

BIOLOGICAL SCIENCES

VEGETATION STUDY ON AN ANTHROPOGENIC PRIMARY SUBSTRATE: SAND SCULPTURES IN THE URBAN AREA OF BURGAS (BULGARIAN BLACK SEA COAST)

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Abstract

This study provides a case example of primary plant colonization on an anthropogenic sandy substrate, represented by temporary sand sculptures in Burgas, on the Bulgarian Black Sea coast. Twelve sculptures were surveyed as sample plots, and a total of eight annual ruderal species were recorded. Three taxa (*Datura stramonium*, *Amaranthus retroflexus*, *Chenopodium pumilio*) are recognized as invasive alien plants in Bulgaria. *Datura stramonium* was the most abundant and frequent species, whereas *Chenopodium album* and *Echinochloa crus-galli* were rare. Most of the recorded taxa are diagnostic for the class *Stellarietea mediae*. The adjacent vegetation, by contrast, included perennials typical of *Artemisietea vulgaris*, reflecting a more advanced successional stage. Cluster analysis revealed a high degree of similarity among the sample plots, related to the uniform origin of the substrate. The study illustrates how cultural installations can serve as small-scale experimental sites for observing the earliest stages of succession on primary substrates, while also demonstrating the potential role of transported sands as vectors for invasive species.

Keywords: primary succession; sand; ruderal vegetation; *Stellarietea mediae*; invasive alien species; urban ecology.

Introduction

Primary succession represents the process by which plant communities gradually establish on bare substrates lacking pre-existing soil or vegetation [11, 17]. On anthropogenic sandy substrates—such as tailings impoundments, quarries, or construction sand deposits—the conditions are particularly stressful: the substrate is unstable, poor in nutrients and organic matter, with low water retention capacity and often subject to extreme temperature fluctuations [1].

Colonization of such substrates begins with pioneer species possessing specific adaptations that allow them to cope with unfavorable conditions, such as well-developed root systems, the ability to stabilize sand, and tolerance to high temperatures, drought, and often increased salinity [9]. These early plants contribute to substrate stabilization by trapping sand and reducing erosion, while the gradual accumulation of organic matter from decomposing biomass improves water-holding capacity and nutrient availability [16].

In more advanced phases, colonization may be accelerated by accidental seed introduction through wind, animals, or human activity. Such processes often facilitate the establishment of ruderal and alien species capable of accumulating considerable biomass and altering substrate conditions, as well documented for *Robinia pseudoacacia* in Central Europe [8]. This may lead to deviations from the classical successional sequence and to the formation of alternative communities.

Along the Bulgarian Black Sea coast, recent studies have shown that dune habitats are characterized by a significant proportion of ruderal plants and ongoing trends of change in species composition, including serious presence of alien invasive species [5,6,15].

Artificial sand sculptures, such as those in Burgas, Bulgaria, represent a unique yet relatively stable experimental substrate that enables the observation of early plant succession in a highly anthropogenic context. The aim of the present study is to record and characterize the plant species and communities that establish primarily on this anthropogenic primary substrate, exemplified by sand sculptures, and to analyze the factors driving their occurrence, including the establishment of invasive alien plants.

Materials and methods

Study site

The Sand Sculpture Festival in Burgas (Bulgarian Black Sea Coast) is an annual cultural event established in 2008 and situated in Lake Park (N 42.51079, E 27.48144), encompassing an area of approximately 5 ha (Fig. 1). Each year, approximately 5,600 t of specially prepared, rain-resistant sand is used to create large-scale sculptures, some exceeding 8 m in height, designed by artists from Bulgaria and multiple continents. The event has become a significant tourist attraction, with more than 100,000 visitors per season [3].



Fig. 1. General view of the study area (photo by P. Glogov); the location map was adapted from d-maps.com (<https://www.d-maps.com/>).

