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Evaluation of Metal Contamination and Soil Properties at Former Mine Sites in Poland

Kaitlyn McClung

Emily Brooks

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Emily Brooks and Kaitlyn McClung
Faculty Advisor: Melanie Szulczewski Dept Earth and Environmental Sciences

Abstract
Surface mining dramatically affects the environment, both where the resource extraction takes place and in the areas where mining wastes and overburden are deposited. Poland is Europe's top coal producing country and is also home to many mines for pyrite, sand, and other mineral resources. We studied soil samples from three former mining areas in Poland: the Bełchatów and Smolnica coal mines, and the Piaseczno sulfur mine. Various substrates, amendments, and trees had been used for remediation, with activities taking place up to 36 years previously. The success of reforestation and soil development varied greatly, especially in pH, organic matter, and metal concentrations.

Background
Surface mining dramatically affects the environment, both where the resource extraction takes place and in the areas where mining wastes and overburden are deposited. Poland is Europe's top coal producing country, and 80% of its electricity still comes from coal, leaving its mark on the landscape. It is estimated that over 61,000 ha of land have been disturbed by mining since 1945. Polish policy does enforce land reclamation, often with a Ministry of Environment office at the larger mine sites, remediating land side-by-side with extraction, approximately 25,000 ha reclaimed through reforestation efforts (Pietrzykowski, 2014). Reforestation is commonly implemented with Scots pine (*Pinus sylvestris*) in eastern Europe since it has low nutritional requirements and does well on acidic soils. Sometimes nitrogen-fixing alder species (*Alnus spp*.) are planted to help reclaim former mining sites, although they are usually used as the first step in a long-term plan.

It is important to monitor the successes- and failures- of various remediation attempts on various "dumped" substrates. For instance, a soil pH of 6 to 7 is most favorable for most plant growth due to nutrient availability (NRCS 1998). Scots pine, however, can grow in soils ranging from 4 to 7 in pH, but thrive in a pH range of 4.5 to 6 (Burns and Honkala 1990).

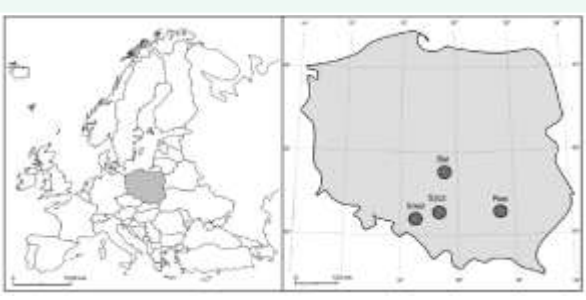

Figure 1. Study site locations: Bełchatów (Bel) coal mine, Smolnica (Smol) coal mine, and the Piaseczno (Pias) sulfur mine

Figure 2. The Bełchatów coal mine and surrounding reclaimed area

Materials and Methods
Study sites: The research was conducted on reclaimed and reforested mining areas in three mining areas in Poland: the Bełchatów (Bel) coal mine, the Smolnica (Smol) coal mine, and the Piaseczno (Pias) sulfur mine (Figure 1). The Szczakowa (Szcz) sand mine was studied separately. A composite soil sample was collected at each site by sampling the top 5 cm of soil with a soil probe. Soil samples were air-dried and screened through a 2-mm sieve, and the <2-mm fraction was retained for analysis

Laboratory Methods: Soil pH was obtained with a 1:1 ratio in deionized water. Bioavailable/ exchangeable metal concentrations were extracted with AB-DTPA (adapted from Soltanpour et al. 1996). Organic matter content was determined by the Loss-On-Ignition (LOI) method from Nelson and Sommers (1996). Total metal concentrations were determined by acid digestion with an adaptation of EPA Method 3050B (1996). All resulting solutions were filtered, then analyzed with a Thermo Scientific i-CAP 6000 inductively coupled plasma-atomic emission spectrometer (ICP-AES) in order to obtain metal and nutrient concentrations. Excel and SPSS were used to analyze data.

