Supplementary material 2

(This is the PDF version of selected pages from the thematic project website (Ćetković et al. 2020), by: Centre for Bee Research of the Faculty of Biology, University of Belgrade; available also at: https://srbee.bio.bg.ac.rs/english/belgrade-general-features; https://srbee.bio.bg.ac.rs/english/m-sculpturalis-2019-survey; with occasional updates.)

Study area – Belgrade (Serbia): basic topography, biogeography, ecological patterns (habitats, land-use, landscapes) and urbanistic zonation

(i) The City of Belgrade: general features

Belgrade is the capital of the Republic of Serbia, and one of the largest cities in southeastern Europe. According to general planning regulation (2003: The 2021 Belgrade Masterplan), core administrative-urbanistic unit (Belgrade "proper") is about 776 km^2 (max. S–N and E–W extent roughly within the 35×36 km rectangle), with population of >1.5 million. It is positioned at the confluence of two large European rivers, mostly navigable and representing important natural and commercial traffic corridors: the Danube River (the second longest in Europe, running from Alps in Germany through much of central Europe, and draining most of SE Europe into the Black Sea), and the Sava River (the second longest within SE Europe, running from Alps in Slovenia roughly west-eastwards to its mouth in Belgrade). The Danube River also marks the northern border of the Balkans east of Belgrade, and the Sava River marks most of the northern Balkans' border to the west. Therefore, Belgrade is situated in the border zone between two large, and quite different geographic units of southeastern Europe: the predominantly hilly to mountainous Balkan Peninsula to the south, and the vast lowlands of the Pannonian Plain to the north.

Its area is also climatically transitional, between temperate-continental and more steppic regime, and its relief is spanning the altitude range of 65–506 m. Biogeographically, the area harbours a varied mixture of elements from three principal provenances: temperate central-European (or, in wider sense, Euro-Siberian), thermophilic southern-European (sub-Mediterranean, or even broadly Mediterranean), and xerothermic-continental-steppic eastern-European (mostly wooded-steppic Pannonian, or in wider sense, Ponto-Pannonian); in more local regionalization, its position may be referred to as southeast-peri-Pannonian, and it is quite remote from higher mountain areas of the Balkans.

The appropriate environmental scope for both urban ecology and landscape ecology studies imply that natural context is largely impacted by socio-economic history and current dynamics, principally affecting land-use pattern. Our wider study area, the urbanistic Belgrade "proper" (Fig. S2.1), encompasses more than 50% of varied agricultural habitats as a matrix, with embedded mosaic of urban, suburban and rural habitats and land use types, showing contrasting patterns in the two distinct regions.

From the initial city core (situated just south of Danube-Sava confluence point, roughly: 44.798–44.825°N, 20.451–20.483°E), Belgrade experienced remarkable spread in all directions, particularly since the mid twentieth century, and gradually merged with different smaller neighbouring settlements. The processes followed somewhat different urbanistic rules and context-dependent dynamics in varying combinations of topography, development history and prevailing land-use, hence resulted in several distinct urban, mixed, and rural landscape and land-use types, with transitions forming dissimilar patterns in different sections and directions.

From the perspective of wild bee studies, various urbanistic sectors are characterized by differing types, extent and relative share of suitable habitats, from managed "urban green" through those in

varied residential and agricultural regimes, to semi-natural and wild ecosystems, along different gradients of urbanized environment.

The available official maps (Fig. S2.1) from 2003 (The 2021 Belgrade Masterplan) mostly follow the standard, relatively simplified urbanistic classification of urban green types, which leaves a relatively large share of potentially important bee habitats hidden under other land-use categories (e.g. several types of residential settlements are remarkably "greenish"). There were attempts to improve the classification and mapping approach, most notably through the project "Green regulation of Belgrade" (2006–2008; link), with elaborate re-classification of urban habitats for assessing their "value for biodiversity", but due to various limitations, this system is also mostly unsuitable for evaluation of bee habitats.

