated, as all the sample sites of the quantitative study by Sõmermaa (1972) were located in inland areas of the country. Instead, the relations of *H. physodes* to forest site type and stand age were studied. *H. physodes* was found to be more abundant in *Vaccinium* type than alvar type pine forests and to have no remarkable preferences in regard to stand age.

H. physodes is a very suitable species for monitoring air pollutant deposition. It has good accumulative capacities, is relatively tolerant of heavy metal and acidic pollution, and can be found in sufficient amounts around sources of this kind of pollution. For pollutant deposition monitoring, it has been very extensively used in Finland (see Halonen et al., 1993 for references), but also in boreal North America (Pfeiffer & Barclay-Estrup, 1992).

H. physodes is a photophilous lichen with a very wide amplitude for light (Ott, 1987). It is classified as an acidophyte, as its optimum range of bark pH is 4.2—4.8, but also as an anitrophyte to moderate nitrophyte (Wirth, 1980). In laboratory experiments *H. physodes* has been shown to benefit from moderate nitrogen supply, but to be destroyed by its excess (Kauppi, 1980; Holopainen & Kärenlampi, 1985; Oksanen et al., 1990). *H. physodes* is able to take up phosphate from very weak solutions and the content of phosphate in nonpolluted rain water was shown to be sufficient for its growth (Farrar, 1976).

The aim of the present study is to show the field relations between the coverage of *H. physodes* and the chemical properties of pine bark, the last varying in a wide range under the influence of the accumulation of airborne pollutants.

MATERIALS AND METHODS

To avoid possible influences of climatic differences, the material for the present study was collected mainly along the northern coast of Estonia, not farther than 20 km from the sea. Pine forests in the suburbs of Tallinn, the surroundings of Kehra (pulp and paper mill), Kunda (cement plant), and Kohtla-Järve (oil-shale processing) were selected as study sites. In these areas bark chemistry was expected to be strongly altered by the deposition of airborne substances. Reference sites with bark chemistry influenced mainly by natural processes were selected in two national parks, Vilsandi and Lahemaa.

It was not possible to find the same forest site type in all study sites; however, all of them were situated in open dry pine forests or groves. Maximum variation of the coverage of *H. physodes* (0—80%) was included into the study, without any physical factor (light, moisture, etc.) being obviously the reason of variation, i.e. the habitat and the sample trees were standardized as much as possible. Straight-standing mature trees with a breast-height diameter of 20—30 cm were selected for sampling. Percentage coverage of lichens was estimated on the side of the trunk with maximum lichen coverage (mostly NW) at a height of 1.3 m in a quadrate of 20×20 cm.

