New plant ecological scales of soil reaction for Leningrad region and St. Petersburg based on Ramensky’s method

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Abstract. The main biogeochemical processes are influenced by soil pH. For assessing pH by the method of vegetation indication a new database of the ecological scales of plant species describing the correlation between classes of species coverage and pH. Field data was collected at 800 sample plots. At sample plots the coverages of plant species and pH of organic upper soil horizons extracted by KCl solution were determined. Synoptic tables with average coverage for each species were compiled for forest types. The range of pH (2.5–5.5) was divided into 7 classes differ by 0.5 unit of pH each. For each species coverage class, the first and third quartile of pH were established. Ecological scales included these two values as minimum and maximum values (amplitude) of the pH for a given coverage class. Determining of soil pH using the ecological scales was a solution of the system of inequalities that are the set of amplitudes of the pH values corresponding to the coverages of species of the certain plant community. Comparing measured and indicated pH values using data for 45 sample plots that were not used for compilation of scales showed excellent match of measured and indicated values.

1. Introduction

Soil reaction is the characteristic of acidity or basicity (alkalinity) of the soil. It is estimated by pH that is the negative logarithm (base 10) of the activity of hydronium ions (H+ or, more precisely, H3O+aq) in the solution. In 1923 C. Olsen published the paper [1] in which the changes in the abundance of individual plant species depending on the hydrogen ion concentration in the soil were shown in tabular form (on the basis of constancy in the Raunkier’s scale). C Olsen [1] has found that the floristic composition of meadow and forest plant communities of Denmark was closely correlated with concentration of hydrogen ion in the soil; and the distribution of plant species was significantly determined by this factor. Olsen has found also that the species richness in plant communities depended on soil reaction; and was maximal when the soil reaction was neutral [1].

Dora Neina [2] analyzed literature concerning the role of soil pH in plant nutrition and soil remediation. She showed that the main biogeochemical processes are influenced by soil pH: it «controls the solubility, mobility, and bioavailability of trace elements, which determine their translocation in plants» [2]; the solubility of organic matter by increasing the dissociation of acid functional groups thus reducing the bonds between the organic constituents and clays and stimulating or repressing microbial activity. Remediation of contaminated soils depends on microbial activity that is maximal when pH is near 7 [2].
M P Austin, [3] recognized three types of gradients as important for development of models for use in vegetation analysis: 1) indirect environmental gradients where the environmental factor has no direct physiological influence on plant growth e.g., elevation; 2) resource gradients where the factor is an essential resource for plant growth and 3) direct environmental gradients where the factor has a direct physiological effect on growth but is not an essential resource. Factor of pH he considered to be of the third type.

C Olsen’s table [1] was the first table, using which it was possible to determine the level of the acidity of the soil, based on the geobotanical description of vegetation. In 1929 L G Ramensky published in Russian and in 1930 in German [4] the methodology of the comparative processing and ordering of lists of plants and plant communities that were determined by several different factors. The units of measurement of habitat conditions were the gradations given by L G Ramensky [4] in the form of scales for each factor separately. These scales characterize the distribution of plant species abundance along ecological gradients when plants grow together in a community. Ecological scales were the amplitudes of a certain factor that were given for several classes of plant abundance of species. Using the ecological scales and the plant species composition, it is possible to indicate the ecological conditions of each site by its vegetation. Ecological scales have been developed by L G Ramensky and his colleagues for moisture content, moisture variability, active soil richness and salinity, thickness of alluvial deposits, and pasture digression for natural pastures and hayfields of the European part of Russia in 1956 [5].

In 1974 H. Ellenberg presented his ecological scales of Central Europe and later the new version of this scales was published [6]. Several geographic alternatives of Ellenberg’s scales were compiled (see the review [7]).

Ecological scales can be divided into three main types [7]: 1) the optimum scales, where only the point of ecological optimum is indicated for each species [6] and others (see review [6]); 2) the amplitude (otherwise interval, or median) scales, that indicate limits of tolerance of the species [8]; and 3) the amplitude–optimum scales, where the amplitude of tolerance of the species to the factor, depends on the species abundance ([5] and several regional scales, see review by [7, 9]).

The indication of pH is present in [6, 8] scales but these scales do not contain data on Bryophytes. Taking into account the absence of Bryophytes we concluded that Ellenberg’s and Tsyganov’s scales are not suitable for forecasting the pH in Leningrad region and Saint – Petersburg where Bryophytes are abundant in many forest types [10].

