How does the variation in the mineralogical and chemical properties of anthropogenic substrate influence plant biodiversity?

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Introduction

In recent history in the United Kingdom, anthropogenic substrates, which are produced as waste materials and/or by-products resulting from many types of industrial processes[1,2,3,4,5,6,7] were often dumped in the natural environment in areas previously associated with industry. People have observed that, if left undisturbed, anthropogenic substrate sites may provide relatively undisturbed spaces for plant species and communities[1,7,8,9,10,11,12,13,14,15] due to variations in chemistry, surface texture, topography and other factors. In particular, unusual and/or important species communities can colonise anthropogenic substrate sites[1,8,9,10,11,12,13,14,15]. As part of my PhD research, I have investigated substrate chemistry and mineralogy, as well as plant species and communities on different types of anthropogenic substrate sites. This work helps with the investigation of plant establishment, survival and growth on anthropogenic substrates in a novel manner.

Methodology

- In 2021, six study sites were visited. On each site, 1 x 1 metre quadrats were used to record plant species in different open plant communities (see Figs. 1D, E and F). Substrate samples corresponding to each of the quadrat locations were collected.
- Most of the recorded species were part of the bryophyte and angiosperm species groups, with some species from additional groups such as Bracken *Pteridium aquilinum*.
- Various analyses were performed on the data, including: Analyses of Similarities (using the vegan package in R [16]); Canonical Correspondence Analyses (using the vegan package in R [16]); Biodiversity analyses (using the BiodiversityRGUI [17], the vegan package[16] and the iNEXT packages in R[18]); and Indval analyses (using the labdsv package in R[19]).

Table 2: Indicator species with the highest Indval scores throughout the six study sites, based on calculations done using the function "indval" in the labdsv R package[19]. Indicator values and p values are reported to 3 decimal places.

Mineral	Species	Indicator Value	P value
Aluminium oxide hydroxide	*Hypochaeris radicata*	1	0.028
Anhydrite	*Alchemilla mollis*	1	0.029
Aragonite	*Daucus carrota*	0.952	0.042
Augite	*Briza media*	0.997	0.023
Birnessite	*Betula pubescens*	1	0.025
Diaspore	*Hieracium spp.*	1	0.026
Goethite	*Centaurium pulchellum*	1	0.024
Haematite	*Hypnum jutlandicum*	0.992	0.002
Langite	*Thuidium tamarascinum*	0.976	0.032
Linnaeite	*Zygodon stirtonii*	1	0.029
Melilite	*Taraxacum agg.*	0.907	0.008
Merwinite	*Alopercus pratensis*	1	0.022
	Avenula pratensis	1	0.028
Microcline	*Stellaria apetala*	1	0.026
Mullite	*Hieracium spp.*	1	0.025
Orthoclase	*Campanula rotundifolia*	1	0.025
	Equisetum variegatum	1	0.025
Orthopyroxene	*Poa annua*	0.965	0.016
Spinel	*Trifolium dubium*	0.982	0.021
Valentinite	*Carex panicea*	1	0.022

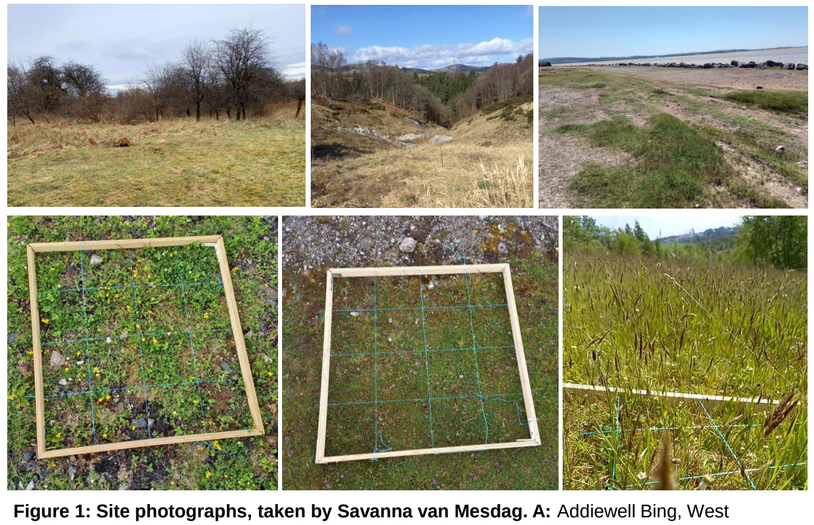

Figure 1: Site photographs, taken by Savanna van Mesdag. A: Addiewell Bing, West Lothian. **B:** South Bank Wood, Penicuik, Midlothian. **C:** RSPB Hodbarrow Nature Reserve, Cumbria. **D:** A quadrat at Fallin Bing, Stirling. **E:** A quadrat at the Warton slag bank, Lancashire. **F:** A quadrat at Fallin Bing, Stirling.

