

## Full Length Article

# Integrating public perception and expert knowledge in mapping and assessing cultural ecosystem services in peri-urban landscape<sup>☆</sup>

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## ABSTRACT

Dynamic peri-urban landscapes, positioned between urban and rural environments, play a crucial role in providing cultural ecosystem services (CES) that enhance human wellbeing. However, CES in peri-urban landscapes are often undervalued and insufficiently integrated into spatial planning due to challenges such as understanding their spatial distribution, connections with geographical variables such as land use, land cover, or protection regimes, and insufficient incorporation of local knowledge. This study addresses these issues by using expert knowledge and public perception. We conducted a mixed-methods analysis across three Slovenian cities, Ljubljana, Kranj, and Koper, mapping CES provision and importance. Experts used a scoring matrix to assess CES provision potential, and participatory mapping with local users was used to identify the perceived importance of CES. Spatial and statistical analyses revealed patterns in CES distribution and their relationship with geographical variables. The findings highlight leisure and recreation activities, aesthetic value, and social relations as the most frequently and intensively perceived CES benefits. Protected, residential, and mixed-use areas emerged as CES hotspots for users, whereas forest, contrary to previous research, was identified as a coldspot in terms of perceived importance. Leisure and recreation activities was the most spatially clustered CES, whereas more cognitive services such as sense of place and identity were more dispersed. We also found that perceived CES benefits are closely linked to the proximity to people's homes and perceived landscape accessibility. This mixed-methods approach effectively captured the diverse values and importance patterns of CES, revealing discrepancies between provision potential and perceived importance. The results emphasize the importance of evidence-based spatial planning that integrates CES to improve human wellbeing and address environmental challenges in peri-urban landscapes.

## 1. Introduction

Peri-urban landscapes lie in the dynamic interface between urban and rural areas. These often overlooked landscapes, which are characterized by their proximity to urban centers while retaining elements of both urban and rural environments, form a mix of land cover and land use. This patchwork includes sprawling settlements, fields, industrial zones, and biodiversity hotspots such as wetlands, rivers, and forests (Komossa et al., 2020; La Rosa et al., 2014). Peri-urban landscapes face threats such as land degradation, habitat fragmentation, soil sealing, and biodiversity loss (Barau, 2017; Bîrsănuș et al., 2019; Frondoni et al., 2011). Moreover, urban expansion in these areas often stems from unregulated, short-sighted land-use decisions driven by speculation rather than long-term strategic planning ((Dadashpoor & Ahani, 2019;

Hudalah & Firman, 2012). Due to the rapid pace of urbanization, coupled with global climate change and various environmental and socioeconomic challenges, researchers and urban planners have begun emphasizing the need for holistic and interdisciplinary approaches in managing peri-urban landscapes (Tan et al., 2024). These approaches integrate concepts such as ecosystem services (ES), resilience, biodiversity, nature-based solutions, and citizen participation into spatial planning and governance, aiming to mitigate environmental degradation, preserve biodiversity, and enhance human wellbeing (Secretariat, 2011; European Commission, 2019, 2020; Hansen et al., 2015; Hoek, 2022).

Amid rapid urbanization, ES are considered at risk due to land conversion as a primary cause (Zank et al., 2016), making peri-urban landscapes crucial for urban and suburban residents, particularly

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because of the intangible benefits provided by their ecosystems (Filyushkina et al., 2022). These benefits, referred to as cultural ecosystem services (CES), are closely linked to the quality of life and wellbeing of local communities (Chan et al., 2012; Cheng et al., 2021). Although research on CES is growing, it remains less developed compared to studies of regulating and provisioning ES (Rendon et al., 2019). In addition, compared to urban spaces, forest, or wetlands, peri-urban areas have received limited attention in studies, particularly regarding public attitudes toward these open spaces (Chen et al., 2019). This gap is especially relevant in light of post-pandemic priorities to preserve peri-urban green space for CES while accommodating increasing housing needs (Beckmann-Wübbelt et al., 2021).

Given the continuously changing character of peri-urban landscapes (Shaw et al., 2020; Žlender, 2021), the provision of their CES is challenged, necessitating a clearer understanding of the supply, demand, and assessment of CES in these types of landscapes. Unlike other ecosystem services, CES are defined by their relational character, meaning that people's perception of CES defines their importance. Assessing who values CES and to what extent poses challenges, leading to difficulties in incorporating CES into spatial management schemes (Milcu et al., 2013). Nonetheless, it is necessary to evaluate CES because they can significantly motivate land ownership, use, management, and protection for various purposes (Dou et al., 2021; Plieninger et al., 2015).

Previous studies show that the value and use of CES vary across regions and cultures, with people's perceptions and preferences being shaped by factors such as user type (Tajima et al., 2023), residency duration (Dou et al., 2021), education, and gender (Martín-López et al., 2012). Landscape features, land use, and land cover have been widely studied, but their influence on CES interactions such as trade-offs, synergies, or supply and demand remains debated. For example, Fagerholm et al. (2016) found that grasslands and agroforestry areas were linked to recreation, aesthetics, and social values, whereas urban areas supported appreciation of culture and history. Dou et al. (2021) emphasized the importance of cultivated lands for education and social ties, and Oteros-Rozas et al. (2018) and Ridding et al. (2018) identified wood pastures and grasslands as rich in cultural and spiritual values. However, Plieninger et al. (2013) found no strong link between grasslands and perceived CES. In contrast, Cusens et al. (2022) argued that accessibility, not land cover, better explains CES distribution, a view supported by several studies (e.g., Ala-Hulkko et al., 2016; Dou et al., 2021; Fagerholm et al., 2019; Kirby et al., 2023; Ridding et al., 2018). Management regimes also influence CES provision, with protected areas often supporting a wider range of services (Muñoz et al., 2020; Ridding et al., 2018). Spatial patterns further vary by CES category: heritage values tend to cluster, whereas aesthetic values are more dispersed (Fagerholm et al., 2019).

