Varying diversity patterns of vascular plants, bryophytes, and lichens at different spatial scales in central European landscapes

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1. Introduction
   Knowledge and lack of knowledge about biodiversity patterns

2. Methods

3. Results
   - Frequency of species
   - Species density at different spatial scales
   - Species-area relationships (SARs)

4. Conclusions and outlook
Introduction

What we know

- Large-scale biodiversity patterns:
  - worldwide: downwards to 10,000 km²
  - central Europe & UK: downwards to approx. 30 km² (1 km²)
- Vertebrates and vascular plants

What we don’t really know

- Small-scale biodiversity patterns, i.e. 1 mm² - 10,000 m²
  - What is the average species density on 100 m² (1 m², 0.01 m²)?
  - What is the most frequent plant species on 100 m² (1 m², 0.01 m²)?
- General description and understanding of the scale dependence of (nearly) all biodiversity parameters
- Biodiversity patterns of non-vascular plants (bryophytes, lichens, macro-algae)
Existing small-scale sampling schemes

Phytosociological relevés/databases

Ecological monitoring programmes, e.g.
- Ecological Area Sampling (EAS) in Germany
- Biodiversity Monitoring (BDM) in Switzerland
- Forest monitoring (Level II) in Europe

Common problems

- No uniform plot sizes
- Only one spatial scale analysed
- Bryophytes and lichens not recorded (or sampled with a deviating approach)
- Other methodological problems
- Sampling within predefined vegetation units disables integration of results on landscape level

Methods

Plot series

- 7 spatial scales, near-equally spread on the log (A) scale: 0.0001 m²; 0.0009 m²; 0.01 m²; 0.09 m²; 1 m²; 9 m²; 100 m²
- Smaller plots replicated 4x in a nested manner within the 100-m² plots
- Complete species lists for all scales
- Cover and environmental data for 9 m²
- All vascular plants, bryophytes, and lichens (including non-terricolous plants and cultivated plants)
- Recording as shoot presence (not rooted presence)

Arrangement of 100-m² plots

- Chosen irrespective of land use and within-plot heterogeneity within the studied landscape sector
- Random coordinates were generated and localized in the field with a GPS

The two study areas in N Germany

- **Lüneburg** (diploma thesis Marc-André Allers):
  - 50 nested plot series within 130 km² (Topographic map sheet 2728)
  - Urban landscape in Lower Saxony
  - 35% forest – 10% grassland – 30% arable land – 25% settlement

- **Brodowin** (student course):
  - 16 nested plot series within 6 km²
  - Rural landscape in Brandenburg
  - 50% forest – 25% grassland – 20% arable land – 5% settlement

Results

Frequency of species

- Total richness recorded in Lüneburg (50x 100-m² plots): 468 vascular plants – 48 bryophytes – 61 lichens

- Species-frequency distribution:
  - far from the postulated log-normal distribution for all spatial scales
### Most frequent species (100-m² plots):

<table>
<thead>
<tr>
<th>Species</th>
<th>Lower Saxony %</th>
<th>Brandenburg %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachythecium rutabulum</td>
<td>84</td>
<td>81</td>
</tr>
<tr>
<td>Lolium perenne</td>
<td>48</td>
<td>63</td>
</tr>
<tr>
<td>Holcus lanatus</td>
<td>46</td>
<td>56</td>
</tr>
<tr>
<td>Agrostis capillaris</td>
<td>44</td>
<td>56</td>
</tr>
<tr>
<td>Hypnum cupressiforme var. cupr.</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>Quercus robur</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>Elymus repens</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>Festuca rubra agg.</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>Taraxacum spec.</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>Lepraria incana</td>
<td>40</td>
<td>44</td>
</tr>
<tr>
<td>Stellaria media</td>
<td>38</td>
<td>44</td>
</tr>
<tr>
<td>Scleropodium purum</td>
<td>34</td>
<td>44</td>
</tr>
<tr>
<td>Dactylis glomerata ssp. glomerata</td>
<td>32</td>
<td>44</td>
</tr>
<tr>
<td>Rubus spec.</td>
<td>30</td>
<td>38</td>
</tr>
<tr>
<td>Sorbus aucuparia</td>
<td>30</td>
<td>38</td>
</tr>
</tbody>
</table>