Optimum scales do not take into account the normal–curve relationship between species success and environment [11], using multiplying of optimum value by the coverage of species, while the certain coverage usually indicates the factor values that are essentially different from the optimum (figure 1).

Figure 1. The hypothetical relationship of species X to an environmental gradient; A? and B? represent possible locations of stands A and B along the gradient, given an observed value for each, after [11].
For the purpose of decreasing the time of calculation of indicated values of ecological factors several computer information–statistic systems containing data bases with ecological scales were compiled [7, 12].

The task of our research was to develop a method for assessing soil acidity by vegetation indication at Leningrad region and Saint – Petersburg because there are no adequate scales for this purpose.

2. Methods and Materials

2.1. Field data collection
Field data used for this purpose was collected at 800 sample plots laid in the forests of Leningrad region and city Saint – Petersburg. Sample plots 1200–25000 m² each were laid at relatively homogenous sites. At sample plots soils and vegetation were studied simultaneously. The study started with digging 20 pits 30 cm depth. Upper soil horizons thickness was measured in the pits. Then in the typical place a soil pit was dug with a depth of p 1.5 m. Soil samples for laboratory analysis were taken along the horizons from small pits for organic and humus horizons and from a large pit for the middle and lower horizons. Soil samples of organic and humus horizons were taken as mixed from 20 small pits.

At each sample plot the forest stand taxation was fulfilled and the projection coverage of shrubs, herbaceous species, mosses and lichens were estimated using 20 samples 1m² each. Relevés were classified in types of forest sites using data on vegetation and soils using the method of Saint Petersburg Forestry Research Institute [10]. According to Russian national standards forest types were distinguished taking into account forest site type and predominating tree species [10].

2.2. Measurement of pH
We used hydrogen ion extraction from the upper organic soil horizon using KCl solution. It shows a potential (latent) soil acidity, which is due to the presence of hydrogen or aluminum ions in the absorbed state. Part of the hydrogen ions absorbed by the soil can be displaced into the solution by the cations of neutral salts. So, if the soil is treated with KCl solutions, then the potassium cations will be absorbed by the soil, and hydrogen ions will pass from the absorbing complex into the solution. On the other hand, pH measurement with KCl extraction is recommended for better and faster results in the pH electrode. The pH of the salt extract was determined in accordance with GOST 26483–85 [13]. The essence of the method was the extraction of exchangeable cations from the soil with a solution of potassium chloride with a concentration of 1 mol/dm³ (1 N) and potentiometric determination of pH using a glass electrode. The pH was determined in samples of organic soil horizons, the extract was prepared at a soil to solution ratio of 1:25. The total error of the method in determining pH was 0.1 pH units.

2.3. The choice of the type of ecological scales
Optimum scales do not take into account the normal–curve relationship between species success and environment [11], using multiplying of optimum value by the coverage of species, while the certain coverage usually indicates the factor values that are essentially different from the optimum (figure 1).

In amplitude scales the average value does not always coincide with their ecological optimum which can be shifted to any of the edge values of the scale due to competition between plants in the community [5]. As it was pointed out above, the method of indication using optimum ignored the real distribution of species abundance along factor gradients and thus this method theoretically is not correct [11]. The amplitude–optimum scales by Tsyganov [8] were also not correct because they have been constructed using the assumption that optimum matches with the amplitude median that occurs very rare [5]. From the mathematical point of view determining environmental factors such as soil pH using the amplitude–optimum ecological scales of plants of Ramensky et al. [5] is a solution of the system of inequalities that are the set of amplitudes of the factor values corresponding to the coverages
of plant species given in the table (figure 2). Thus, the of Ramensky’s approach is methodologically suitable for solving the problem of compiling ecological scales of plants.

![Graph showing ecological amplitudes of three species.](image)

**Figure 2.** The hypothetical solution of indication of ecological factor (8.2) for plant community with three species and their values: A=40, B=80; C=60.

### 2.4. Compilation of ecological scales
Synoptic tables consisting of constancy and average coverage for each species were compiled for forest types and their geographical variants occurring in different landscapes. For each variant of forest type average pH of organic horizon was calculated. The range of pH was divided into several classes differ by 0.5 unit of pH each. Then for each species two–dimension tables where columns were classes of pH and rows were classes of coverage and cells contained the number of cases recorded for certain coverage and pH classes were compiled.