These findings reveal several key gaps, which this study addresses. First, there is inconsistency in how CES preferences relate to land use and cover types, management regimes, and sociodemographic characteristics. Second, several CES such as spiritual and educational services remain underrepresented in studies and thus weakly integrated into spatial assessments and plans (Bachi et al., 2021; Mocior & Kruse, 2016). Third, methodological diversity and the inconsistency and limitations of individual methods in assessing CES, particularly in terms of data collection methods and mapping approaches, may shape reported outcomes (Havinga et al., 2020; Muñoz et al., 2020), which complicates cross-study comparisons.

With regard to methodological approaches, researchers have developed a variety of methods and tools for mapping and evaluating CES across spatial scales and social and ecological contexts. Among these, participatory GIS-based assessments (Brown & Brabyn, 2012; Bryan et al., 2010; Solecka et al., 2022) and preference scoring assessment (e.g., Burkhard et al., 2009; Karrasch et al., 2019; Kopperoinen et al., 2014; Müller et al., 2020) are the most widely used. Creating viewsheds has been also presented as a sound methodology, especially for quantifying

aesthetic appeal (Ridding et al., 2018), and various crowdsourcing approaches such as social media analysis have been gaining popularity (see Schirpke et al., 2023, for a review), although doubts regarding the sociodemographic representativeness of samples from such sources have been raised (Havinga et al., 2020). However, despite the growing recognition of CES, challenges remain in terms of uneven assessment of ecosystem services and their supply, demand, and use (Boerema et al., 2017; Burkhard & Maes, 2017; Crouzat et al., 2022). Most studies have primarily focused on assessing potential supply, with less frequent evaluation of importance, actual use, or demand, as noted by Crouzat et al. (2022).

CES are challenging to quantify using remote sensing or land cover data because they are based on human perceptions, values, and experiences that are not directly observable through biophysical indicators. As a result, participatory mapping has become the most common approach to producing spatially explicit outputs in CES assessments (Raymond et al., 2014). This method facilitates the integration of CES into landscape planning and decision-making, which often prioritize explicit quantification and mapping (Casado-Arzuaga et al., 2014). Mapping CES helps identify spatial distribution patterns between supply and demand, thus informing spatial planning and policy. Ecosystem services mapping has also been strongly encouraged by policies such as those adopted by the European Union (e.g., European Environment Agency, 2014; European Commission, 2013, 2020). Participatory mapping has become an important tool in CES research, effectively engaging stakeholders in identifying and mapping CES values while promoting transparency, inclusiveness, and environmental justice in CES management (Xia et al., 2023). Prior studies have shown that mapping preferred locations in the landscape allows for the identification of CES hotspots and the relative influence of factors such as land use (Brown & Brabyn, 2012), accessibility (Crouzat et al., 2022), and management regimes (Muñoz et al., 2019) on perceived value. However, despite its increasing application, the use of participatory mapping remains geographically uneven, with limited representation in peri-urban contexts and certain global regions (Brown & Fagerholm, 2015; Kirby et al., 2023). In addition, land cover data have been used to approximate CES supply, but they fail to reflect the relational and experiential dimensions of CES, which depend on people's actual use, values, and perceptions (Crouzat et al., 2022). This gap underscores the need for spatially explicit, perception-based CES assessments across underrepresented landscapes.

Thus, this study identifies two further gaps: the limited application of participatory mapping in peri-urban areas and the insufficient integration of locally grounded CES perceptions with spatial landscape features. In an attempt to address these knowledge gaps, the main objectives of this study are: 1) to determine the value of various CES and identify their spatial distribution patterns as perceived by users of peri-urban landscapes; 2) to better understand the relationship between the provision potential and demand for CES; and 3) to assess the methodological approach of combining various data collection methods for mapping CES. To achieve these objectives, the following research questions are addressed:

Q1: What CES are perceived and valued in peri-urban landscapes? Do they vary between sites?

Q2: How are these CES spatially distributed within peri-urban landscapes in terms of type, number, and value? Do they vary between sites?

Q3: What is the relationship, if any, between the distribution of CES and several geographical variables (i.e., land use, land cover, and protection regimes) in peri-urban landscapes?

Q4: Are there discrepancies between the potential provision and perceived importance of CES and geographical variables in peri-urban landscapes?

Q5: What are the implications of the findings for managing CES in peri-urban landscapes?