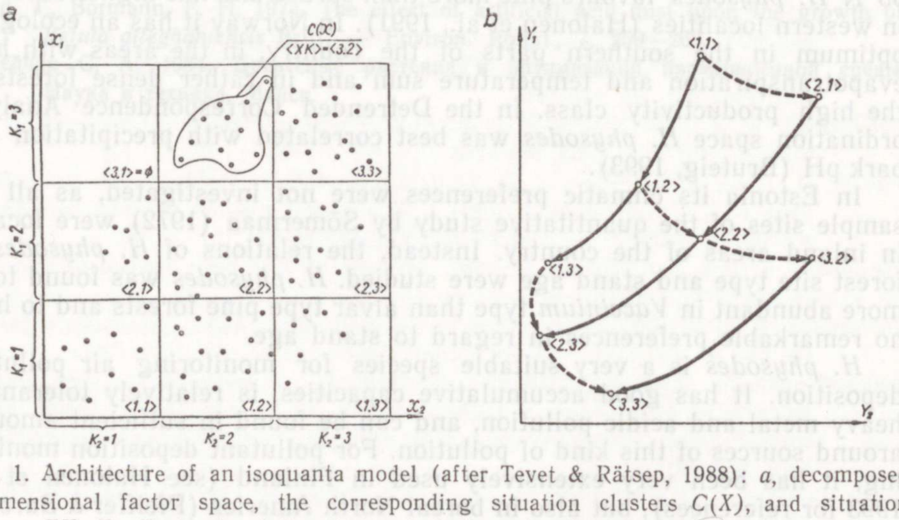

Fig. 1. Architecture of an isoquanta model (after Tevet & Rätsep, 1988): *a*, decomposed 2-dimensional factor space, the corresponding situation clusters $C(X)$, and situation vectors XK, K_1, K_2, levels of X criteria; *b*, 2-dimensional phase space with isoquanta.

Bark flakes (*c.* 2 mm thick) were collected from the same quadrate for chemical analysis. In laboratory, the bark flakes were studied under binocular lens to determine the lichens not recognized or not seen in field study. Lichens were carefully removed from the bark and the bark flakes (not ground) were shaken for 2 hours with distilled water (1:100, wt/v) at room temperature. Electric conductivity and ammonium, nitrate, phosphorus, sulphate, and calcium content of the bark extract were determined by the standard methods of water analysis in the Estonian Central Environmental Research Laboratory. Full chemical analysis was made of 100 bark samples. Bark pH of 220 sample trees was measured in the laboratory of the Tallinn Botanical Garden, the ratio of bark/water was 1:20 (wt/v).

The material was treated applying the method of isoquanta analysis (Tevet & Mäemets, 1985; Tevet & Rätsep, 1988). The method is based on decomposition of N-dimensional factor space $R(X)$ into non-overlapping subspaces or situation clusters $C(X)$ (Fig. 1*a*). For each situation cluster the corresponding regression function is established. The isoquantum is a regression curve of one independent X-criterion when the values of the rest X-criteria are fixed on definite levels (Tevet & Rätsep, 1988). Isoquanta may be represented in a phase space $R(Y)$ (Fig. 1*b*) or in a mixed factor—phase space.

In the present study, the input or X-criteria are the chemical variables of the pine bark (pH, electric conductivity, and the content of the ions studied). The output or Y-criterion is the percentage coverage of *H. physodes*. Isoquanta models are composed using the combinations of two X-criteria.

RESULTS AND DISCUSSION

In the present dataset most of the chemical variables of the pine bark, as well as the coverage of *H. physodes*, varied in a wide range. In background areas the pH values of the bark of Scots pine were 3.6—4.2. The lowest pH value in this dataset was 3.3, which was registered under moderate acidic pollution in the suburbs of Tallinn. The highest pH value was 8.5 in the area of heavy alkaline dust deposition load near the cement plant of Kunda.

For isoquanta analysis the values of the bark pH were divided into five levels with the first level having the lowest pH values (Table 1). *H. physodes* had high coverage in the case of three first pH levels. At the fourth pH level its coverage was under 5% and at the fifth level it was absent. Of all the chemical variables, bark acidity had the strongest negative correlation with the coverage of *H. physodes* (Table 2). The regression curve of the coverage vs. the bark pH is presented in Fig. 2.

The values of ammonium, nitrate, sulphate, and calcium content and of electric conductivity were divided into three levels. Only two levels of phosphorus content were distinguished since the scope of its variation was relatively small (see Table 1). Reference values from the two national parks were under the detection limits for calcium, within the lower level for phosphorus and electric conductivity, and within the medium level for ammonium, nitrate, and sulphate. The highest contents of ammonium, nitrate, and phosphorus were found in different places in the suburbs of Tallinn. Calcium and sulphate content and electric conductivity were the highest in the surroundings of the cement plant of Kunda, where pine boles were partly covered with cement crust, and the only lichens growing on the bark were *Caloplaca holocarpa* (Hoffm.) Wade and *Lecanora dispersa* (L.) Sommerf., which normally grow on limestone, mortar, or asbestos.