Bełchatów Coal Mine
Located near Łódź in south-central Poland, this mine produces over half of Poland's lignite (aka soft or brown) coal. Mining has continued here for over 50 years, with Poland's largest power plant nearby (Figure 2). Sampling at this location included sites where coal waste and fly ash was deposited within a week of sampling to sites which were reclaimed 10 or 12 years ago. Sites Bel-2 and Bel-3 were created by mixing coal waste with sewage sludge while the coal waste was mixed with acidic sands deposits at Site Bel-4

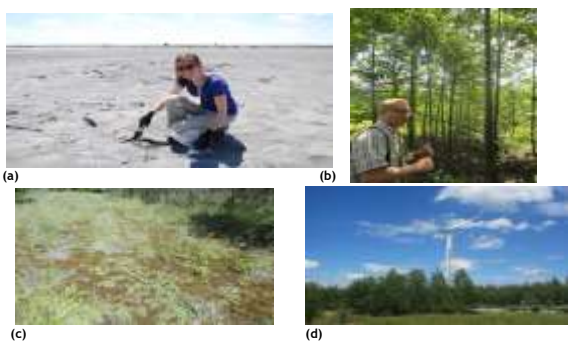

Figure 3. The Bełchatów coal mine and reclaimed sites. (a) Site Bel-1; (b) Site Bel-2; (c) Site Bel-3; (d) Site Bel-4

Table 1. Soil characteristics of the Bełchatów coal mine reclaimed sites and initial materials. Soil metal content analysis is ongoing.

Site	Treatment	Years since Treatment	Soil pH	Soil Organic Matter %	% Sand	% Clay	% Silt
Be-1	None	0	9.74 ± 0.09	2.2 ± 0.1			
Be-2	SS/ Black alders	10	8.13 ± 0.04	7.8 ± 0.5	80.02	7.49	12.49
Be-3	SS No trees	12	8.25 ± 0.01	2.1 ± 0.2	91.25	5.00	3.75
Be-4	Acidic sands Scots pine	10	4.19 ± 0.01	1.5 ± 0.1			
Be-pure coal dust			5.28 ± 0	63.4 ± 0.3			
Be- acidic sand			2.94 ± 0.32	0.33 ± 0.05			

Smolnica Coal Mine
The Smolnica hard coal mine is located in the Upper Silesian Coal Basin in the south of Poland. This area contains the highest concentration of heavy industry in the country along with over a dozen active mines, mostly coal but also some metal ores. The reclaimed overburden heaps consist mostly of coal processing wastes mixed with local carbonaceous shales and sandstones. Sampling at this location included sites where coal waste was deposited within a week of sampling to sites which were reclaimed up to 36 years ago.

Table 2. Soil characteristics of the Smolnica coal mine reclaimed sites and initial deposits.

Site	Treatment	Years since Treatment	Soil pH	Soil Organic Matter %	% Sand	% Clay	% Silt
Smol-1	None	0	7.39 ± 0.6	19.0 ± 0.3	82.57	12.45	4.98
Smol-2	None	3	4.24 ± 0.03	23.1 ± 0.2	80.05	9.973	9.97
Smol-3	Scots pine	16	4.66 ± 0.10	14 ± 1	85.17	7.415	7.42
Smol-4	Scots pine	36	4.02 ± 0.01	25.2 ± 0.6	72.35	17.60	10.06

Figure 4. The Smolnica coal mine and reclaimed sites. (a) Site Smol-1; (b) Site Smol-2; (c) Site Smol-3; (d) Site Smol-4

Piaseczno Sulfur Mine (Site Pias-1)
Forest reclamation in this area involved planting Scots pine on dumped overburden 35 years ago

Figure 5. The Piaseczno Sulfur Mine reclaimed site

Table 3. Soil characteristics of the Piaseczno Sulfur mine reclaimed sites.

Site	Soil pH	Soil Organic Matter %	% Sand	% Clay	% Silt
Pias-1	6.86 ± 0.04	10.8 ± 0.1	62.31	22.61	15.08
Pias-2	7.35 ± 0.01	3.1 ± 0.1	62.61	26.17	11.22

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