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Original article

Quantification of wall surface heterogeneity and its influence on species diversity at medieval castles – implications for the environmentally friendly preservation of cultural heritage

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ABSTRACT

Historic buildings are important for cultural history and provide a variety of habitats for animals and plants. Especially structural heterogeneity of wall surfaces is perceived to support biological diversity. Nevertheless, in traditional approaches goals of biodiversity preservation and monument restoration are perceived to interfere and to be mutually exclusive. As a consequence, priority is often given to constructional restoration accepting the loss of local populations and biodiversity. At walls of medieval castles, including an experimental restoration project where conventional and less intensive restoration techniques were applied, we relate species composition and richness to wall properties. Especially wall surface structure is quantified using a novel approach. The study focuses on lichens, mosses and vascular plants. Boosted regression tree analyses and non-metric multidimensional scaling techniques are applied to detect the influence of abiotic site conditions on biodiversity. We find species richness to be promoted by wall surface heterogeneity. However, species composition is more affected by restoration approaches than species richness. Lichen composition varies considerably while vascular plants and mosses are less affected by wall properties. We suggest strategies that are combining both societal targets, the preservation of historic monuments and of species diversity. Careful restoration is capable of supporting both, the maintenance of cultural heritage and of rare and unique anthropogenic habitats. Wall surface heterogeneity needs to be witnessed for both aspects as it affects both species composition as well as the effectiveness of cleaning methods.

1. Introduction and research aims

The preservation of historic monuments and buildings, which represent a country's cultural heritage, constitutes a high societal priority. Future generations must have the opportunity to witness former social structures, the endeavour, aesthetic sentiments and architectural achievements of their ancestors.

Another societal priority, even affirmed in international contracts, is the concept of maintaining biodiversity. Many rare and protected species are bound to nutrient-poor habitats with specific microclimatic conditions such as rocks. Others depend on low disturbance frequency and long-term stable site conditions. Both preconditions are rarely found in cultural landscapes but given at castles and ruins. In Central Europe, many of such anthropogenic habitats exist since centuries.

Whenever both societal ambitions meet at the same object, like an old castle or city wall, they tend to exclude each other. Frequently, prioritisation leads to withdrawal at the side of nature conservation. It is a widely held but unproven belief that all plants, fungi, lichens or animals are causing damage to historic monuments.

Besides the aesthetic surplus, which old castles or city walls can gain through plant cover [1], old monuments often provide habitats for highly specialised animals and plants [2,3]. An influence of the surface structure of walls on biological diversity is documented [4,5]. However, approaches are rare that quantify the influence of structural properties on biological diversity [6,7]. A sound statistical proof for a linkage between biotic diversity and heterogeneity of wall surfaces is still missing.

Modern building techniques are avoiding open joints and niches that serve for instance as protected hiding places for animals but also as germination site for plants. Specific mural vegetation is hence restricted to old constructions. Despite this, it is

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surprisingly uncommon to see buildings as valuable habitats for biota that require precaution during restoration processes.

During the course of constructional restoration at (historical) buildings dry masonry walls are often jointed, cracks are filled with grounding mortar and the surfaces are cleaned. In consequence, the characteristic mural vegetation as well as habitats of many insects and animal species (e.g. birds and bats) are lost.

Here, we study four medieval castles according to impacts of different restoration treatments on plant communities in order to evaluate the impacts of restoration techniques. To assess best practice restoration techniques for biological diversity we investigated the influence of wall structures on floristic diversity.

2. Material and methods

2.1. Study area and castles

The study area (Fig. 1) is located in Upper Franconia and is characterised by low mountain ranges. The studied fortress “Festung Rosenberg” and the castles “Giechburg”, “Burg Waischenfeld” and “Burg Rabenstein” differ in regard to history, climate and landscape traits. As the monuments were constructed with stones from local parent material, the building material is characteristic for the landscape matrix of the monuments. Table 1 provides an overview on abiotic factors and historic characteristics of the examined castles.