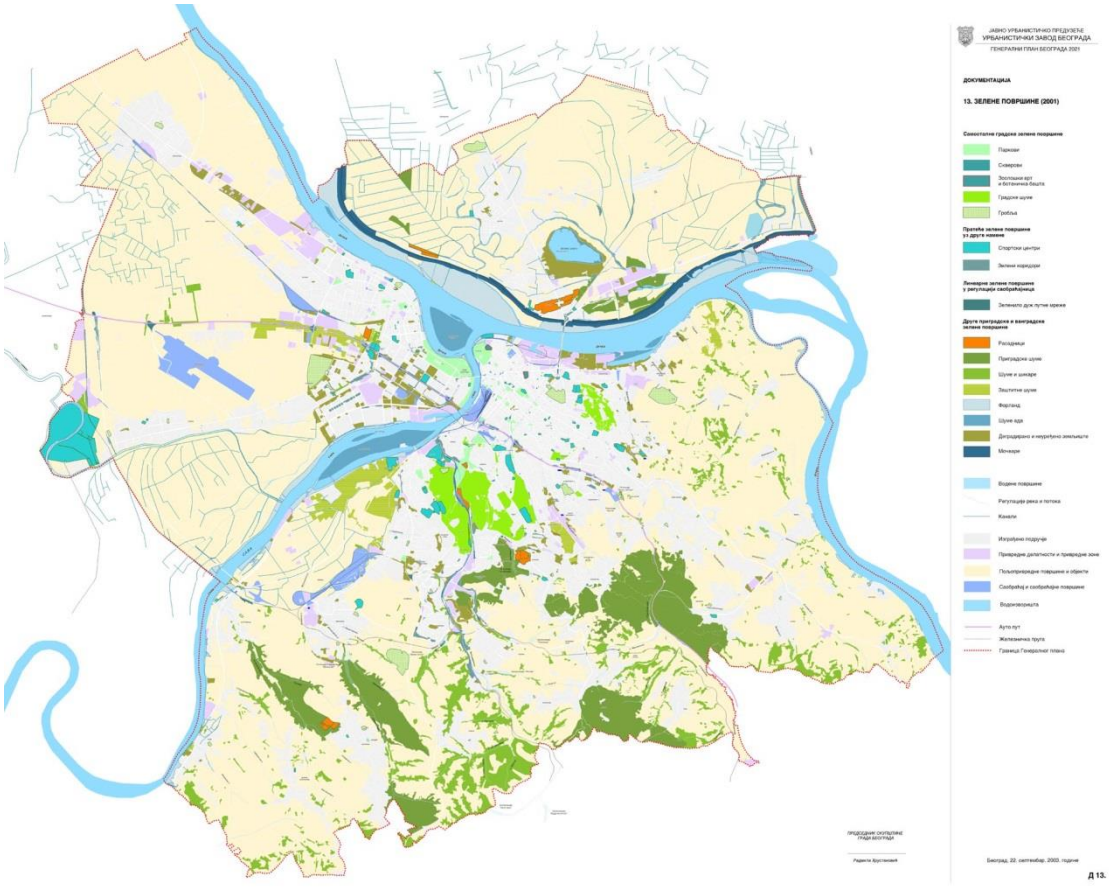

Figure S2.1. Main land-use types of Belgrade "proper" area, according to "The 2021 Belgrade Masterplan" (2003). The dominant pale-yellow colour denotes agriculture, whitish-grey and pale-violet denote dominantly built areas (largely with impervious fabric), and wide spectre of green/greenish/green-bluish/green-brownish denote a variety of "urban and peri-urban green surfaces". (The state from 2001/2002; slight changes that have happened since that period are negligible for our context.)

Available alternative is to reduce the quality of assessment to CORINE land-cover classes (Corine Land Cover (CLC) 2018, version 2020_20u1 or Urban Atlas LCLU 2018, which is currently too simplified and of inappropriate resolution for this region (often reduced to measures of "impervious surfaces" *vs*. "green surfaces"). Until a more detailed habitat mapping is available, **we use our own "tailored" approach**, specifically suited for diverse wild bee studies. It is based on landscape scale characterization of available elements of physiography (topographic, pedological, etc.), land-cover, urbanistic, and other features (variously combined), with the focus on management regime within relevant/key urban habitat classes and respective resource

availability. We defined a basic set of wider "urbanistic zones", characterized with broadly predictable generalized patterns of positive *vs.* negative impacts on bee populations and communities regarding various aspects and gradients of urban environments. The concept allows to be conveniently fine-tuned to relevant taxon-specific or habitat-specific situations, for each particular study.