Then for each pH class the total number of cases was calculated and values of the first and third quartile were established. These two values were taken as the minimum and maximum values of the coverage for a given pH class. According to Ramensky [5] the values of quartiles were more convenient that average or median, reflecting not a point, but a known amplitude, the volume of conditions. Such a “volume” was the quarterly standard formed by the first and third quartiles of each indicator; these quartiles reflect the usual or average limits of fluctuations in all indicators within the pH class. In significantly heterogeneous groups of vegetation lists, the first quartile for most plants is zero (i.e., plants are absent in more than 25% of the group's lists). In these cases, the volume standard can be characterized by a set of third quartiles [5].

### 2.5. Testing ecological scales.
Verification of the compliance of the environmental scales was performed on the material of 45 sample plots of 7 forest types, where the coverages of plant species were estimated, and the pH were determined by means of laboratory analyses and indication using coverage of species and ecological scales. These data were not used to construct the scales.

To test the correlation between the pH values indicated by species composition and determined by analyses the linear regression equation was compiled and coefficient of determination was computed using Microsoft Excel. We calculated standard deviation between indicated and measured pH values and standard error of indication.

### 3. Results and Discussion

#### 3.1. Forest site types and their acidity
The pH values were measured directly for 25 forest site types (series of forest types) and 49 forest types that were distinguished by [7]. The pH varied from 2.5 to 5.5. The most acid organic horizons (pH 2.5–3.5) were found in *Pinetum cladinosum, Pinetum ledosum* and *Pinetum sphagnosum*. The organic horizon with pH 4.4–4.8 was at *Nemoriherbosa* site type on acid loams and pH 5.1 on the loams rich
with calcium carbonate. Oxalidosa and Myrtillosa site types had moderate values of pH. The values of pH of peats of Myrtilloso–Sphagnosa and Polytrichoso–Myrtilloso site types were between that of Myrtilloso and Ledosa site type (3.0–3.5).

3.2. The scales of acidity

The scales of reaction compiled for the differential species of main forest groups of forest site types on the normally drained soils are presented in table 1.

