Botanical data as sources for assessment of long-term environmental changes

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Plants and environments

Botanical data can tell us about changes in the environment. Plant species display specific habitat preferences. Obviously, no plant species grows everywhere, thus indicates a specific type of habitat(s). Whereas a species' preferences do not change in historical times, the environments do; consequently environmental changes can be derived from the changes of plant species occurrences. Plants are sessile organisms, hence reflecting well especially the long-term trends and major changes. Of course, annuals will be more dependent on short-term events than long-living species.

Environmental factors, e.g. air temperature, precipitation, soil fertility and acidity, or management, create the specific – and changing – combination of conditions. A species can be confined to a narrow range of a factor (i.e., soil acidity range), or delimited by a certain value of it (i.e., the spring temperature), while some other factor can be almost unimportant – the species occupy *niches* (Odum, 1971; Begon *et al.*, 1996). Not all combinations of the factors, their ranges, levels, and species occurrences are observed. There are patterns, tendencies of certain species to clump together in certain environmental conditions. Consequently, not only individual *plant species*, but also *plant communities* occur in specific environments.

If we have data on plant species' occurrences spanning over a time period, we can analyse the changes and interpret them as changes in environment. Obviously, a special kind of information is needed here; it is the knowledge about the plant species' and communities' demands on environment, or what they *indicate*. However, besides the environment, other events and relations can play a role; omitting the genetic mechanisms, intra- and interspecific competition, and migrations should be considered (Harper, 1977; Silvertown and Charlesworth, 2001). They are important in unstable habitats and plant communities, and at places with a high flow of diaspores (seeds, saplings, etc.), notably in the human-created habitats as urbanized areas. Nature-close ecosystems (woodlands, wetlands, mountain ecosystems) are amongst the most stable, i.e., changing in long-term periods, European habitats, putatively reflecting the slow-acting environmental processes.

It should be noted that under environmental factors we can understand either natural factors being mediated by the substrate, climate, plants, animals, etc., or human influence, either direct (typically the management) or indirect (mediated e.g. by atmosphere or water). The factors vary along the intensity and frequency gradients (Clark, 1985). Generally, intensity is negatively correlated with frequency. Big storms and fires occur once a century, whereas local windbreaks can be observed annually. Most factors, such as soil moisture, nitrogen content, or grazing intensity, usually fluctuate around the intermediate level, having no drastic impact. How precisely an observed change in plant occurrences between two or more time points can be associated with a gradual or an abrupt environmental change depends on the accuracy of our information, namely the frequency of observations and the availability of the data on environmental events.

The data

We can roughly distinguish three kinds of botanical data, which comprise utilizable information about the past state of the plant cover. They consider: 1) flora, 2) vegetation composition, and 3) vegetation units. Flora means occurrences of individual plant species sometimes quantified, more or less accurately localized. Vegetation composition concerns mostly complete species lists for a rather narrow locality. Typically, it is a delimited plot. Vegetation units are abstract entities, products of the analysis of vegetation compositions and/or other parameters characterizing vegetation.

1) Floristic data are usually commented lists of plant species occurrences within a given territory and time. They used to be linked with plant specimen collections in herbaria, thus can be checked independently. “Floras” reach back to the end of the 18th century. The first reliable floras were, however, published in the early 19th century and the tradition continues on to the present times. From the pioneer surveys of floras of attractive localities, whole territories and preliminary lists for the lands and countries, floristics has developed into systematized science giving the species listings within grid-fields defined by geographical coordinates.

In surveys of floras, common species are usually only given for the presence, while rare species are watched more carefully, providing an information about numbers of individuals, more exact localization, habitat characteristics, etc. Nowadays, national atlases of plant species distributions are available (e.g., Zając and Zając, 2001), or in progress. In some cases, they even provide information on the past and the present distributions of individual species (e.g., Hardtke and Ihl, 2000). The tendency to decrease / increase is apparent. Having information on the environment or its changes, the environmental processes can be assessed.

2) Data of vegetation compositions can be considered a special case of the floristic listings within much smaller fields termed plots. At one hand, they are represented with phytosociological relevés. From literary-like pictures of “plant world”, vegetation records have developed into a specific branch of vegetation science broadly called phytosociology (Braun-Blanquet, 1964), which has been established since around the beginning of the 20th century. This branch of plant ecology aims – amongst the other purposes – to classify the variability of vegetation, using principally the plant species composition as a criterion for delimiting vegetation units (see the next paragraph). Relevés are nearly standardized lists of all plant species present at regularly shaped plots, with estimated abundance. The relevés’ areas vary roughly from 1 to 1000 square metres, depending on the type of vegetation. In forests, relevés are about (50)-100 to 400-(500, or even more) sq. metres large. There are several millions of relevés all around the world, but chiefly in Eurasia and North America (Ewald, 2001). They cover the period from about the 1920s. Importantly, relevés are usually not exactly localized with delimited boundaries.

Another data source concerns permanent plots (Bakker *et al.*, 1996), sampling units employed in experimental field ecology and for monitoring purposes. It is however extremely difficult to repeat recordings on permanent plots for more decades, which makes them worthy only in short time ranges. With some rare exceptions, vast majority of permanent plots do not reach back more than one or two decades. They are exactly localized and delimited.