We explore the distribution of CES in peri-urban landscapes of the Slovenian cities of Ljubljana, Kranj, and Koper. We evaluate the

association between the provision potential and perceived importance of CES by integrating stakeholder perspectives. Provision potential is understood as the *perceived* ability of an area to provide ecosystem services based on its inherent landscape qualities, rather than actual use or theoretical maximum yield (Kopperoinen et al., 2014). Expert opinions help assess the CES provision potential, and local users participate in mapping activities to report their importance and usage. We analyze the spatial distribution of CES through frequency, intensity and diversity indices. The results obtained show how geographical variables influence CES perception. The integration of spatially explicit mapping into planning methods is also discussed. This study presented here is part of a KESPlan project (<https://kesplan.uirs.si/en-us/>), which aimed at establishing a framework for integrating CES values into landscape planning and policy decisions in peri-urban landscapes.

## 2. Methods

### 2.1. Study areas

In Slovenia, the significance of recognizing CES in spatial planning and policy is underscored in various strategic documents, although mostly indirectly. The importance of CES is emphasized at national and regional levels in various documents such as the Slovenian Development Strategy 2030 (Sooš et al., 2017) or the Spatial Development Strategy of Slovenia 2050 (Bartol et al., 2024), especially in relation to green infrastructure, often referring to European guidelines (Hribar et al., 2021). At the local level, spatial planning is governed by municipal spatial plans, which ought to be created and periodically updated by each municipality; however, many municipalities still lack a current plan. Peri-urban landscapes are rarely addressed in these plans, and references to CES are even rarer (Žlender, 2021). A frequent challenge arises from insufficient data and expert knowledge required to envision long-term sustainable development. This study focuses on peri-urban landscapes of three Slovenian cities: Ljubljana, Kranj, and Koper (see Fig. 1).

Ljubljana, Slovenia's capital and largest city with a population of over 288,000, has a star-shaped layout with green wedges linking the center to its surroundings (MOL, 2010). It is bordered by the Ljubljana Marsh to the south, the flat Sava River area to the north, the Polhov Gradec Hills to the west, and the Sava Hills to the east. The city experienced dispersed development and adverse effects of urbanization in the 1990s, which have been somewhat mitigated by a comprehensive spatial plan (Šašek Divjak, 2008; Svirčić Gotovac et al., 2021). The Ljubljana Municipal Spatial Plan (MOL, 2010), furthermore defined as the Plan, identifies past issues related to sprawling development, particularly the loss of local and national identity due to new developments that often disregard natural dynamics and traditional settlement characteristics. The Plan defines peri-urban landscapes in terms of recreational and seminatural areas surrounding the city. It designates several peri-urban areas, including isolated hills, parks, green corridors, and bodies of water, highlighting their crucial role in recreation and shaping identity. In the context of green space planning, the Plan explicitly requires that ecosystem services be identified and considered. Its priorities include preserving agriculture and open space, promoting recreation and tourism, limiting urbanization, and ensuring recreational uses are compatible and publicly accessible.

Kranj and Koper are medium-sized cities with historic centers that have experienced significant growth since the Second World War. Kranj has a population of nearly 38,000 and Koper more than 26,000 (SiSTAT, 2024). Although they are smaller than Ljubljana, they serve as important economic, cultural, and social hubs in their regions. Both cities face housing and infrastructure pressures that affect agricultural land (Nilsson et al., 2013; Spyra et al., 2021). Kranj's terrain is varied, with the Škofja Loka Hills to the west and a blend of agricultural and forested areas in other directions. Suburban development extends mainly in the north and east of the town, along the rivers. Its Municipal Spatial Plan

(MOK, 2014) characterizes the peri-urban landscape of the Kranj–Sora Plain and the Škofja Loka Hills as multifunctional, combining urban and rural uses. It emphasizes multifunctional development while preserving the cultural landscape and the distribution of smaller settlements. The Plan highlights recreational functions in the Sora Plain and the importance of maintaining natural and cultural structures, linking green areas to sports, recreation, and tourism.

Located on the Adriatic coast, Koper is surrounded by the sea, hills, and karst terrain, which shape its landscape identity and influence spatial development (MOK, 2022; Pintar et al., 2013). The coastal area's attractiveness and the port's presence exert strong urban growth pressures. Balancing this expansion with the protection of agricultural and leisure spaces is challenging (Pintar et al., 2013). Suburbanization is evident on the urban fringe, whereas the surrounding rural countryside faces a population decline and agricultural abandonment, leading to forest overgrowth. The PLUREL project (Pintar et al., 2013) identified key land use issues in Koper, including land pressure from housing and industry and potential degradation of high-value natural areas. The latest draft of the Municipal Spatial Plan (MOK, 2022) proposes development in urban, peri-urban, and rural zones, aiming to protect agricultural and leisure areas while reinforcing the municipality's cultural landscape and protected heritage and nature sites.

All three cities have been the subject of various projects addressing peri-urban issues (Piorr et al., 2011; RENATUR, 2023; Žlender, 2021). Peri-urban boundaries were determined using a predefined methodology based on the combination of population density, imperviousness, land use and the conceptualization of peri-urban areas in municipal spatial plan (for further details, see Žlender & Brišnik, 2023; Žlender, 2021). The characteristics of the three study areas in terms of geographical variables are illustrated in Fig. 1. The peri-urban landscape of Ljubljana encompasses almost the entire Ljubljana Marsh, bordered by hills that provide a barrier for rapid city access. Kranj's peri-urban landscape includes much of the Kranj–Sora Plain and settlements around Lake Trboje, gravitating toward Preddvor. In Koper, the peri-urban landscape comprises the suburban plain and the initial ridges of the surrounding hills.

