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Original article

The utility of ancient forest indicator species in urban environments: A case study from Poznań, Poland

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ABSTRACT

We aimed to assess the impact of land-use structure on AFIS occurrence and evaluation of these bioindicators in urban conditions. We compiled data about forest continuity based on archival maps and forest management plans; floristic records of 79 AFIS occurrences were collected within a 1 × 1 km grid and land-use form structure in Poznań (W Poland). We tested fidelity of AFIS using χ^2 tests and effects of land-use structure using random forest models. We also checked spatial autocorrelation and its impact on AFIS distribution patterns within old and recent forests, using spatially explicit generalized linear models. We found a strong relationship between AFIS number per grid square and fraction of forests and waters in land-use structure. Relationships between AFIS distribution and land-use shows that AFIS are a good proxy describing human impact or an urbanity gradient. AFIS number per grid square shows small, but significant positive spatial autocorrelation, which suggests possibilities of migration into new forests. AFIS, treated as a bioindicative group of species, may be a useful indicator of landscape and land-use structure transformation in urban environments. Occurrence of many AFIS that are endangered at the city scale indicates the need for conservation of old forests in urban areas, to preserve biodiversity in urban environments. Thus, AFIS may act as indicators of old forests with high conservation value in cities, which need special protection.

1. Introduction[1]

Ancient forest indicator species (AFIS) are plant species which show fidelity to forests which have documented long-term continuity in the area under consideration. Duration of the time period considered depends on availability of reliable data sources. In Great Britain, to be considered ancient a woodland should be continuously present since 1600 AD, but in Central Europe it is usually since 1800 or 1850 AD. The concept of AFIS was introduced by Peterken (1974), who prepared the first list of AFIS in England, for determination of the most precious woodland areas. Based on European and North American analyses, despite their different species composition, the species have a set of traits in common. AFIS are usually shade-tolerant geophytes or hemicryptophytes, have intermediate moisture requirements and weak dispersal abilities (Hermy et al., 1999; Verheyen et al., 2003). Their limited dispersal abilities are considered most important in terms of their precision as bioindicators (Peterken, 1974; Dzwonko, 1993; Hermy et al., 1999; Wulf, 2003). On the other hand, Hermy et al. (1999) indicated that there was heterogeneity of AFIS as a group, thus AFIS lists should be constructed at regional scales, to better fit local conditions. For example, species considered as AFIS in Central Europe (Dzwonko and Loster, 2001) in Scandinavia may show affiliation with recent forests growing on post agricultural lands (Brunet, 2007), while also showing lack of affiliation to both ancient and recent forests in Western Europe (Schmidt et al., 2014). Thus, indicative value of the same species may depend on bioclimatic region.

Due to strong transformation of land cover and severe disturbances, urban environments are especially vulnerable to biodiversity loss (Gilbert, 1989). In cities the main factors responsible for extinctions of species typical to natural ecosystems are habitat fragmentation, loss and degradation of natural and semi-natural ecosystems (especially forests), ground water table lowering, alkalization and eutrophication, as well as frequent disturbances and soil, water and air contamination (Kowarik, 2011). Cities are also more vulnerable to biological invasions (Kowarik et al., 2013; Dyderski et al., 2015). Native, specialized species extinction, along with eurytopic, frequently cosmopolitan alien species, lead to the biotic homogenization of urban floras (Olden et al., 2004; Kühn and Klotz, 2006; McKinney, 2006). The process of biotic

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[1] Abbreviations: AFIS – ancient forest indicator species.

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homogenization goes quickly, which threatens urban floras with loss of their most precious (from the conservation point of view) elements (McKinney, 2006). Therefore specialized species, including AFIS, are most threatened in urban areas.

Urban forests and green areas are crucial in maintaining urban species diversity (Gilbert, 1989; Clark et al., 1997; Alvey, 2006; McPherson, 2006; Dearborn and Kark, 2010). Occurrence of AFIS, as species connected with threatened habitats, is useful in nature conservation evaluation (Hermy et al., 1999). AFIS are also indicators of understory plant species richness in forest ecosystems (Stefańska-Krzaczek, Kącki, and Szypuła, 2016). One of their main features is reaction to land-use change – retreat and local extinction (Peterken, 1974; Hermy et al., 1999; Verheyen et al., 2003). However, studies on how these species are connected with urbanization and other land-use changes, which changes phytosociological relationships among plant species and creates novel ecosystems (Kowarik, 2011), are scarce. Most of them focus on post-agricultural lands (e.g. Brunet, 2007; Orczewska, 2009; De Frenne et al., 2011). Only Gilbert (1989) mentioned application of AFIS in urban ecosystems, however he did not assess their indicative value.

The aims of this study were to assess the impact of land-use structure (considered as Corine land cover classes) on AFIS occurrences and to evaluate their affiliation with old forests in urban areas at a large spatial scale, i.e. 1 km^2 grid. In urban conditions we assume land cover classes as a manifestation of diverse human impacts, connected with urbanization-driven habitat transformations (Kowarik, 2011), therefore describing both human impact intensity and habitat availability for AFIS. We hypothesized that (1) old forests in the city are able to host AFIS, (2) AFIS number per grid square will be affected by land-use type structure, connected with human impact, (3) AFIS number per grid square will exhibit positive spatial autocorrelation, which will be limited to the nearest grid square, due to limited dispersal abilities of AFIS.