**Table 1.** Range of pH for scores of plant species coverage.

| Species and their groups | Coverage, % |
|--------------------------|-------------|
|                          | >8 | 2.6–8 | 0.30–2.5 | 0.1–0.2 | <0.1 |
| **Tree dominants**       |    |       |          |         |      |
| Betula pubescens Ehrh.   | 4.0–5.5 | 4.0–5.5 | 4.0–5.5 | 4.0–5.5 | 3.5–5.5 |
| Pinus sylvestris L.       | 3.0–3.5 | 3.0–3.5 | 3.0–3.5 | 3.0–4.0 | 3.0–5.0 |
| Picea abies (L.) H. Karst. | 4.0–5.5 | 4.0–5.5 | 4.0–5.5 | 4.0–5.5 | 3.5–5.5 |
| Populus tremula L.        | 4.0–6.0 | 4.0–6.0 | 4.0–6.0 | 3.5–6.0 | 3.0–6.0 |
| Sorbus aucuparia L.       | 4.0–5.0 | 4.0–6.0 | 3.0–6.0 | 3.0–6.0 | 3.0–6.0 |
| **Differential species of Cladina and Vaccinium site types** |    |       |          |         |      |
| Arctostaphylos uva–ursi (L.) Spreng. | 3.0–6.0 | 3.0–6.0 | 3.0–6.0 | 3.0–6.0 | 3.0–6.0 |
| Calluna vulgaris(L.) Hull. | 2.8–3.0 | 2.8–3.5 | 2.8–4.0 | 2.8–4.0 | 2.8–4.0 |
| Carex ericetorum Poll.    | 2.5–3.0 | 2.5–3.0 | 2.5–3.5 | 2.5–3.5 | 2.5–4.0 |
| Cetraria islandica (L.) Ach. | 2.5–3.0 | 2.5–3.0 | 3.0–2.5 | 3.0–2.5 | 2.5–4.0 |
| Cladina arbuscula (Wallr.) Flot. | 2.5–3.0 | 2.5–3.0 | 2.5–3.5 | 2.5–3.5 | 2.5–4.0 |
| Cladina rangiferina (L.) F. H. Wigg. | 2.5–3.0 | 2.5–3.0 | 2.5–3.5 | 2.5–3.5 | 2.5–4.0 |
| Cladina stellaris Pouzar & Vezda | 2.5–3.0 | 2.5–3.5 | 2.5–3.5 | 2.5–4.0 | 2.5–4.0 |
| Cladonia amaurocraea Schaerer | 2.5–3.0 | 2.5–3.0 | 2.5–3.5 | 2.5–3.5 | 2.5–4.0 |
| Festuca ovina L.          | 4.0–4.5 | 3.0–5.0 | 3.5–5.2 | 3.0–5.5 | 3.0–6.0 |
| Hieracium pilosella L.     | 4.0–5.0 | 4.0–5.0 | 3.0–5.0 | 3.5–5.5 | 3.0–6.0 |
| Hieracium umbellatum L.    | 4.5–5.0 | 4.0–5.0 | 3.0–5.0 | 3.5–5.5 | 3.0–6.0 |
| Lycopodium complanatum (L.) Holub | 2.7–3.0 | 2.7–3.5 | 2.7–4.0 | 2.7–4.5 | 2.5–5.0 |
| Polytrichum juniperinum Hedw. | 2.5–3.0 | 2.5–3.0 | 2.5–3.0 | 3.0–3.5 | 4.0–5.0 |
| Polytrichum piliferum Hedw. | 3.0–3.5 | 3.0–3.5 | 3.0–3.5 | 3.0–3.5 | 3.0–3.5 |
| **Differential species of boreal forests** |    |       |          |         |      |
| Avenella flexuosa(L.) Drejer | 3.4–4.0 | 3.0–4.5 | 3.0–5.0 | 3.0–5.0 | 2.0–6.0 |
| Dicranum polysetum Hedw.   | 3.0–3.5 | 3.0–3.5 | 3.0–4.0 | 2.5–5.0 | 2.5–6.0 |
| Dicranum scoparium Hedw.    | 2.5–5.5 | 2.5–5.5 | 2.5–5.5 | 2.5–5.5 | 2.5–5.5 |
| Hylocomium splendens (Hedw.) Schimp. | 3.0–5.0 | 3.0–5.0 | 3.0–5.0 | 3.0–5.0 | 2.5–5.0 |
| Melampyrum pratense L.     | 3.0–4.0 | 3.0–4.0 | 3.0–4.0 | 3.0–5.0 | 3.0–6.0 |
| Pleurozium schreberi (Brid.) Mitt. | 2.5–3.5 | 2.5–3.5 | 2.5–3.5 | 2.5–3.5 | 2.5–3.5 |
| Pohlia nutans (Hedw.) Lindb. | 2.5–3.5 | 2.5–3.5 | 5.0–6.0 | 2.5–6.0 | 2.5–6.0 |
| Vaccinium myrtillus L.     | 3.0–4.0 | 3.0–4.0 | 3.0–4.0 | 3.0–5.0 | 3.0–6.0 |
| Vaccinium vitis–idaea L.    | 3.0–3.5 | 3.0–3.5 | 3.0–3.5 | 3.0–4.0 | 3.0–5.0 |
### Differential species of *Myrrhis* site type

| Species                        | 4.5–5.5 | 4.5–5.5 | 4.5–5.5 | 4.0–6 | 3.5–6 |
|-------------------------------|---------|---------|---------|-------|-------|
| *Dryopteris carthusiana* (Vill.) H. P. Fuchs |          |         |         |       |       |
| *Luzula pilosa* (L.) Willd. |          |         |         |       |       |
| *Majanthemum bifolium* (L.) F.W. Schmidt |          |         |         |       |       |
| *Oxalis acetosella* L. |          |         |         |       |       |
| *Rubus saxatilis* L. |          |         |         |       |       |
| *Trientalis europaea* |          |         |         |       |       |

### Differential species of *Oxalis* site type

| Species                        | 5.0–6.0 | 4.5–6.0 | 4.0–6.0 | 3.5–6.0 | 3.0–6.0 |
|-------------------------------|---------|---------|---------|---------|---------|
| *Aegopodium podagraria* L. |          |         |         |       |       |
| *Carex digitata* Wild. |          |         |         |       |       |
| *Melica nutans* L. |          |         |         |       |       |
| *Paris quadrifolia* L. |          |         |         |       |       |
| *Pyrola tundriola* L. |          |         |         |       |       |
| *Viola riviniana* Rchb. |          |         |         |       |       |