### 2.2. Study design

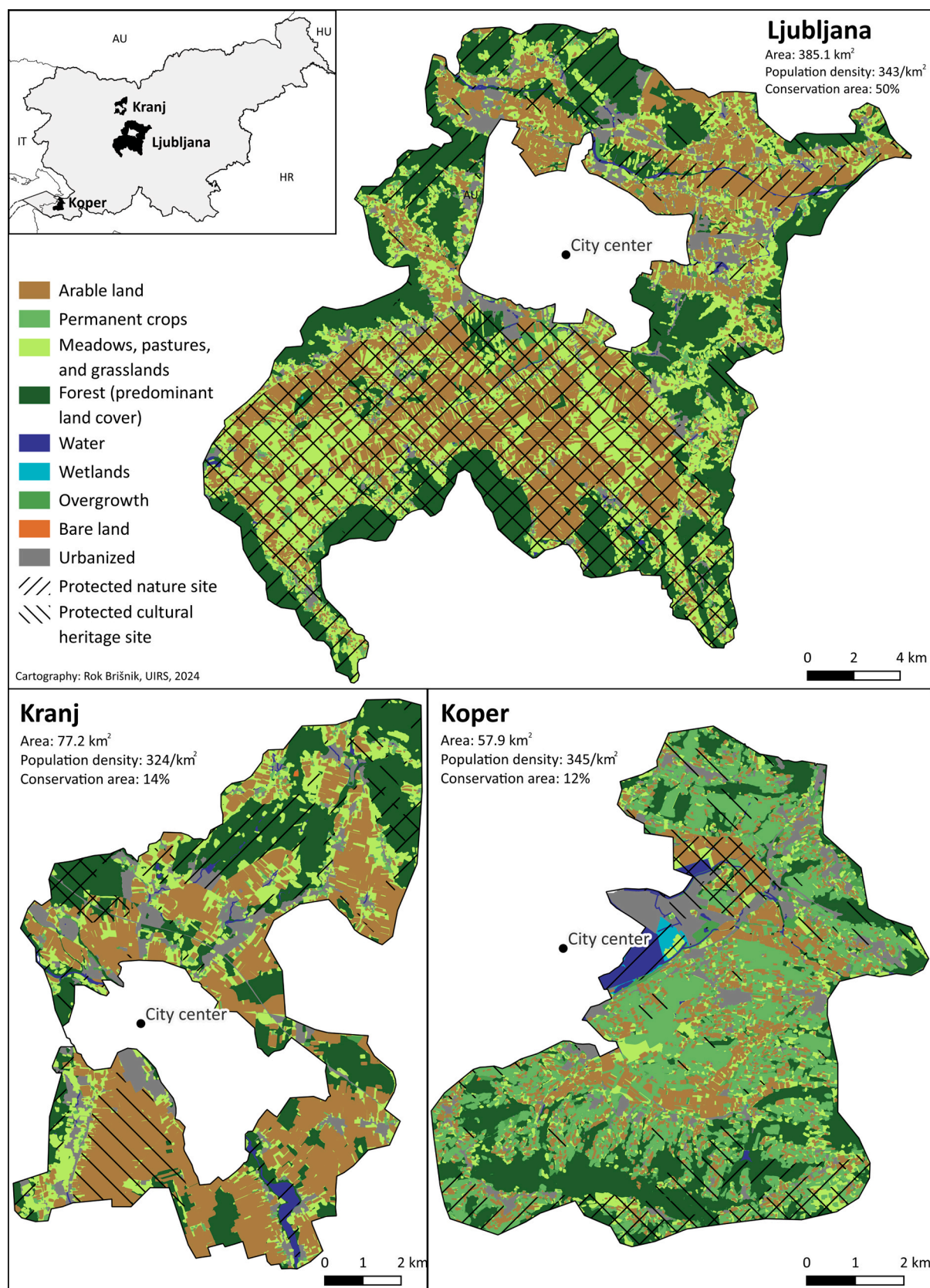
The study follows a mixed-methods approach, illustrated in Fig. 2. Following a literature review and the selection of case study areas, expert input was gathered using a matrix model not related to the actual case study areas, and user input was collected through a public participatory GIS (PPGIS) questionnaire. Data obtained using both methods were then statistically and spatially analyzed to address the research questions.

### 2.3. Selection of CES and geographical variables

To compare the provision potential and perceived importance of CES in peri-urban landscapes, we defined lists of CES and geographical variables for both expert and user inputs. These lists were developed with the characteristics of peri-urban landscapes in mind, taking into account currently available CES classification systems (e.g., Haines-Young & Potschin, 2018; MEA, 2005; Sukhdev et al., 2010). For this study, we carefully selected nine distinctive categories of CES to ensure comprehensive coverage relevant to peri-urban contexts, considering the unique cultural dynamics at the interface between urban and rural settings (Appendix, Table A1). Furthermore, we follow Brown and Hausner's (2017) distinction between services, which are the benefits people gain from ecosystems, and values, which indicate the importance of these benefits.