Table 1: Biodiversity indices for the ten plant communities with the highest q = 0 number, on the six study sites, calculated in R. Values are reported to 3 decimal places. Hill Number q = 0, q= 1, q= 2 and sample coverage were calculated using the iNEXT pacakage in R[18], Pielou's Species evenness was calculated using the vegan package in R[16].

	Hill Number q = 0	Hill Number q= 1 (Modified Shannon diversity)	Hill Number q=2 (Modified Simpson diversity)	Sample coverage	Species richness	Pielou's Species evenness (mean)
Barrow 3	17.931	5.827	4.476	0.993	14	0.668
Barrow 5	19.328	5.077	2.756	0.993	19	0.551
Barrow 9	17.354	8.451	5.476	0.993	16	0.770
Hodbarrow 5	18.457	11.090	9.517	0.998	18	0.832
Fallin Bing 1	19.625	10.538	8.352	0.998	18	0.815
Fallin Bing 4	18.417	9.098	7.137	0.998	18	0.764
Fallin Bing 5	21.188	12.511	10.531	0.998	19	0.858
Addiewell Bing 1	15.890	7.331	4.791	0.992	17	0.703
Addiewell Bing 3	21.720	10.403	7.301	0.992	23	0.747
Addiewell Bing 5	26.117	9.2441	5.319	0.992	22	0.720

Results

- Biodiversity indices throughout the six study sites, with some particularly high biodiversity levels being recorded on the Barrow-in-Furness slag bank, the Hodbarrow RSPB Reserve, Fallin Bing and Addiewell Bing (Table 1).
- Some of the species on the study sites were associated with specific minerals, these findings merit further investigation (Table 2).
- Several chemical variables were recorded as being strongly influential for the presence of plant species across the six study sites, including Al_2O_3, P_2O_5, CaO and pH level (Figure 2).
- It is clear from this study that many of the geochemical variables on the anthropogenic substrate study sites influenced plant community and/or species composition, with varying biodiversity levels indicating the conservation importance of many of the communities on the study sites.

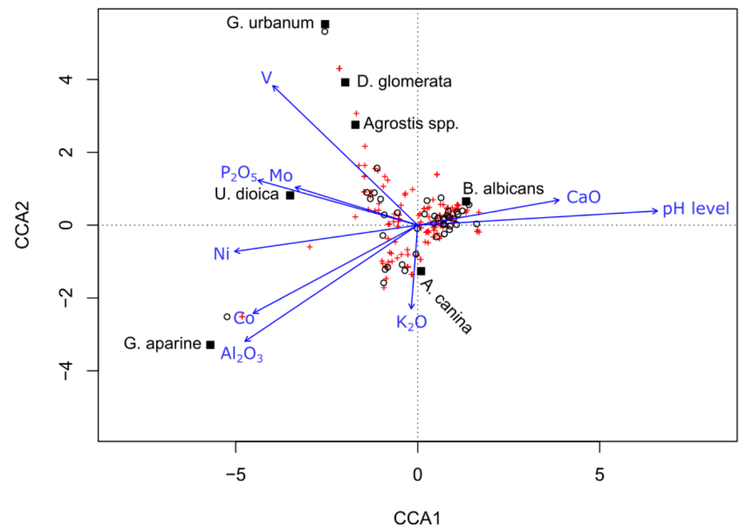

Figure 2: Plot for a canonical correspondence analysis for plant data for all six field sites, including the most relevant variables (Al_2O_3, CaO, Co, K_2O, Mo, Ni, P_2O_5, pH level and V, anova F statistic = 1.6185, anova p = 0.001). White circles represent plant communities and red crosses show plant species, some selected species are labelled to represent variation between species and substrate chemistries.

References 1. Allan et al., (1997) *Scottish Natural Heritage Review;* **2.** Bradshaw. (1977) *Proceedings of the Royal Society of London*; **3.** Courtney et al., (2009) *Restoration Ecology*; **4.** Di Carlo et al. (2019) *Soil Research* **5.** Gomes et al. (2019) *Green Chemistry Series No. 63;* **6.** Piatak et al. (2015) *Applied Geochemistry;* **7.**Thomas. (1930) *Journal of Ecology*; **8.** Ash et al., (1994) *Journal of Applied Ecology*; **9.** Batty. (2005) *Mine Water and the Environment*; 10. Bonthoux et al. (2014) *Landscape and Urban* Planning; **11.** Harrison & Davies. (2002) *Journal of Environmental Management*; **12.** Macadam & Bairner, (2012) *The Glasgow Naturalist*; **13.** Macadam et al. (2013) *Scottish Natural Heritage Commissioned Report;* **14.** Palmer, (2008). *Cumbria Biological Data Network;* **15.** Riding et al. (2010) *ADAS UK Ltd;* **16.** Oksanen et al. (2022) vegan: Community Ecology Package_. R package version 2.6-4; **17.** Kindt. (2023) Package 'BiodiversityR', R package, version 2.15-2. **18.** Hseih et al. (2022) Package 'iNEXT', version 3.0.0. **19.** Roberts. (2023) Package 'labdsv', version 2.1-0.