The sculptures were created in June 2025. The material used for their construction consists of clayey sand (ISO 14688: SAND with clay; USCS: SC) fine to medium-grained, moderately sorted, sub-rounded, quartz-dominated, containing approximately 10–25% fines (<0.063 mm), of which approximately 5–15% are clay (<0.002 mm). The fine fraction exhibits low to medium plasticity (PI approximately 7–18%). Slightly calcareous, non-organic, and uncemented. The expected permeability is k approximately 10^{-6} – 10^{-5} m/s (depending on compaction). The construction material is delivered in June, 2025 from the Novoseltsi aggregate quarry which is located approximately 15 km southwest of Burgas, near the village of Konstantinovo and adjacent to Lake Mandra. It exploits Pliocene fluvial deposits and produces a range of screened and washed fractions, including sands (0–4 mm, 0–2 mm), gravels (4–30 mm,

>30 mm), and clays, in compliance with BDS EN standards. Geologically, the deposit exhibits complex and irregular alternations of sand, gravel, and clay, with variable lithology and granulometric proportions. This heterogeneity, typical of alluvial Pliocene sequences, presents both challenges and opportunities for tailored geotechnical applications and resource optimization.

Methodological approach

The study was conducted in August 2025. For this investigation, all 12 individual sand sculptures were treated as sample plots (SPs), ranging in size from 3.5×3.5 m to 5×5 m (Fig. 2). These sculptures, displayed outdoors for extended periods, represent an artificial yet stable primary substrate and provide a controlled environment for examining processes of primary plant succession as well as the colonization and spread of anthropophyte species.



Fig. 2. Sample plots (SPs)

For the purposes of this study, a phytocoenological survey was conducted both within the sample plots (SPs) containing the sand sculptures and in the areas immediately adjacent to them. The survey recorded the floristic composition, the total vegetation cover, and the individual cover of each plant species (expressed as percentage outside the SPs and as number of individuals per m² within the SPs). Species frequency was calculated according to the formula $(n/N) \times 100\%$, where n is the number of SPs in which a given species occurs, and N is the total number of SPs. Taxonomic determination of the recorded species followed [4] with additional consultation of [18] when necessary to verify synonymy.

The biological types of the species were also identified (annuals, biennials, perennials, shrubs, and trees). Anthropophytes/ ruderal species followed [7] and [14]. Invasive alien species for Bulgaria were identified according to [12].

Cluster analysis of the phytocoenological data was performed using the specialized software SYNTAX [13]. The classification of plant communities followed the floristic approach of [2], diagnostic and constant species for the syntaxa are mainly according [10].

Results

The vegetation in the immediate vicinity of the SPs with the sand sculptures is ruderal grassland. The

total tree cover is 3%, consisting of two species: *Platanus × acerifolia* (2%) and *Prunus cerasifera* (1%). The second phytocoenotic layer accounts for 1%, represented by *Gleditsia triacanthos* (1%) and *Prunus cerasifera* (+). The total grass cover is 15%, with most species diagnostic and constant for the class Stellarietea mediae: *Hordeum murinum* (5%), *Avena fatua* (2%), *Setaria viridis* (<1%), *Digitaria sanguinalis* (5%), *Chenopodium album* (<1%), *Erigeron canadensis* (<1%), *Senecio vulgaris* (1%), *Helminthotheca echioides* (<1%), *Lactuca seriola* (<1%), and *Datura stramonium* (1%). Other species are associated with the class Artemisietea vulgaris: *Cichorium intybus* (1%), *Convolvulus arvensis* (1%), *Cynodon dactylon* (5%), and *Epilobium hirsutum* (<1%).

The floristic composition in the SPs includes eight annual species (Table 1). All recorded taxa are ruderal, of which three—*Datura stramonium*, *Amaranthus retroflexus*, and *Chenopodium pumilio*—are invasive alien species in Bulgaria [12]. *Datura stramonium* showed the highest abundance and frequency, whereas *Chenopodium album* and *Echinochloa crus-galli* were least represented. Three species (37.5%) from the SPs—*Datura stramonium*, *Cynodon dactylon*, and *Chenopodium album*—also occurred in the areas immediately adjacent to the SPs.