Table 1

Levels of the chemical variables of pine bark used in isoquanta analysis

Variable	Level					Detection limits	No of records over detection limits
	1	2	3	4	5		
pH	3.3—3.9	4.0—5.0	5.1—6.1	6.2—7.2	7.3—8.5	0.1	100
Electric conductivity, $\mu S \cdot cm^{-1}$	15—49	51—87	117—898			1.0	100
NH_4, $mg \cdot l^{-1}$	0.5—2.8	3.0—4.9	5.1—25.6			0.1	100
NO_3, $mg \cdot l^{-1}$	0	0.1—0.9	1.1—6.8			0.1	70
SO_4, $mg \cdot l^{-1}$	0—15	16—40	41—353			0.1	97
Ca, $mg \cdot l^{-1}$	0	2—10	12—164			0.5	53
P-PO_4, $mg \cdot l^{-1}$	0—0.44	0.46—2.44				0.02	84

Table 2

Correlation matrix of chemical characteristics of the pine bark and the coverage of *Hypogymnia physodes*

	NH_4	NO_3	P	Ca	SO_4	Electric conductivity	Coverage, %
pH	0.183	−0.088	−0.292*	0.540*	0.211*	0.470*	−0.559*
NH_4		0.191	0.181	0.305*	0.377*	0.462*	−0.089
NO_3			0.207*	0.019	0.156	0.076	0.028
P				−0.089	−0.006	−0.060	0.158
Ca					0.744*	0.905*	−0.272*
SO_4						0.880*	−0.153
Electric conductivity							−0.266*

* significant correlations, $p<0.05$.

In the isoquanta analysis the bark pH was used as an $X1$-criterion, all the rest of the chemical variables being used in turns as $X2$-criteria. Isoquanta are represented in a factor—phase space, where the X-axis shows the bark pH values and the Y-axis the lichen coverage values. In the numbers of clusters the first figure indicates the level of the $X1$-criterion and the second number that of $X2$-criterion. The numbers of clusters with statistically reliable (after Q-criterion; see Tevet & Rätsep, 1988) output values of the coverage of *H. physodes* are encircled.

The best results in the isoquanta analysis were obtained using sulphate and nitrate as $X2$-criteria. Higher levels of sulphate were related to lower coverage of *H. physodes*, the relation being remarkable at the second and the third pH level (Fig. 3). On the contrary, higher nitrate levels were related to higher coverage of the lichen, the effect could also be followed at the second and the third pH level (Fig. 4).

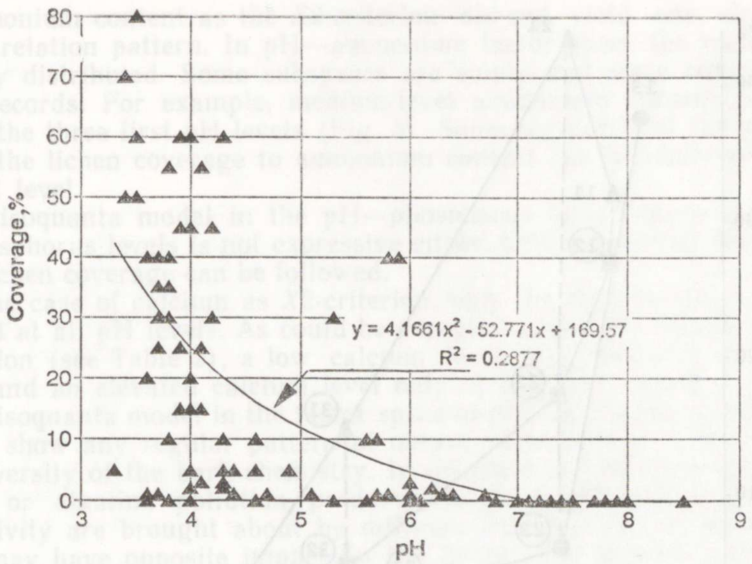

Fig. 2. Regression curve of the coverage of *H. physodes* vs. pH of pine bark.