*Brachythecium rutabulum* was the most frequent species for six scales; only at 1 cm², *Pinus sylvestris* and *Fagus sylvatica* (10%) were slightly more frequent than this moss (8%).
## Results

### Species density at different spatial scales

#### Total species density

<table>
<thead>
<tr>
<th>Area [m²]</th>
<th>Mean ± SD</th>
<th>Difference</th>
<th>Absolute</th>
<th>Coefficient of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lüneburg</td>
<td>Brodowin</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>0.0001</td>
<td>1.6 ± 1.2</td>
<td>NA</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>0.0009</td>
<td>2.4 ± 1.7</td>
<td>2.7 ± 1.8</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>0.01</td>
<td>3.5 ± 2.4</td>
<td>4.2 ± 2.5</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>0.09</td>
<td>5.1 ± 3.4</td>
<td>6.2 ± 3.3</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>8.5 ± 5.6</td>
<td>11.0 ± 5.9</td>
<td>0</td>
<td>28</td>
</tr>
<tr>
<td>9</td>
<td>15.2 ± 9.8</td>
<td>18.1 ± 8.6</td>
<td>0</td>
<td>55</td>
</tr>
<tr>
<td>100</td>
<td>38.7 ± 25.5</td>
<td>42.9 ± 22.2</td>
<td>2</td>
<td>137</td>
</tr>
</tbody>
</table>

- Higher species densities in Brodowin at all scales presumably can be attributed to higher regional species pool
- Lower CV of species densities in Brodowin at all scales presumably can be attributed to the smaller size of this landscape sector
Species densities in different landscape types

- At 1-m² scale
Species densities in different landscape types

- At 100-m² scale
Proportions of species groups dependent on scale

- Major taxonomic groups
- Proportions of species groups dependent on scale

  ▶ Floristic status

![Bar chart showing proportions of species groups dependent on plot size. The chart includes categories for Indigenous species, Neophytes, Archaeophytes, and Cultivated species. The x-axis represents plot size in square meters (m²), and the y-axis shows mean species proportion.]
Species-area relationships (SARs)

- **Best fitting model**
  - The power function $S = cA^z$ on average was the best fitting function for the 50 SARs.
  - Logarithmic ("exponential") and saturation functions in most cases only poorly fitted the data.

- **Variability of $z$**

<table>
<thead>
<tr>
<th>All taxa</th>
<th>Vascular plants</th>
<th>Bryophytes</th>
<th>Lichens</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.327</td>
<td>0.322</td>
<td>0.271</td>
<td>0.481</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indigenous species</th>
<th>Neophytes</th>
<th>Archaeophytes</th>
<th>Cultivated species</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.315</td>
<td>0.472</td>
<td>0.428</td>
<td>0.091</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Arable land</th>
<th>Settlement</th>
<th>Grassland</th>
<th>Forests</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.276</td>
<td>0.404</td>
<td>0.252</td>
<td>0.288</td>
</tr>
</tbody>
</table>

- **High $z$-value = high spatial turnover**
Results

Scale dependency of $z$

![Graph showing scale dependency of z](image)

Conclusions

- Most of the analysed biodiversity parameters and relationships are significantly influenced by spatial scale.

- Bryophytes and lichens usually contribute considerably to total plant diversity, but their biodiversity parameters “behave” differently from those of vascular plants.

- Thus, in studies on plant diversity patterns several spatial scales and also non-vascular plants should be included.

- The proposed biodiversity sampling scheme provides a wide range of standardised biodiversity indicators.

- This approach is particularly suitable for comparing biodiversity patterns and for monitoring biodiversity change at landscape scale.