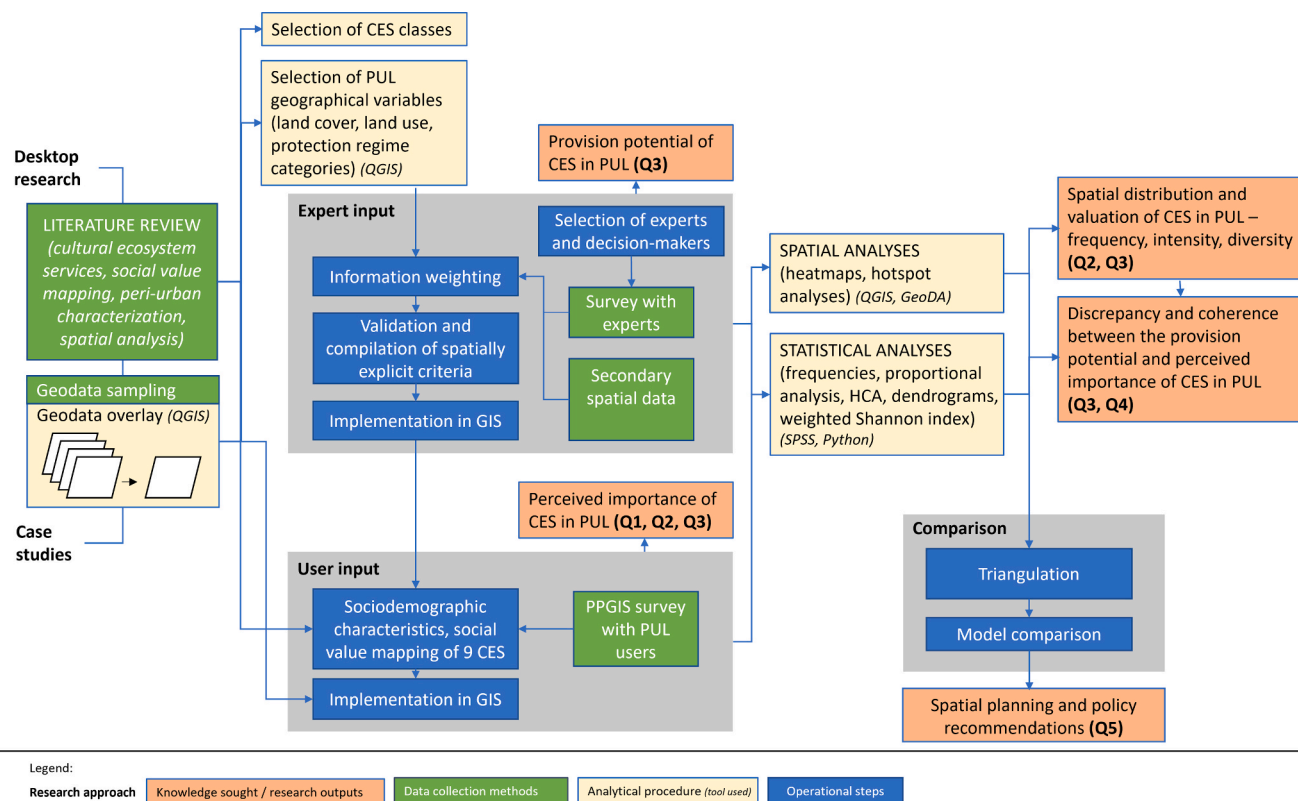
To map CES provision potential, we selected geographical variables in relation to land use, land cover, and nature and cultural heritage protection regime characteristic of peri-urban landscapes. We subdivided urban land use into various subcategories. The list of categories





**Fig. 1.** Study areas with geographical variables (based on Ministry of Agriculture, Forestry, and Food, 2023; Ministry of Culture, 2023; Slovenian Environment Agency, 2023).





**Fig. 2.** Study design (PUL = peri-urban landscape, CES = cultural ecosystem services, Q = question, PPGIS = public participatory geographic information system, HCA = hierarchical cluster analysis).

was tested and refined based on expert feedback, resulting in twenty classes representing CES provision potential. The complete list with descriptions can be found in Table A2 in the Appendix.

## 2.4. Data collection methods

### 2.4.1. Expert input: An expert-based matrix model

The matrix model developed by Burkhard et al. (2009) was used as a basis for expert scoring. This model offers a robust framework for spatially assessing the provision potential of CES by linking land use, land cover, and protection regimes with expert-provided values. In addition, the scoring scale was adopted from Kopperoinen et al. (2014): in order to establish the spatial conditions for CES provision potential, the contribution of each land use, land cover, or protection regime category was measured on a scale that included the following values: very favorable, favorable, slightly favorable, no connection, slightly harmful, harmful, very harmful. The matrix also included confidence scoring on a three-level scale, as suggested by Campagne and Roche (2018). Slovenian experts with knowledge of peri-urban landscapes in Slovenia were contacted using a snowball sampling approach, while aiming to maintain a balance in terms of expertise (e.g., spatial, urban and landscape planners, geographers, landscape architects) and professional roles (e.g., practice, research, decision-making). They were informed about the study's objectives and asked for their consent to receive an online questionnaire. This questionnaire included a CES value assessment matrix and five additional questions related to their current occupation, education, field of expertise, familiarity with the ES concept (including when they became familiar with it), and its use in their work. It took approximately one hour to complete the matrix.