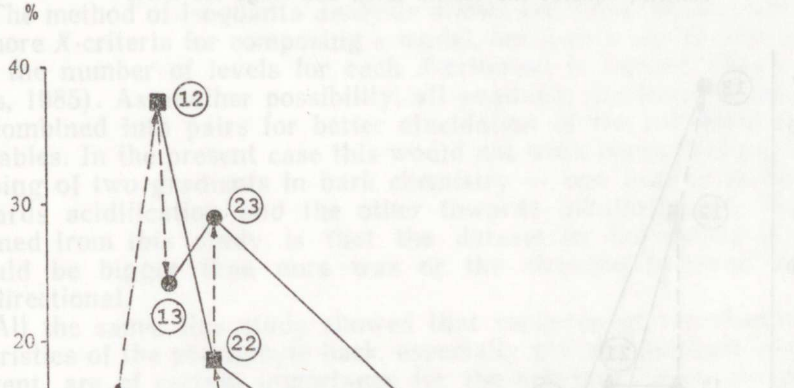

Fig. 3. Isoquanta model: *Y*, coverage of *H. physodes*; *X*1, pH; *X*2, sulphate content of pine bark. The first number denotes the level of *X*1 and the second one that of *X*2; statistically reliable clusters are encircled. Triangles denote the first level of sulphate content, squares the second level, and rings the third.

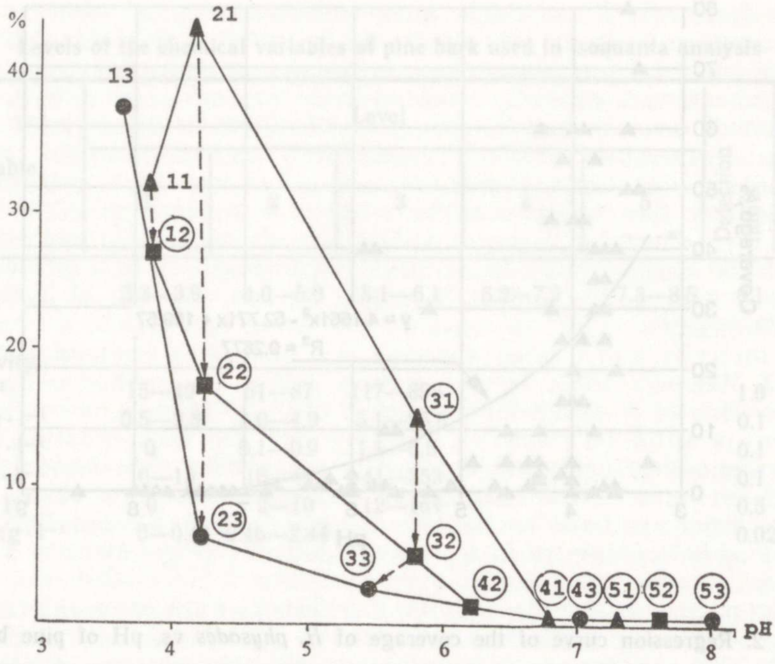

Fig. 4. Isoquanta model: *Y*, coverage of *H. physodes*; *X*1, pH; *X*2, nitrate content of pine bark. The first number denotes the level of *X*1 and the second one that of *X*2; statistically reliable clusters are encircled. Triangles denote the first level of nitrate content, squares the second level, and rings the third.