(ii) Zonation of Belgrade *(version_01: survey in 2019)*

The zonation emphasizes the differences between the two main sections (the Balkan and the Pannonian), within the framework of usual urban-rural gradients (Fig. S2.2).

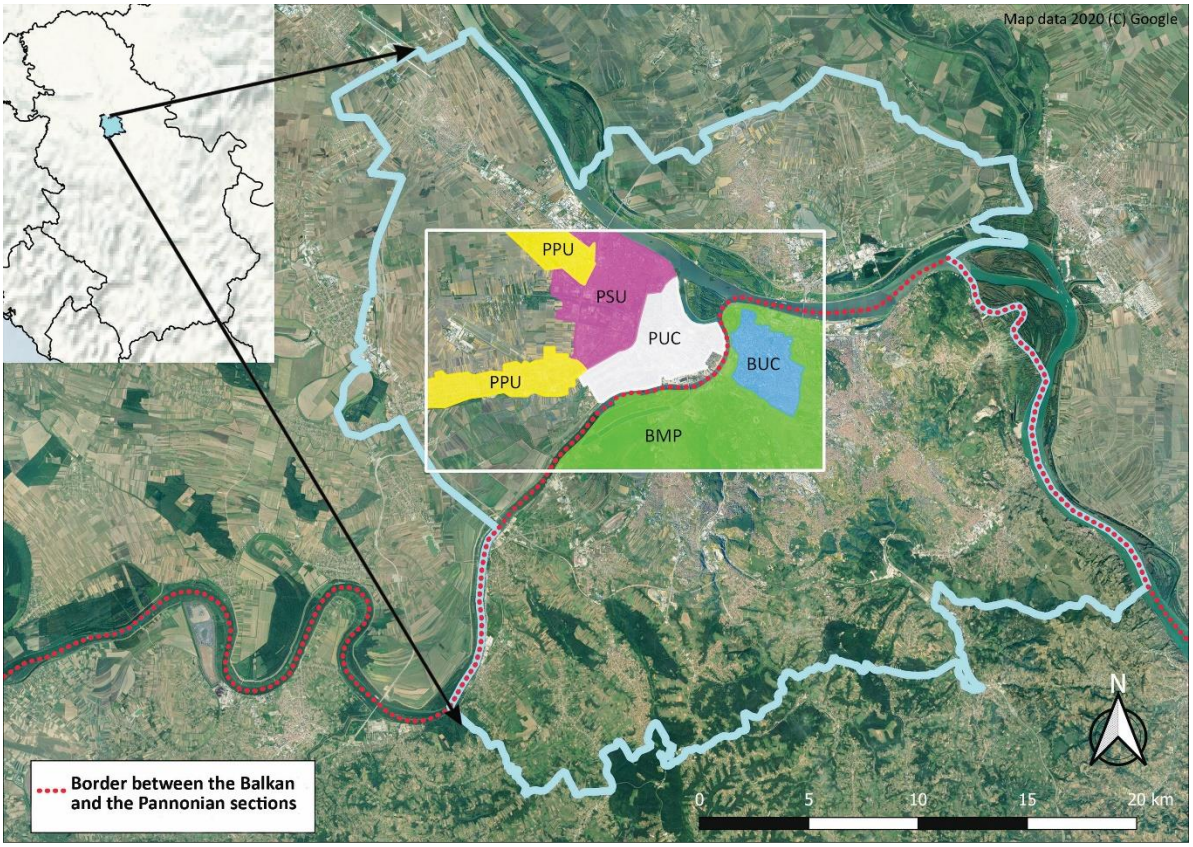

Figure S2.2. Urbanistic zonation of the study area in Serbia (18×11 km), within the Belgrade "proper" (light blue outline; sections separated by the red dotted-line): BUC – Balkan Urban Core; BMP – Balkan Mixed Periphery; PUC – Pannonian Urban Core; PSU – Pannonian Semi-Urban; PPU – Pannonian Peri-Urban.