### 2.4.2. User input: A PPGIS questionnaire for peri-urban landscape users

To ground expert assessments in local realities and ensure that the model's outputs reflect the actual experiences of those interacting with

peri-urban landscapes, we deemed it necessary to gather input from landscape users. We designed a semi-open-ended questionnaire incorporating various types of questions: single- or multiple-choice, four- or five-point scales, open-ended questions, and geolocation queries. Each questionnaire was accompanied by a tailored A3-format map specific to one of the three study areas, indicating the main land uses, settlement names, topography, and the delineation of the study area. It comprised five parts, but this article focuses on the geolocation questions, for which respondents marked locations on the map while completing the statement "In this area, there are places that are important for me because ...". They rated the importance of these places on a four-point scale (not important, slightly important, moderately important, and very important). Importance was linked to nine distinct CES, presented in an easily understandable manner (for details, see Figure A1 and Table A1 in the Appendix, column "Description for users"). Respondents could indicate as many locations as they wished using points, shapes, or lines. They were not required to mark those CES on the map that were not important to them.

We pilot tested the questionnaire on a small group, making adjustments based on their feedback. Completing the questionnaire took about thirty minutes. The survey ran for three months, from September to December 2023. Data were collected in two ways. First, along with the authors of this article, two trained master's students collected questionnaires on-site at preselected locations. They set up temporary stands in high-traffic areas, such as at grocery stores, post offices, popular recreation spots such as hill tops, lake shores, cycling routes, and local events, engaging passers-by to participate. We aimed for evenly distributed collection points across the study area and in different types of spaces. Participants had to be at least fifteen years old and knowledgeable about the pilot area. To encourage participation, a promotional reward, such as sunscreen, a water bottle, a notebook, a sports towel, or a similar item, was offered, yielding 579 completed questionnaires. Second, we mailed questionnaires to the committees of local urban and

rural communities within the test area. These committees, composed of elected members from among local residents, serve as advisory bodies to the municipal council and were targeted because they are expected to be well-acquainted with the local area and capable of providing meaningful responses to questions concerning it. After one reminder was sent, this method resulted in 124 completed questionnaires, representing 20% of the total sent. The completed questionnaires were subsequently entered onto a survey platform 1KA (<https://1ka.arnes.si/>) for further analysis.

## 2.5. Data preparation

We digitized the geographical locations of the CES, collected during the mapping exercise in the user survey into polygons using QGIS. Four percent of the locations mapped extended outside the study areas and were excluded from further analyses. The individual attributes of respondents were documented in SPSS 29. Data from both software programs were linked with an identification number assigned to each respondent. In addition, we created a 100 m vector grid in QGIS for each study area, accompanied by an attribute table. This grid size proved to be the best fit for the landscape scale of our analysis, as confirmed by earlier testing (for details, see Žlender & Brišnik, 2023). On the grid, we tabulated the proportion of each geographical variable and experts' scores to provide individual CES and link the survey data to each cell. This table served as the basis for multiple analyses, as described in the following sections.

## 2.6. Data analysis

To address Q1, we analyzed data from the user input. We employed descriptive statistics, non-parametric tests, and cross-tabulation with chi-squared tests to identify significant associations between the identification and values of CES among respondents from various sites.

To address Q2, we used data from the user input to examine the spatial distribution of CES, as marked on the maps by users, and geographical variables through frequency, diversity and intensity indices. **Frequency** quantifies the total number of CES and is determined using overlay analysis of all the CES mapped within each study area, with results presented as heatmaps. **Intensity** (Bryan et al., 2010) assesses the strength of CES importance. We calculated the intensity for each CES separately by first tabulating all the CES polygons into grid cells in QGIS. Each CES was then weighted based on its assigned importance (2 = slightly important; 3 = moderately important; 4 = very important), and these values were summed for each grid cell. The resulting values were imported into GeoDA (Center for Spatial Data Science, 2021) to create maps of intensity hotspots, identifying high and low value clusters using the Local G\* analysis tool (also known as the Getis-Ord G\* statistic; Getis & Ord, 1992). Local G\* identifies clusters of significant spatial concentration, indicating “hotspots” (areas with high importance values surrounded by other high values), and spatial dispersion, indicating “coldspots” (areas with low values surrounded by other low values). **Diversity** was calculated for each cell using a weighted form of the Shannon diversity index (Shannon, 1948):

$$H(\text{cell}) := \sum_{x \in \text{CES}} n(x) \log \frac{n(x)}{n}$$

where  $x$  represents all CES,  $n(x)$  is the number of polygons intersecting the cell marked with CES  $x$ , and  $n$  is the total number of polygons intersecting the cell. A higher adjusted Shannon index value indicates greater diversity and evenness in CES within a specific area. Maps of diversity hotspots were also created using Local G\* in GeoDA.

To address Q3, we conducted separate analyses of the data derived from the expert and user inputs.

The expert input was calculated for each CES by computing the weighted mean of expert scores  $P_k$ , with weights assigned based on their confidence levels  $C_k$ :

$$P = \sum_k C_k P_k$$

These values were spatially represented as attribute values on a 100 m vector grid for each study area. A spatial aggregation analysis was performed using QGIS, normalizing cell values on a scale from  $-3$  to  $3$  to treat each CES equally when aggregating into joint layers for CES provision potential. Detailed information about this analysis can be found in Žlender (2024).

