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Twenty years of woodland establishment through natural succession on a sandy landfill site in Berlin, Germany

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ABSTRACT

This case study investigates natural colonization and woodland establishment over twenty years after beginning on bare ground on a sandy landfill site at Berlin–Malchow. The landfill, 6 ha in extent, was capped with an N-poor, but Ca-rich, mineral soil from a construction site nearby. This deposited soil originated from deep horizons and therefore contained no seed bank. The focus of the paper concentrates on woody species, due to their dominant role during succession. A total of 35 tree species colonized the landfill within twenty years which represent more than 60% of the native and introduced naturalized tree flora of the region. The first colonizers and the dominant tree species were willows and poplars, especially *Salix x rubens* Schrank. Most tree species arrived within the first 6 years and built a tree layer >5 m in height within the first decade. After 20 years of succession, mean species density from three 10 m × 20 m sample plots was 58 ± 10.6 species/200 m^2. Nearly half of the species were woody species (20 ± 3.6 tree species and 6 ± 1.0 shrub species). Mean total cover of the tree layer was 78.3 ± 2.9%, and mean height was 13.3 ± 1.5 m. Mean basal area of trees >7 cm DBH (in total 2500 ± 391 stems/ha) was 28.25 ± 3.9 m^2/ha. The herb layer was dominated by perennial grasses, especially Calamagrostis epigejos (L.) Roth. The processes of colonization and succession on the landfill site show that effects of contingency, such as surrounding vegetation, year effects and priority effects act as drivers of vegetation dynamics. The N-poor substrate and the lack of a soil seed bank were no obstacles to the establishment of a woody vegetation cover in a relatively short time.

1. Introduction

In recent years there has been a growing awareness among scientists that 'passive restoration' and the establishment of woodlands by spontaneous succession is a 'site-adapted', sustainable and cheap alternative to forest plantations (Prach and Pyšek, 2001; Oldfield et al., 2013; Prach and del Moral, 2015). This is especially valid in cases where timber production has no priority and the biodiversity of the various successional stages and other environmental services are the main aims in woodland creation. In urban areas, woodland is mainly desired to mitigate climate change through carbon storage and sequestration, to reduce water run-off and soil erosion, to improve local climate by filtering pollutants and by promoting cooling effects in summer, to provide habitats for biotic diversity and places for recreation and amenity (Beckett et al., 1998; Zipperer, 2002; Pataki et al., 2011; Ordóñez and Duinker, 2013; Nowak et al., 2013).

There is ample knowledge about spontaneous succession over more than a century from natural environments, abandoned fields in rural landscapes, and from urban-industrial ecosystems including mine wastes (Finegan, 1984; Gray et al., 1987; Bradshaw, 1997; Walker and del Moral, 2009; Pickett et al., 2009; Meiners et al., 2015), but there is still a sceptical caution by practitioners of restoration and foresters or even legislative restriction to use this knowledge. The main concerns are that natural colonization would be too slow to get a closed canopy in a short time and that woody plants would scarcely establish without the help of foresters (Wali, 1999; Zahawi et al., 2014). Studies in temperate regions reveal that woodlands develop spontaneously on different substrates and soils, but at different speeds (Wolf, 1985; Prach, 1994; Bornkamm, 2007). The formation of woodland may even be faster on nutrient-poor substrates, where tree colonization is not inhibited by competition from herbs (Rebele, 2013).

Literature on landfills deals mostly with sanitary landfills and the problems with their restoration, especially afforestation

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(Gilman et al., 1982; Wong, 1988; Robinson et al., 1992; Rawlinson et al., 2004). The landfill in this study is not a typical sanitary landfill (see Section 2) and does not show the ecological problems associated with waste disposal from households etc., such as decomposition gases, leaching of pollutants, or heavy erosion.

However, from it we can learn more about the processes of primary succession on a newly created habitat in an urban environment. Rebele and Lehmann (2002, 2007) studied early succession (year 1–year 10) on permanent quadrats and vegetation development on mown versus unmown sample plots on the same landfill which is subject of the present study.

It is often stated that long-term studies are necessary to understand vegetation dynamics (Rees et al., 2001) and to document restoration success (Oldfield et al., 2013). The present paper presents floristic data of woody species which colonized the whole landfill, beginning with bare ground, over a timespan of twenty years. We also studied species composition and vegetation structure in 20-year old woodland stands in 10 m × 20 m sample plots. We addressed the following questions:

1) How quickly will woody cover be established?
2) What kinds of woody species will dominate on nitrogen-poor mineral soil?
3) How productive is woodland growing on nutrient-poor soil?

2. Methods

2.1. Study area

The study area is located in the northeast of Berlin (Germany), about 1 km east of the village of Malchow (Fig. 1), which was incorporated into Berlin in 1920. The region is part of the Barnim plateau, a young morainic landscape shaped by the last glaciation (Weichselian) (Assmann, 1957). The plateau is composed of glacial till. In the west of the study area a wetland depression had survived (Malchower Aue). Before cultivation, the wetland was mainly covered with woodland, dominated by *Alnus glutinosa* (L.) P. Gaertn. The natural vegetation on the till plain had been deciduous forest, dominated by *Quercus petraea* Liebl. with *Carpinus betulus* L. and *Tilia cordata* Mill. (Krausch, 1965). In the Middle Ages, land has been almost completely cultivated and changed into farmland and meadows. The area where the landfill was established has been used for agriculture since the 14th century. In the 1980s, new housing estates with multi-storey buildings were constructed about 1–2 km east and south of the study location (at Wartenberg and at Hohenschönhausen, respectively).