### Differential species of *Nemoritherbosa* site type

| Species                        | 5.0–6.0 | 5.0–6.0 | 5.0–6.0 | 4.5–6.0 | 4.0–6.0 |
|-------------------------------|---------|---------|---------|---------|---------|
| *Actae aspicata* L. |          |         |         |       |       |
| *Asarum europaeum* L. |          |         |         |       |       |
| *Galium odoratum* (L.) Scop. |          |         |         |       |       |
| *Lathyrus vernus* (L.) Bernh. |          |         |         |       |       |
| *Palmonaria obscura* Dumort. |          |         |         |       |       |
| *Ranunculus cassubicus* L. |          |         |         |       |       |
| *Stellaria holostea* L. |          |         |         |       |       |
| *Stellaria nemorum* L. |          |         |         |       |       |

### Differential species of clearings

| Species                        | 4.5–5.0 | 4.0–5.0 | 3.5–5.5 | 3.0–6.0 | 3.0–6.0 |
|-------------------------------|---------|---------|---------|---------|---------|
| *Calamagrostis arundinacea* (L.) Roth |          |         |         |       |       |
| *Calamagrostis epigeios* (L.) Roth |          |         |         |       |       |
| *Chamerion angustifolium* (L.) Scop. |          |         |         |       |       |

### Differential species of *Myrtilloso-Sphagnosa* and *Polytrichosa* site types

| Species                        | 2.5–3.0 | 2.5–3.5 | 2.5–4.0 | 2.5–5.0 | 2.5–5.5 |
|-------------------------------|---------|---------|---------|---------|---------|
| *Carex globularis* L. |          |         |         |       |       |
| *Molinia coerulea* (L.) Moench |          |         |         |       |       |
| *Polytrichum commune* Hedw. |          |         |         |       |       |
| *Rubus chamaemorus* L. |          |         |         |       |       |
| *Sphagnum capillifolium* Hedw. |          |         |         |       |       |
| *Sphagnum girgensohnii* Russow |          |         |         |       |       |
| *Sphagnum magellanicum* Brid. |          |         |         |       |       |
| *Sphagnum squarrosum* Crome |          |         |         |       |       |
| *Sphagnum warnstorfii* Russow |          |         |         |       |       |
| *Sphagnum wulfianum* Girg. |          |         |         |       |       |

### Differential species of Ledosa and Sphagnosa site types

| Species                        | 2.5–3.0 | 2.5–3.0 | 2.5–3.0 | 2.5–3.5 | 2.5–3.5 |
|-------------------------------|---------|---------|---------|---------|---------|
| *Andromeda polifolia* L. |          |         |         |       |       |
| *Chamaedaphne calyculata* (L.) Moench |          |         |         |       |       |
3.3. Determining soil pH using scales

Mean measured and indicated pH values and their standard errors for 7 forest types are presented at table 2. Strong correlation appeared between indicated and measured pH values for 45 sample plots. The coefficient of determination was 1.00 (figure 3), standard error was 0.03.

Table 2. Mean measured and indicated pH values and their standard errors for 7 forest types.

| Method | Pinetum cladinosum | Pinetum vacciniosum | Pinetum myrtillusum | Pinetum oxalidium | Betuletum nemortiherbosum | Pinetum myrtillus-sphagnosum | Pinetum ledosum |
|--------|--------------------|--------------------|--------------------|------------------|--------------------------|------------------------------|-----------------|
|        | 10                 | 10                 | 5                  | 5                | 5                        | 5                            | 5               |
| Indication | 3.02±0.02         | 3.2±0.05           | 3.94±0.02          | 4.14±0.04        | 4.52±0.03                | 3.40±0.03                    | 2.90±0.02       |
| Measure  | 2.99±0.01          | 3.26±0.01          | 3.84±0.03          | 4.38±0.02        | 4.51±0.04                | 3.38±0.06                    | 2.86±0.01       |

Figure 3. Correlation between indicated and measured pH values.
4. Conclusion
The main biogeochemical processes are influenced by soil pH. In our study we have compiled optimal–amplitude scales of pH using the method of Ramensky [4, 5]. Comparing measured and indicated pH values using the scales for 45 sample plots joint to 7 forest types showed excellent match of measured and indicated values of pH. Indicated values using vegetation analyses compared to actual environmental measurements have advantage because the direct study of environmental conditions through experiments, chemical analyses and long–term observations were expensive and time–consuming. In conditions of ecological assessment of extensive territories this technique allows us to determine quickly and accurately the ecological conditions of the habitat using plant species composition.

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