A) The **Balkan section** of Belgrade, as the northernmost portion of the Šumadija region of central Serbia, consists of markedly hilly terrain (mostly within 120–250 m of altitude, very limited area in 300–500 m range) of varied geology and pedology, while some sectors of river banks are relatively flat (65–90 m) and wide, hence with high water table and occasionally flooded in the springtime (alluvial). The Balkan section shows relatively clear gradient of decreasing urbanization intensity, principally along the NW–SE axis, and also less markedly towards the east and the southwest. We recognise two sufficiently distinct units within the Balkan section (acronyms as in Fig. S2.2–S2.3):

- the small, highly urbanized and populated ***"old downtown" core*** (about 10 km^2), with largely impervious land cover and dense fabric of commercial, residential, infrastructural facilities (BUC); it transforms gradually into

- a wide, more loosely structured ***peripheral zone***, with a variety of suburban, peri-urban and/or rural settlements of less intensive or countryside lifestyles, more greenish areas and recreational assets, but also some extensive industrial areas and transportation facilities (BMP).

A more prominent presence of semi-natural habitats and near-natural remnants of original forest ecosystems emerges from about 2–4 km distance from the urban core, mixed with growing share of agricultural land cover further outwards. Beyond the distance of 5–7 km from the core area to the south and east, agricultural and semi/near-natural habitats are represented in much larger continuous tracts. They are intermixed with more agriculturally oriented settlements, resulting in variously marked transition from sub-urban outskirts to "rural belt", roughly semi-circularly positioned around the Balkan urban core of Belgrade. Within this complex greenish matrix, old peri-urban villages and small towns are progressively being inter-dispersed with a variety of newly created modern settlements, along main traffic corridors (particularly after 1960s); they eventually became merged with more central city zones, occasionally representing sub/urban sprawl situations. Agriculture of the Balkan section is mostly of small scale to moderately intensive type, with widespread abandonment in several tracts, particularly closer to the sub-urban margins.

B) The **Pannonian section** consists of two regions, delimited by major rivers: the Syrmia Region (between Sava and Danube rivers) and the Banat Region (north of the Danube). It is markedly flat and lowland, either alluvial and originally marshy, frequently flooded (in Banat and in part of Syrmia Region, alt. 67–80 m), or somewhat raised loess formations (represented in large part of Syrmia Region, alt. 80–105 m). Most of the marshlands were channelled and drained long ago, and the whole area was largely converted into a highly productive agriculture, often of intensive type.

In the Syrmia Region, older settlements of traditional Pannonian type (villages or small towns) were situated mostly in loess areas – less prone to flooding, separated by marshy area about 3–4 km wide from the Belgrade old core. Since 1950s, an entirely new peri-urban settlement was developed in between, built upon thick layers of riverine sand, brought to raise the ground level (which also lowered the water table). This modern town (named Novi Beograd = "New Belgrade") of the Le Corbusier architectural style is composed of spaced multi-story buildings and ample urban green areas, varying from strictly managed park-like blocks to spontaneous vegetation (in different successional stages); it follows mostly a regular spatial pattern – much unlike in the Balkan section. Started as a vast and populous residential unit, over decades it evolved into a multi-functional municipality with extensive commercial, infrastructural and some industrial features. The expansion of a new city unit gradually merged peri-urban Pannonian settlements along loess ridge with the core of Balkan section across the Sava River. Therefore, within comparatively more uniform environmental settings, at least three units of distinctive urban landscape pattern can be recognized (acronyms as in Fig. S2.2–S2.3):

- the ***Pannonian "new urban" core*** (about 16 km^2) of largely regular fabric, without marked gradient pattern in urbanistic regime (except for the age of establishment of various blocks) (PUC);
- the ***mixed semi-urban area***, now peripheral to the "new core", representing the merged Pannonian settlements (from highly impervious centre of Zemun municipality to extensively rural ones) with its own distinctive pattern of modern development; it comprises a variety of habitat types (including: heterogeneous residential unit types, some small-scale agriculture, industry, infrastructure, and semi-natural habitats) (PSU);
- the ***peri-urban settlements***, loosely connected to the peripheral zone, urbanistically transitional from the village to town state, but still strongly oriented to agriculture; it is embedded into a vast and intensive agricultural matrix, representing the wide "rural belt"

of the Pannonian section, but not showing a circular pattern (relative to the urban core areas) (PPU).