2.2. Vegetation data and sample design

Vegetation and related environmental parameters were sampled on seven walls of the four selected castles (Table 1) summarising a variety of different monument restoration treatments (Table 2). Of special interest is Festung Rosenberg, where different restoration techniques were applied on three parts of the front wall of “Waffenplatz Philipp” in 2001. Each restoration technique was applied on a $11 \times 4\,\mathrm{m}^2$ sized part of the wall (Fig. 2). During the environmental sound restoration only woody plants were removed. All remaining vascular plants, mosses and lichens were left on the stones and within gaps. The humus layer on the wall coping was lifted and refitted after restoration work. Wall surface was only cleaned on those places where restoration was conducted. Grouting was reduced to a necessary minimum. For the conventional restoration all plant cover on the wall and the humus layer on the wall coping was removed. The wall surface and gaps were cleaned entirely with superheat stream. Gaps larger one centimetre were grouted. Surface defects were closed using epoxide resin while imbued and vulnerable areas were closed using common lime-cement mortar. The third application was a compromise solution between the two former mentioned methods. While mosses and lichens were left in the gaps, woody plants, herbs and grasses were removed. The humus layer was lifted and refitted after restoration work. Only those places were restoration was conducted were cleaned with superheat stream. Grouting was reduced to a necessary minimum [3]. Impacts on wall flora, feasibility and costs of conservation are depicted.

Temperature and water availability on a wall is closely related to its aspect [8]. Thus, species composition of vascular plants, mosses and lichens often varies strongly between north- and south-facing walls [9,10]. Even if some studies did not find aspect to significantly influence plant cover [11], in our study the examined walls are microclimatically standardized to south and south-west orientation.

The applied plot size of $1\,\mathrm{m}^2$ is regarded to represent an adequate plot size for wall vegetation (including mosses and lichens) [6]. Via stratified random sampling three plots were placed on the upper and lower parts of each castle wall, respectively. This approach enabled a separate sampling of the upper wall part that is characterised by extreme drought stress, as well as of the lower wall parts with high disturbance intensity and nutrient inputs [2]. Altogether 42 plots were established (six on each wall) and recorded in 2006 and 2007 (lichens only 2007). Species frequencies were assessed. Each plot was divided in 25 subplots of $0.04\,\mathrm{m}^2$ size and species presence/absence for vascular plants, mosses and lichens were recorded. Plant records of 2006 and 2007 were summarised taking the mean frequency of a plant species in a specific plot of both years. Nomenclature follows Oberdorfer [12] for vascular plants, Frahm and Frey [13] for mosses and Wirth [14] for lichens.

2.3. Abiotic variables

While exposition was held constant at all sampling sites, other abiotic influences, namely water availability, the quality of substrate, and surface structure of the wall were analysed in detail.

Quality of building material (stones and mortar) is influencing the vegetation on walls for instance via pH, nitrate- or calcium-availability [9,15]. Therefore substrate samples (ca. $1–2\,\mathrm{cm}^3$) were analysed for each plot. The content of sodium, potassium, calcium, magnesium, ammonium as well as fluoride, chloride, nitrate, phosphate and sulphate was measured by ion chromatography.

To estimate the available water electric conductivity was measured four times per plot. In addition, high resolution infrared photos were taken. However, detailed analyses of the resulting estimates of moisture indicated that both methodologies are not providing reliable results and were thus not included in further analyses.

2.4. Wall structure

To quantitatively record the structure of wall surface a grid of profile drawings comparable to elevation profiles in landscapes was found to be most suitable to elaborate metrics that could quantify the structure of the wall. The profiles were gained via a contact based contour measurement sensor (Fig. 3a). This approach is not biased by insolation and shadow [16]. For each plot three direction and cross direction profiles of 90 cm length were conducted in a standardised procedure. The profiles were digitalised with a resolution of 1 mm (Fig. 3 a, b). Based on these profiles a variety of different parameters that adequately resemble the structural heterogeneity of the wall surface were calculated (Table 3). If not mentioned differently, the mean value of those parameters per plot was taken for further calculations.

2.5. Calculations

Environmental variables were standardised (scaled to zero mean and unit variance). All analyses were performed in the statistical program R [17].

Boosted regression trees were used to detect drivers of species richness for all groups (vascular plants + mosses + lichens) jointly as well as separately. All environmental variables were included as predictors. Boosted regression trees were calculated using function gbm step (gbm 1.6–3) [18]. Model settings as well as summary statistics can be depicted from Table 4.

Non-metric Multidimensional Scaling (NMDS) was used to visualise the similarity in species abundance and composition of the plots. The applied Bray-Curtis index is independent from the data distribution and thus ideal for non-normal distributed data [19]. By using NMDS the number of dimensions in the ordination space has to be defined a priori. Two dimensions were chosen to facilitate visualisation. Quality of a NMDS can be estimated by the stress value. Low stress values indicate a good fit of the distances between the samples to the dissimilarities of species assemblages. Stress