2. Methods

2.1. Study area

Poznań is a city located in Western Poland (52°24′N, 16°57′ E, 60–154 m a.s.l.). Long-term meteorological observations (1951–2010) have shown a mean annual temperature of 8.4 °C and mean annual precipitation of 521 mm (Statistical Yearbook of Poznań city, 2013). Mean length of growing season, considered as number of days with mean temperature ≥5 °C, is 225 days (Żmudzka, 2012). Poznań was established in the 10th century, however the most extensive period of development was at the end of the 19th century. Now the city covers 262 km^2, with a population of 550,700 inhabitants (Statistical Yearbook of Poznań city, 2013). The dominant type of potential natural vegetation in Poznań is deciduous forest, dominated by *Quercus robur*, *Carpinus betulus* and *Tilia cordata*. There are also habitats of coniferous forests with *Pinus sylvestris*, mixed-coniferous forests with *Pinus sylvestris* and *Quercus robur*, as well as riparian forests with *Salix* spp., with *Populus* spp., with *Ulmus* spp. and with *Alnus glutinosa* and *Fraxinus excelsior*. Since the period before settlement, forests within the present borders of the city were systematically used as a source of fuel and building material, thus nowadays forests cover only 13% of the city area (Jackowiak, 2011). Most forests in Poznań (2.2 km^2) are municipal forests. Median age of these forests is 63 years and 47.4% of the city's forests are between 61 and 80 years old, while forests older than 80 years compose 10.5% of forest area (Jaszczak and Wajchman, 2015). Most of the forests were planted after the Second World War, although the remnants of natural forests may be found in the river valleys, which are claimed to be the best preserved vegetation patches in Poznań (Jackowiak, 2011; Dyderski et al., 2015; Dyderskiet al., 2017). Old forests cover 525 ha, 14.8% of the total forest area of Poznań.

2.2. Data sources

We verified a list of all available floristic data recording the occurrence of species considered AFIS in Poland (Dzwonko and Loster (2001)) within Poznań and assigned them to grid squares (**Table S1**). We did not reject species which are doubtful or not typical to forest ecosystems in Polish Lowlands, to include in analyses all species which were claimed to have indicator value as AFIS in Poland, especially because there are no regional AFIS lists in Poland. We also did not exclude species outside their natural ranges, as Wulf (2003) found that even alien invasive species may act as AFIS. Most of the floristic records come from Jackowiak's (1993) atlas, as his study covered the whole vascular flora inventory of the city within its borders during the 1980s (228.6 km^2; Jackowiak, 1993). Thus, the primary source of data covered the whole study area and the data type is not presence-only, but detection/non-detection data, as it is impossible to collect real presence-absence data from an area of this extent, and we limited the study area to these borders. However, as some AFIS were recorded after this study, we included these observations in the dataset, to update the database and increase data reliability, as flora may change in a significant way after 30 years (e.g. Dyderski et al., 2015). Merging this data might be a disadvantage, due to merging records from a 35-year period and prevalence of forest species extinction over immigration (Chocholoušková and Pyšek, 2003; Knapp et al., 2010; Jarošík et al. 2011; Williams et al., 2015). However, new AFIS localities most frequently represented forest patches where AFIS occurrence was a result of regeneration, especially in sites where Jackowiak (1993) reported historical stands. Similar to Jackowiak (1993), we used a grid of 1 km squares, based on the ATPOL system (Zając and Zając, 2001). In total, we analyzed data about AFIS occurrence within 242 grid squares (Fig. 1). We excluded *Dactylis polygama* (= *D. aschersoniana*) from the analyses, as in Jackowiak (1993) this species was treated as *D. glomerata* ssp. *aschersoniana*, thus recorded jointly with *D. glomerata* ssp. *glomerata*, which is a meadow plant species. Plant nomenclature follows Mirek et al. (Mirek et al., 2003).

As the peak of the city's territorial expansion was near the end of the 19th century, we assumed the year 1900 as a threshold between old and recent years; there was a lack of accurate and complete cartographic materials from earlier periods, which did not allow reconstruction of changes of forest cover over the entire study area. Older maps had lower resolution or did not cover the whole area of Poznań. We assumed old forests to be those with continuous presence in four sources: in Messtichblatt maps (1:25000) from 1890 (Messtischblatt, 1890a,b), a Military Geographic Institute map from 1936 (Wojskowy Instytut Geograficzny, 1936), CIA satellite CORONA 98 imaginary from 1965 (USAF/CIA/NRO, 1965) and from the 2015 Forest Data Bank (Bank Danych o Lasach, 2015). Due to high spatial resolution we assumed that grid squares with even small cover of old forest were old forest squares, because even small areas may act as significant refugia for forest flora, even if these species occurred in new forest. For that reason we did not establish any threshold of old forest area; also Rolstad et al. (2002) argued that when spatial scale of the considered phenomena is unknown, forest continuity should be considered at the scale of single tree stands, defined as areas of 0.1–10 ha, thus presence of small areas of old forest allowed us to classify the whole square as a 'square with old forest'. Thus, we classified grid squares where any area of old forests was present, as squares with old forests. Squares with present forests, which were not marked as old forest were further classified as new forests and squares where forests were not present were further classified as non-forest. Therefore, our results consider relationships between AFIS and old forests only at the scale of grid squares (1 km^2). This approach is more conservative and highlights the role of even small old forest patches in maintaining forest flora within a grid square. It also reflects low migration rates of AFIS, calculated in centimeters rather than in meters (Peterken, 1974; Dzwonko, 1993; Orczewska and Fernes, 2011).