Table 1.

Quantitative participation of species in the SPs

Species/№ of SP	Life form	Quantitative participation of species (number of individuals per m ²)												Occurrence (%)
		1	2	3	4	5	6	7	8	9	10	11	12	
<i>Datura stramonium</i>	annual	53	67	23	78	46	17	44	37	61	34	71	28	100
<i>Cynodon dactylon</i>	annual	4	1	2	4	2	0	9	2	1	6	1	0	67
<i>Portulaca oleracea</i>	annual	2	5	2	6	0	0	10	5	1	2	4	7	67
<i>Setaria viridis</i>	annual	6	0	1	3	5	0	2	2	2	0	2	0	58
<i>Amaranthus retroflexus</i>	annual	0	0	0	0	1	2	1	0	0	0	0	0	25
<i>Chenopodium pumilio</i>	annual	0	0	0	0	0	0	0	1	1	1	0	0	25
<i>Echinochloa crus-galli</i>	annual	0	0	0	0	0	0	1	0	0	0	0	0	8
<i>Chenopodium album</i>	annual	0	0	0	0	0	0	0	0	0	0	0	1	8
Total		65	73	28	91	54	19	67	47	66	43	78	36	

Legend for Sample Plots (SP):

SP1 – Snow White; SP2 – The Three Musketeers; SP3 – Cinderella; SP4 – Puss in Boots; SP5 – Pippi; SP6 – Aladdin; SP7 – Ali Baba and the Forty Thieves; SP8 – Baron Munchausen; SP9 – Clever Peter; SP10 – The Giant Turnip; SP11 – Alice; SP12 – Pinocchio.

The cluster dendrogram (Fig. 1) indicates a high degree of similarity in species composition and abundance among the SPs. All recorded taxa are annuals and represent diagnostic or constant species of the class *Stellarietea mediae*.