For the user input analysis, we applied proportional analysis as outlined by Brown et al. (2015) to assess the relevance of geographical variables for each CES. Specifically, we calculated the proportion of each geographical variable within the shapes drawn by each user for each CES. We then computed the mean ( $\bar{X}$ ) and the standard deviation ( $\sigma$ ) of these proportions across all users within a given study area. In addition, we calculated the overall proportion ( $\mu$ ) of each geographical variable within the entire study area. To determine whether a certain geographical variable was more prevalent within the user-drawn polygons compared to the entire study area, we calculated the z-score:

$$Z = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}}$$

Z-scores greater than  $+1.96$  (two-tailed test,  $\alpha = 0.05$ ) indicate a significantly higher frequency of each CES within a given geographical variable class, and z-scores lower than  $-1.96$  indicate a significantly lower frequency. We inspected statistically significant deviations for each pair by study area. Moreover, we applied a hierarchical clustering (based on the Euclidean distance, using the UPGMA algorithm) on the matrices of the z-scores computed, to investigate the clustering of CES or geographical variables across the three study areas.

Q4: To assess the similarities and discrepancies between the potential provision (as defined by experts) and perceived importance (as defined by users) of CES and geographical variables in peri-urban landscapes, we compared the results of expert scores with the proportional analysis. To allow comparison, we created a spreadsheet with users' values of all CES–geographical variable pairs across the three case studies, and for the experts to facilitate comparison, flagging significantly positive or negative values as extreme averages of  $< 2.14$  and  $> -2.14$  for experts, and z-values  $> 1.96$  and  $z < -1.96$  for users.

Q5: The results of all the methods implemented were triangulated to provide spatial planning and policy recommendations.

## 3. Results

### 3.1. Study response and sample characteristics

Regarding the expert input, twenty-five experts completed the matrix. They had diverse educational backgrounds and areas of expertise, such as landscape architecture, urban planning, and nature conservation. Their affiliations spanned several, sometimes overlapping sectors: research ( $n = 19$ ), spatial planning practice ( $n = 9$ ), higher education ( $n = 6$ ), decision-making roles involving legislation, regulation or public financing at national to municipal levels ( $n = 3$ ), and implementation or land management roles (e.g., managing protected areas or working in regional agencies;  $n = 4$ ). Thirteen experts became familiar with the concept of ecosystem services between 2011 and 2019, and eighteen had already applied the concept in their professional work.

The user questionnaire was completed partially or fully by 703 respondents; 303 in Ljubljana, 246 in Kranj, and 154 in Koper (see Table 1). In all three study areas, Census data show that the populations are nearly gender-balanced (Ljubljana: 50.25% male, 49.75% female; Kranj: 50.38% male, 49.62% female; Koper: 50.25% male, 49.78% female; Statistical Office of the Republic of Slovenia, 2023), whereas the sample used in the survey included more women (54%) than men (46%). The largest age group in all study areas is thirty to sixty-four years old

**Table 1**

Participation statistics and the sample's sociodemographic characteristics by case study area.

| Characteristic                   | Total     | Ljubljana | Kranj     | Koper     |
|----------------------------------|-----------|-----------|-----------|-----------|
| <b>Sex (%)</b>                   | (n = 698) | (n = 301) | (n = 243) | (n = 154) |
| Male                             | 46        | 47        | 47        | 44        |
| Female                           | 54        | 53        | 53        | 56        |
| <b>Age group (%)</b>             | (n = 692) | (n = 299) | (n = 243) | (n = 150) |
| 15–29                            | 29        | 28        | 33        | 23        |
| 30–64                            | 52        | 59        | 46        | 50        |
| 65+                              | 19        | 13        | 21        | 27        |
| <b>Completed education (%)</b>   | (n = 702) | (n = 302) | (n = 246) | (n = 154) |
| Primary school                   | 15        | 9         | 21        | 18        |
| Vocational training              | 21        | 14        | 27        | 22        |
| High school                      | 18        | 21        | 16        | 16        |
| Associate degree                 | 12        | 14        | 10        | 14        |
| Bachelor's degree                | 22        | 25        | 19        | 20        |
| Graduate degree                  | 12        | 17        | 7         | 10        |
| <b>Employment status (%)</b>     | (n = 702) | (n = 302) | (n = 246) | (n = 154) |
| Employed                         | 46        | 52        | 40        | 45        |
| Self-employed                    | 6         | 6         | 5         | 7         |
| Unemployed                       | 4         | 4         | 4         | 5         |
| Retired                          | 22        | 17        | 25        | 26        |
| Student                          | 21        | 21        | 25        | 16        |
| Other                            | 1         | 0         | 1         | 1         |
| <b>Residency in the area (%)</b> | (n = 702) | (n = 303) | (n = 245) | (n = 154) |
| Yes                              | 51        | 51        | 43        | 65        |
| No                               | 49        | 49        | 57        | 35        |

(Ljubljana: 58.04%, Kranj: 56.20%, Koper: 58.72%), and our sample was similar in this regard, with the only major difference observed in Kranj (46%). The smallest age group in all study areas is fifteen to twenty-nine (Ljubljana: 19.41%, Kranj: 19.50%, Koper: 16.51), but in our sample it was the group sixty-five and older. Statistics are not kept for visitor parameters. Overall, the sample shows a relatively balanced distribution across sociodemographic characteristics.