The Banat Region is largely similar to Syrmia Region in basic environmental conditions, but with somewhat different urbanization history and landscape configuration of settlements *vs*. agricultural assets. It is currently outside the scope of this study, hence not elaborated in more detail.

(iii) Survey design and processing of geospatial framework

The **five broad urbanistic units of Belgrade "proper"**, as defined above, represent the **zonation framework** suitable for setting the broad environmental context of this study: (1) Balkan Urban Core – **BUC**, (2) Balkan Mixed Periphery – **BMP**, (3) Pannonian Urban Core – **PUC**, (4) Pannonian Semi-Urban – **PSU**), and (5) Pannonian Peri-Urban (**PPU**). They are based principally on the coarse landscape-scale features and regional physiography (Balkans vs. Pannonian), i.e., encompassing the contagious areas of roughly similar landscape types and urban management regimes. However, the exact and entirely consistent delimitation can not be realized in all situations, particularly in cases where the transition of principal urbanistic features are essentially gradual between otherwise distinct zones (e.g. part of southeastern delimitation between Balkan core and periphery).

For the spatial scope of this paper, we are showing zonation within the 18×11 km rectangle (Fig. S2.2), which includes all the locations surveyed for *Styphnolobium japonicum*. Areas and/or landscape types not covered by the study are excluded from zonation mapping: extensive agricultural area in the Syrmia region, the whole area of the Banat region, parts of the Sava River wider coastal zone; some areas remained entirely beyond this map extent (e.g. rural belt of Balkan section). Apart from two centrally positioned urban cores (old and new), all other zones are present also beyond the defined frame, hence not shown. For the consistent delimitation of the urbanistically quite uniform Balkan old core, the heterogeneous peripheral zone of Balkan section is extended to include also wider coastal area west and north of the old core, which is justified by its overall habitat composition.

All surveyed locations were primarily georeferenced in Google Earth Pro ver. 7.3.3.7786 (Google Inc. 2020), and further prepared as distribution maps in QGIS ver. 3.4 (QGIS Development Team 2018). To deal with the uneven and patchy distribution of surveyed *S. japonicum* trees, and the logistic limitations of the sampling approach, we grouped the point-sampled quantitative data (trees, their blooming status, and the presence of bees) following the rationale similar to landscape ecology studies on wild bees. We defined a primary framework of circular sectors of 250 m radius (hereafter: S250; Fig. S2.3A), manually fitted to include point-locations of all surveyed trees without overlapping. We selected the position of each sector, so that **(a)** it entirely or largely fits into one urbanistic zone, and **(b)** the closest neighbouring trees from different sectors are spaced more than 250 m, but taking care that **(c)** if observation points of neighbouring *M. sculpturalis* records are spaced less than 300 m, they would fit into a single sector, while if more than 300 m apart, they are included in different sectors. Various bees perceive the landscape composition and configuration (particularly distribution of resources and other habitat features) at different spatial scales, since their foraging ranges principally depend on size; the radius of 250 m is commonly used to define the smallest meaningful study scale, while larger bodied bees may forage at much larger distances. Due to the spatial limitations of the sampled area, we added just one coarser scale (sectors of 500 m radius; hereafter: S500; Fig. S2.3B), for testing for different scale effects (in relationship of bee vs. plant distribution). To define S500 sectors we could follow only the first criterion (included tree and bee records being within the same urbanistic zone), while merging contents from 2 or 3 S250 sectors wherever closely adjacent. As a result, all recording sites were arranged into two series of standardised circular sectors: 40 locations S250 (ca. 0.2 km^2), and 23

locations S500 (ca. 0.8 km^2), and all parameters were calculated per those spatial units (Suppl. material 3).