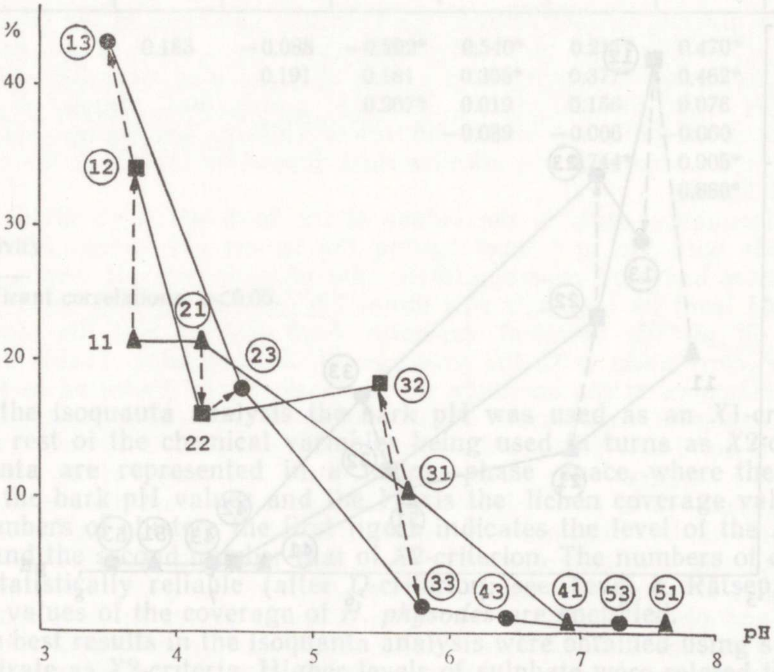

Fig. 5. Isoquanta model: *Y*, coverage of *H. physodes*; *X*1, pH; *X*2, ammonium content of pine bark. The first number denotes the level of *X*1 and the second one that of *X*2; statistically reliable clusters are encircled. Triangles denote the first level of ammonium content, squares the second level, and rings the third.

Ammonium content as the $X2$-criterion did not yield any clear and regular relation pattern. In pH—ammonium factor space the records are unevenly distributed. Some subspaces are empty and some contain only a few records. For example, medium-level ammonium content is found only at the three first pH levels (Fig. 5). Some regularity of the relationship of the lichen coverage to ammonium content can be observed at the first pH level.

The isoquanta model in the pH—phosphorus factor space with only two phosphorus levels is not expressive either, only inessential differences in the lichen coverage can be followed.

In the case of calcium as $X2$-criterion, only the medium calcium level occurred at all pH levels. As could be expected after their strong positive correlation (see Table 2), a low calcium level was met only at low pH values and an elevated calcium level only at high pH values.

The isoquanta model in the factor space of pH and electric conductivity did not show any regular pattern of output values either. The reason is high diversity of the bark chemistry. In different air pollution conditions (acidic or alkaline pollution predominating), equal values of electric conductivity are brought about by different combinations of electrolytes, which may have opposite impact on the lichen. The highest coverage of *H. physodes* occurred in the cluster of the lowest pH and the medium electric conductivity.

Statistically unreliable values of output criteria were found mostly at the first pH level. At this level records from reference areas with a high lichen coverage as well as those from the areas of moderate acidic pollution with a reduced lichen coverage were obtained. Therefore, the variation of output criteria in some situation clusters is too high to give reliable medium values.

The method of isoquanta analysis allows the simultaneous use of three or more X-criteria for composing a model, but then a big dataset is needed and the number of levels for each X-criterion is limited (Tevet & Mäemets, 1985). As another possibility, all available X-criteria in turns could be combined into pairs for better elucidation of the influence of certain variables. In the present case this would not work because of partial overlapping of two gradients in bark chemistry — one from reference values towards acidification and the other towards alkalinization. The lesson learned from this study is that the dataset for the isoquanta analysis should be bigger than ours was or the changes followed should be unidirectional.

All the same, this study showed that variation of the chemical characteristics of the phorophyte bark, especially pH and sulphate and nitrate content, are of certain importance for the epiphytic lichen *H. physodes*. The data of the present field study do not contradict the results of the experimental investigations cited in the introduction and are in good accordance with an earlier study (Nilson, 1988) dealing with the lichens of the deciduous trees in Kadriorg park, Tallinn.

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