From 1985 to 1990 the landfill was established in the neighborhood of the new large housing districts. The landfill was originally used for the storage of topsoil. However, building rubble was also deposited and, later on, primarily subsoil from the large construction sites in the neighborhood. During 1995, the central and the northern part of the landfill were capped with a sandy, Ca-rich, slightly alkaline mineral soil which was very low in organic matter and nitrogen. The substrate was also rich in Mg and moderately high with respect to P and K (Table 1). The deposited soil originated from deep horizons and therefore contained no seed bank.

The landfill hill is 6–8 m higher than the surrounding landscape and borders on peaty wetland in the west which is situated between the village Malchow and the study area. Since the end of deposition, the 6 ha large landfill site has become part of the nature reserve “Malchower Aue” which has a total area of 22.2 ha (Senatsverwaltung für Stadtentwicklung, Der Landesbeauftragte für Naturschutz und Landschaftspflege, 2007). The wetland contains secondary woodland dominated by *Alnus glutinosa* and *Salix* species, small ponds created by peat cutting, and mesic to wet meadows (Fig. 1). In contrast to the largely wet part of the nature reserve, the landfill site is well-drained and mostly dry, especially in years with low precipitation and high summer temperatures.

Table 1
Soil characteristics at the beginning of succession (year 2) on the landfill site (data from Lehmann, in report) and of a forest soil in the North of Berlin for comparison (data from Rebele, in report); for details of soil analyses see Rebele and Lehmann (2002).

Variable	Malchow, landfill	Hobrechtsfelde, oak forest
Fine soil <2 mm	silty to clayey sand Means ± sd (n = 17)	fine sand, humus rich Means ± sd (n = 5)
Coarse soil >2 mm%	6.6 ± 1.5	7.9 ± 2.0
C organic%	0.61 ± 0.01	4.66 ± 1.82
N total%	0.016 ± 0.005	0.361 ± 0.162
P available mg kg^{-1}	54.3 ± 11.8	20 ± 5.8
K available mg kg^{-1}	94.9 ± 27.6	60.8 ± 15.5
Mg available mg kg^{-1}	247.2 ± 56.0	27.0 ± 7.2
Ca available mg kg^{-1}	10870 ± 2850	179 ± 45
pH $CaCl_2$	8.1 ± 0.1	3.2 ± 0.1

Mean annual temperature from 1995 to 2014 was 9.5 °C, which was 0.9 °C warmer than the long-term annual mean of 8.6 °C (CDC, 2015a). 1996, the first year of succession, had the lowest annual temperature (7.4 °C) and 2014 had the highest annual temperature (10.7 °C) during the period of observation. Mean annual precipitation during the years 1995–2014 was 592 mm (CDC, 2015b), which was higher than the long-term annual mean (1909–1969) of 569 mm for the region. Precipitation fluctuated with a minimum of 401 mm in 2003 to a maximum of 789 mm in 2007. The first spring (1996) after the end of substrate deposition was wet with rainfall in May about 2.5 times higher compared with the long-term mean.

Most parts of the landfill (more than 80% of the total area) have been left unmanaged since the end of the deposition. The landfill hill is not fenced and plants, especially woody species, are moderately browsed by roe deer (*Capreolus capreolus* L.). Occasional disturbance by visitors occurs, but is restricted to small patches (e.g. footpaths). After twenty years of spontaneous succession, about 3/4 of the landfill hill had become densely covered by woodland. No timber harvesting had occurred; dead trees remained in place in the forest stands on the hill. About 1/4 of the area had become covered by grassland dominated by *Calamagrostis epigejos* (L.) Roth with scattered trees and shrubs.

2.2. Monitoring plant arrival and vegetation development

The landfill site was visited at least twice each year from 1996 until 2015 and all vascular plants arriving in the area were noted continuously. More detailed methods consisted of (a) abundance/cover estimation over the entire area of 6 ha and (b) survey of three sample plots of 200 m^2 each.

a) In 2001, the number or cover of each species was estimated using a DAFOR-scale (Goldsmith, 1991) with D (dominant) >20% cover, A (abundant) >1000 individuals, F (frequent) >100–1000 individuals, O (occasional) >5–100 individuals, R (rare) 0–5 individuals for the whole area of 6 ha. In 2015, an inventory using the DAFOR-scale was repeated for all woody species.
b) In 2015, three woodland plots of 10 m × 20 m were investigated: Malchow A (coordinates of the plot centre: 52°34′49.33″N, 13°29′29.78″E, from Google Earth), Malchow B (coordinates: 52°34′48.68″N, 13°29′31.09″E) and Malchow C (coordinates: 52°34′46.24″N, 13°29′31.95″E). Two of the plots (A and B) are located in the northern part of the landfill, the third plot (C) is located on the 1–2 m higher plateau. The locations were chosen on sites which had been undisturbed since the start of succession. Vegetation relevés were carried out with visual estimates of total cover of each layer, and percent cover of each component