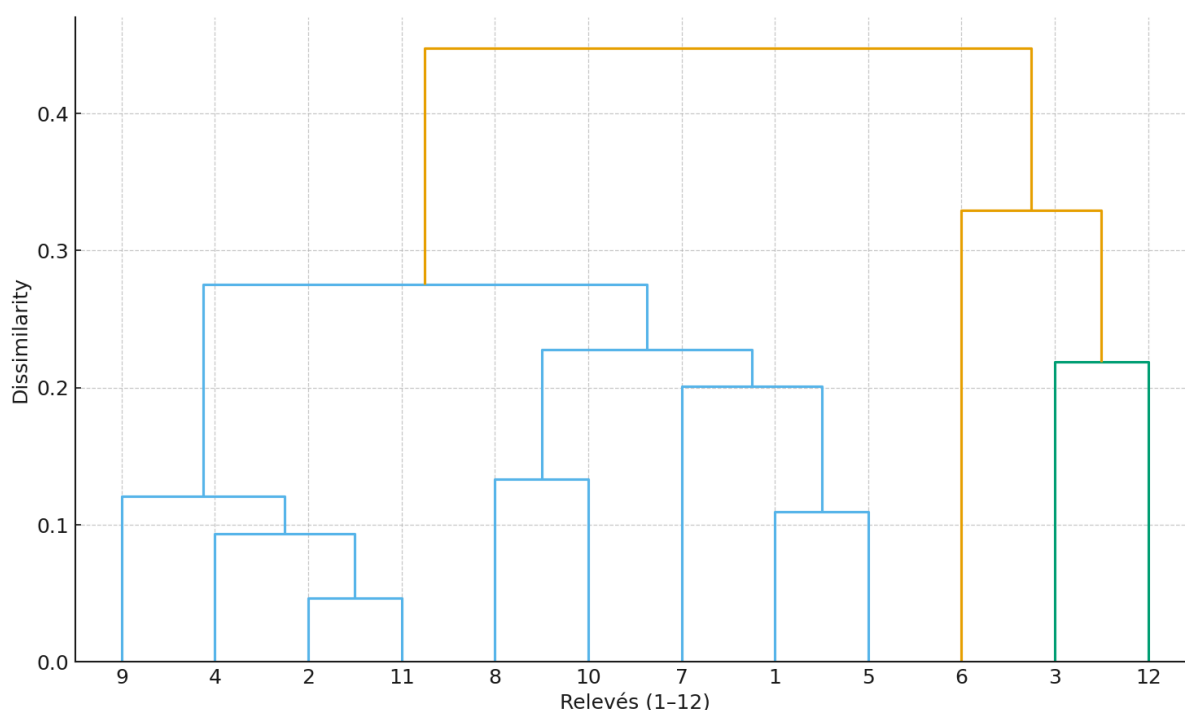


Figure 3. Cluster dendrogram based on Bray–Curtis dissimilarity among relevés in the SPs

Discussion

The vegetation colonizing the sand sculptures follows the expected pattern of primary succession on anthropogenic substrates, dominated by annual ruderal species. More significant, however, is the fact that the leading taxa—most notably *Datura stramonium*—show extraordinary abundance within the plots, which does not correspond to their limited presence in the surrounding vegetation. This strongly supports the interpretation that the main source of propagules was not the

local seed bank but rather the **sand imported from the quarry**. The seeds, likely originating from previous seasons, demonstrate high viability and plasticity, allowing invasive alien plants to establish rapidly in novel conditions.

This finding highlights an important and often underestimated mechanism of invasion: **construction and cultural practices that transfer substrates containing persistent seed banks**. In this case, a cultural event—the Sand Sculpture Festival—unintentionally

acted as a vector of biological invasions into the urban environment. Thus, even temporary installations can serve as “entry points” for alien species into urban landscapes.

Equally important is the contrast with adjacent areas, where perennial ruderals of the class *Artemisietea vulgaris* are already established. This difference illustrates a **chronological gradient of succession**, in which the sculptures capture the very earliest stage of colonization, while the surrounding habitats reflect a more advanced phase. Such a spatial juxtaposition provides valuable insight into the pace and trajectory of vegetation change on anthropogenic sands.

Individual species display distinct colonization strategies. *Cynodon dactylon* and *Portulaca oleracea* exhibit strong drought and trampling tolerance, making them characteristic colonizers of compacted sandy substrates. *Amaranthus retroflexus* and *Chenopodium pumilio*, though less frequent, confirm the role of invasive aliens as integral elements of early successional stages. By contrast, the sporadic occurrence of *Chenopodium album* and *Echinochloa crus-galli* likely reflects weaker competitiveness under these conditions.

The high similarity among sculptures, revealed by cluster analysis, reflects the **homogeneity of substrate origin and propagule supply**, rather than plot-specific differences. This uniformity effectively transforms the sculptures into a “living laboratory,” where ruderal succession can be observed synchronously and repeatedly.

From a broader perspective, the study demonstrates that **urban cultural initiatives relying on quarry sands** may inadvertently accelerate the introduction of invasive alien plants. These findings contribute to a broader discussion on the role of temporary anthropogenic habitats as stepping stones for invasive aliens, with implications for urban biodiversity management along the Bulgarian Black Sea coast.

Conclusions

The vegetation colonizing the sand sculptures consists exclusively of annual ruderal species, diagnostic for the class *Stellarietea mediae*, representing the earliest stage of primary succession on anthropogenic sandy substrates.

The extraordinary dominance of *Datura stramonium* indicates that invasive alien seeds were most likely introduced with the quarry sand, underlining the role of construction materials as vectors of biological invasions.

Temporary cultural initiatives such as sand sculpture festivals can inadvertently facilitate the establishment and spread of invasive alien species, highlighting the need for preventive monitoring and management measures in urban and coastal contexts.

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