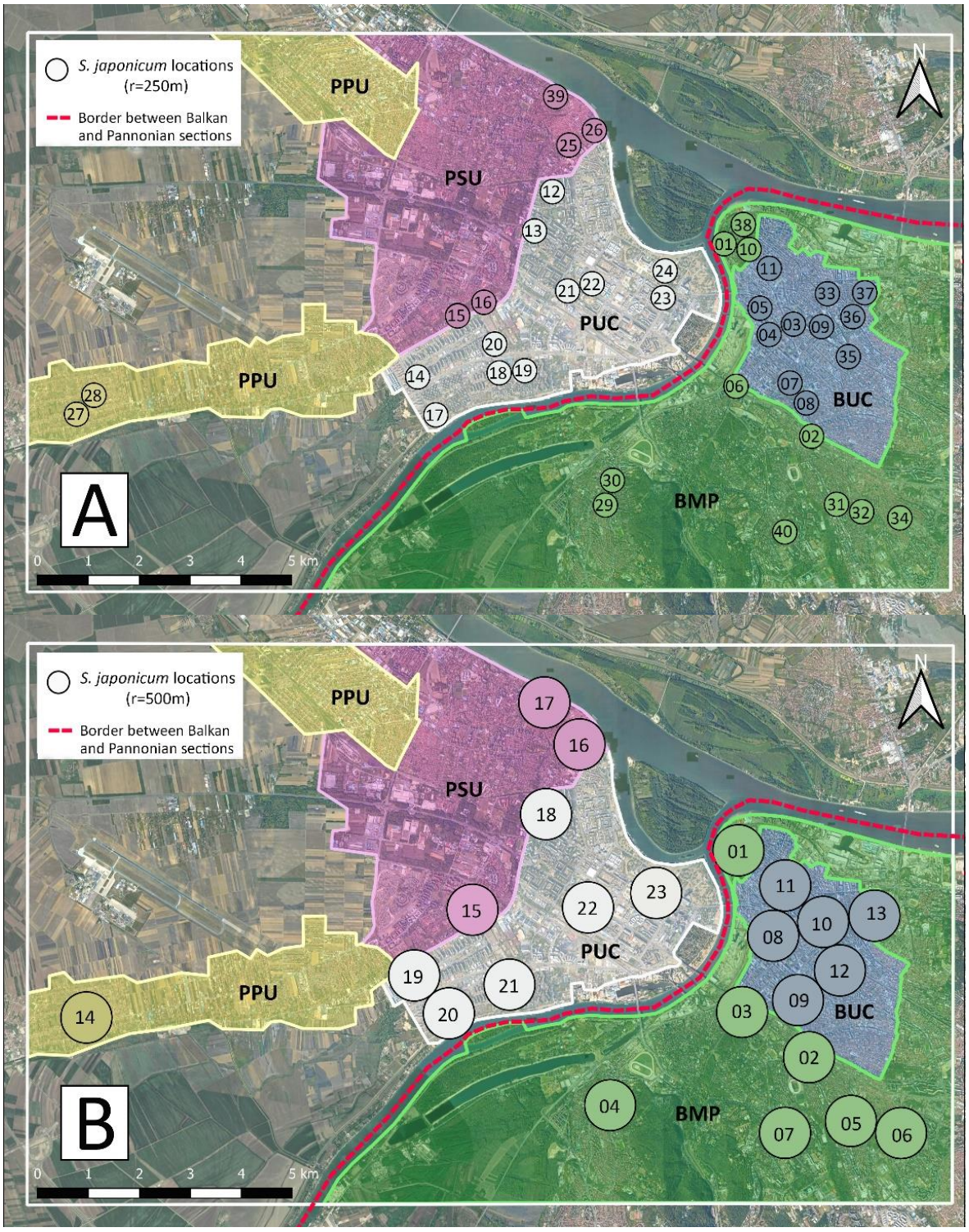

Figure S2.3. Distribution of surveyed locations for *Styphnolobium japonicum* in August 2019, defined as a series of non-overlapping circular sectors in the two-scale framework: (**A**) S250 (r=250 m, ca. 0.2 km^2), and (**B**) S500 (r=500 m, ca. 0.8 km^2), respectively, assigned to defined urbanistic zones of the study area (S250/S500): **BUC** – Balkan Urban Core: 11/6; **BMP** – Balkan Mixed Periphery: 11/7; **PUC** – Pannonian Urban Core: 11/6; **PSU** – Pannonian Semi-Urban: 5/3; **PPU** – Pannonian Peri-Urban: 2/1; (few sectors are positioned across the adjacent zones border, hence assigned to the zone where the surveyed plant micro/habitats predominantly belong). For the list of locations see in Suppl. material 3: Table S3.2.