3) Vegetation units are abstract representations of assumed natural plant communities. As such they do not provide concrete “field lists” of plant species, however posses characteristics concerning “typical” species composition and habitat preferences. This gives them an important predictive and indication ability. If we know changes of their distribution in time, we can deduce the environmental changes. Vegetation units can be delimited more or less precisely – from minute differences between variants of one plant community distinguished with one species, to formations defined by dominant growth forms. Going down into species compositions, an expert’s fieldwork is needed, whereas formations can be recognized using aerial photos and remote sensing, being processed and analysed with geographical information systems (GIS).

The satellite images have not been available for a long time. Aerial photographs, on the other hand, cover about the last one hundred years. When we classify the types of the vegetation cover recognized at them, it is relatively easy to analyse the temporal changes of the different vegetation types and deduce the causes. More difficult situation comes with vegetation maps, which can be of several kinds (e.g., Bohn and Neuhäusl, 2000). For our purpose, maps of actual vegetation (i.e., really present at the time) can be used. However, they do not date back more than a couple of decades; their content is very dependent on the author’s view in terms of experiences and system of units.

Comparing past and present

The presented approach is methodologically based on records distributed in time, and on indication ability of plant species and communities. A crucial aspect is spatial variability. Since we are interested in time changes, i.e. the “vectored” temporal variability, spatial variability can be denoted as “noise information” in this respect. If the sequential records are always at the identical places (with no overlaps or moving), there is no spatially given “noise”. However, this is quite exceptional for narrower localities – only permanent plots do so – and broader locations “wipe out” the necessary detail in environmental variability. (For further reading see Hédl, 2003.)

This holds true especially for the first and second type of data. The most important are **floristic records** and **phytosociological relevés**. When comparing the sequential states, often by repeating the same records after a time period, there is always a rather high uncertainty, whether the observed change is due to the real temporal process, or the inexact re-localization (or even to the so called observer’s bias). Several re-sampling strategies are worth to think of, according to the character of the data (density, localization exactness) and environment (heterogeneity).

If the territory is covered with records densely enough and/or is homogeneous, it is worth to place the new records pair-wise in the assumed locations of “historical” records. If the sampling density is low, thus the potential area of the individual record is relatively heterogeneous, one can try to describe the recent variability with independent new records and relate it to the past variability stages. Concerning the heterogeneity, the question always remains whether a present heterogeneity is the product of temporal changes, or if it stayed constant. In this respect, trying to represent the observed entities (typically the vegetation units) with the same number of records as the past can be quite a tricky solution. From the third type of data the most important are aerial photos. The most difficult task is the processing (rectification) and vegetation cover classification. There are no individual records hence the observed changes in spatial variability equal the temporal change.

To assess the environment

Knowledge about the relations between plant species, communities and vegetation formations, and factors of environment, can be obtained several ways; either with a field observation, or with measurements in natural conditions, or in manipulated conditions – experimentally in the field or in a lab. There is a vast number of individual plant species studies focusing on selected characteristics, often concerning the species' (eco)-physiology (Larcher, 2003). Ecological studies usually describe the relation between a complex of measured environmental parameters and the species present at the place, which is usually a plot with measurement points. The main groups of the factors concern parameters of climate (temperatures, precipitation, snow cover, etc.), substrate (bedrock type, texture, structure, soil water characteristics, acidity, nutrients' contents, organic matter characteristics, salinity, etc.), light (insolation, under the canopy or due to the relief and latitude), biota (grazing, parasites, etc.) and the humans (mainly the management type and intensity).

Knowing the concrete species' demands on environmental factors, we can assess the conditions at a place inhabited by the species without measurements. This approach is sometimes termed *calibration* in plant ecology (Jongmann *et al.*, 1987). Clearly, a list of values for species regarding the particular factor is needed. Average value (or median, weighed, range, etc.) can be computed from the values of species present, obtaining the value for the plot.

Although large quantities of data of all kinds have been collected, overviews applicable to any locality within a given territory are very scarce. The most successful and broadly used is the Ellenberg's indicator values for Central European flora. H. Ellenberg with collaborators (Ellenberg *et al.*, 1991) have created a list of indicator values for more than 2700 plant species regarding seven important environmental parameters, namely light, temperature, continentality, soil moisture, reaction, and nitrogen. The meaning of the parameters has been a topic of discussions, but it serves as the unique basis for assessments of environment in Central European nature. Variants of this system were created at national bases or for special purposes (e.g., in woodland history).

The same way as the environmental conditions are calibrated for plots a computation can be made for any object with growing plants. The examples are territories with mapped distributions of species, any place with species list (even incomplete), or vegetation units with a known species assemblage. The latter case implies the potential use of vegetation maps. Aerial photos do not yield enough information about plant species composition hence no calibration based on species indication can be done. However, from shifts between the area and distributions of vegetation formations, conclusions on main environmental processes can be derived.

Summary

We can summarize that there are three kinds of botanical records utilisable in the assessment of environmental changes. They concern floristic data, phytosociological relevés and, more remotely, aerial photos. Plant species, communities and vegetation units indicate certain environmental conditions. If we have previous knowledge of these demands from observation or measurements, it is possible to assess the environmental conditions at any place or area with plant species and cover. Temporal changes in species' and vegetation occurrence can be interpreted as due to environmental processes, which can be of natural or human-induced character.

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