### 3.2. CES values in peri-urban landscapes

Survey respondents mapped 3,046 locations important for individual CES, 4% of which fell outside the study area, which reduced their number to 2,929. A minimum of one and maximum of twelve locations marked were recorded per individual, with an average of 1.38 locations (1.52 for Ljubljana, 1.38 for Kranj, and 1.09 for Koper). For detailed descriptive statistics regarding locations marked across the three study areas, see Table A3 in the Appendix.

In the survey scoring of CES importance, a total of 696 respondents were included, comprising those who rated at least one CES category. Only four respondents (out of 696) indicated that no CES were at least somewhat important. In contrast, 92.1% of respondents rated one or more CES categories as very important. Fig. 3 presents details on the frequencies of individual CES ratings. Social relations was the CES most frequently rated as very important, by 71% of respondents, followed by leisure and recreation activities (61%) and aesthetic value (58%). In contrast, spiritual and religious services were rated as very important by only 18% of respondents.

Regarding Q1, the results of the Kruskal–Wallis test (see Table A4 in the Appendix) showed significant differences in six CES categories across the three study areas in how respondents assigned values to individual CES categories. Post-hoc pairwise comparisons revealed that Koper had consistently higher mean ranks, especially for *sense of place and identity*, *educational resource*, *research resource*, and *cultural significance*. Significant differences were also observed between Ljubljana and Kranj in *spiritual and religious services* and *sense of place and identity*. However, we did not find significant differences in the values assigned to *leisure and recreation activities*, *aesthetic value*, and *social relations*. These CES were relatively important for respondents from all study areas. Furthermore, for respondents from Koper, *sense of place and identity*, *research*, and *educational resource* were significantly more important

than for those from Kranj. In contrast, respondents from Ljubljana rated all CES, except *leisure and recreation activities*, *aesthetic value*, and *social relations*, as significantly less important compared to those from Koper. They assessed *cultural significance*, *sense of place and identity*, *educational resource*, and *spiritual and religious services* as significantly less important than those from Kranj (see Table A4 in the Appendix).

### 3.3. Spatial distribution of CES in peri-urban landscape

#### 3.3.1. Provision potential

Maps based on the experts' matrix scoring illustrate the potential for CES provision (see Fig. 8). Semi-natural environments, particularly forest, show the highest potential for CES across the three study areas. In Koper, these areas are mainly along ridged hills and the rim of the Karst Plateau, whereas in Kranj they are found around the town and the Brdo Castle estate. Ljubljana's key areas are located at marshland edges and in hilly wedges to the east and west, and on a few isolated hills to the north. In contrast, heavily modified zones such as transportation and industrial areas exhibit low CES capacity and hinder connections to high-capacity areas, particularly in Kranj and Koper.

#### 3.3.2. Perceived importance

We analyzed the spatial distribution of CES in the mapping provided by survey respondents, focusing on CES frequency, intensity, and diversity indices. The **frequency** analysis indicated that only a few areas were deemed unimportant for any CES (see Fig. 4). In Ljubljana and Kranj, respondents were primarily attracted to hills, lakes, farmland, and parks. In Koper, apart from the Škocjan Lagoon Nature Reserve, the village cores were the main points of interest. The lowest CES frequency was found in areas with high concentrations of transport infrastructure and industrial zones, such as the Port of Koper.

The analysis of CES **intensity** (Fig. 5) highlights key differences and similarities across the study areas, reflecting the distinct landscape characteristics and land-use patterns in each of them. In Ljubljana and Kranj, high-intensity areas were concentrated around natural features such as hilltops, nature reserves, nature parks, and lakes. These are landscapes that offer accessible green space and diverse CES opportunities. In contrast, Koper's main hotspots included the Škocjan Lagoon Nature Reserve and village cores. These reflect the coastal and cultural-historical character of the area, where proximity to water and preserved rural settings shape the CES supply. Common low-intensity areas across all cases, such as industrial zones and major thoroughfares, correspond to landscapes with limited ecological or recreational value and poor accessibility.

In Ljubljana, *leisure and recreation activities* hotspots were concentrated around peri-urban hilltops and Lake Podpeč, a popular leisure spot, and other CES spread over larger areas, such as Ljubljana Marsh Nature Park. The area features the Ljubljana Marsh pile dwellings (a UNESCO site), the Ig Gorge, nature reserves, and several thematic trails. Coldspots for all CES were mainly located in the foothills and foothill settlements surrounding Ljubljana, in the outermost parts of the peri-urban landscape, and in the eastern part of Ljubljana, which is heavily urbanized and broken up by road and rail infrastructure. The south-western region, characterized by farmland, wetlands, and meadows, was a significant coldspot for *social relations*.

In Kranj, the Brdo Castle estate and nearby lake areas were key hotspots for most CES, except *educational resource*. The Kranj–Sora Plain, a protected cultural landscape in which agriculture, forestry, and leisure activities are intertwined, was a significant hotspot for *leisure and recreation activities*, *sense of place and identity*, *research resource*, *educational resource*, *social relations*, and *source of inspiration*. Meanwhile, its surrounding heritage villages were significant hotspots for *spiritual and religious services*, *social relations*, *research resource*, *sense of place and identity*, and *cultural significance*. Coldspots appeared in areas with limited access, such as those broken up by highways, railways, and industrial zones.



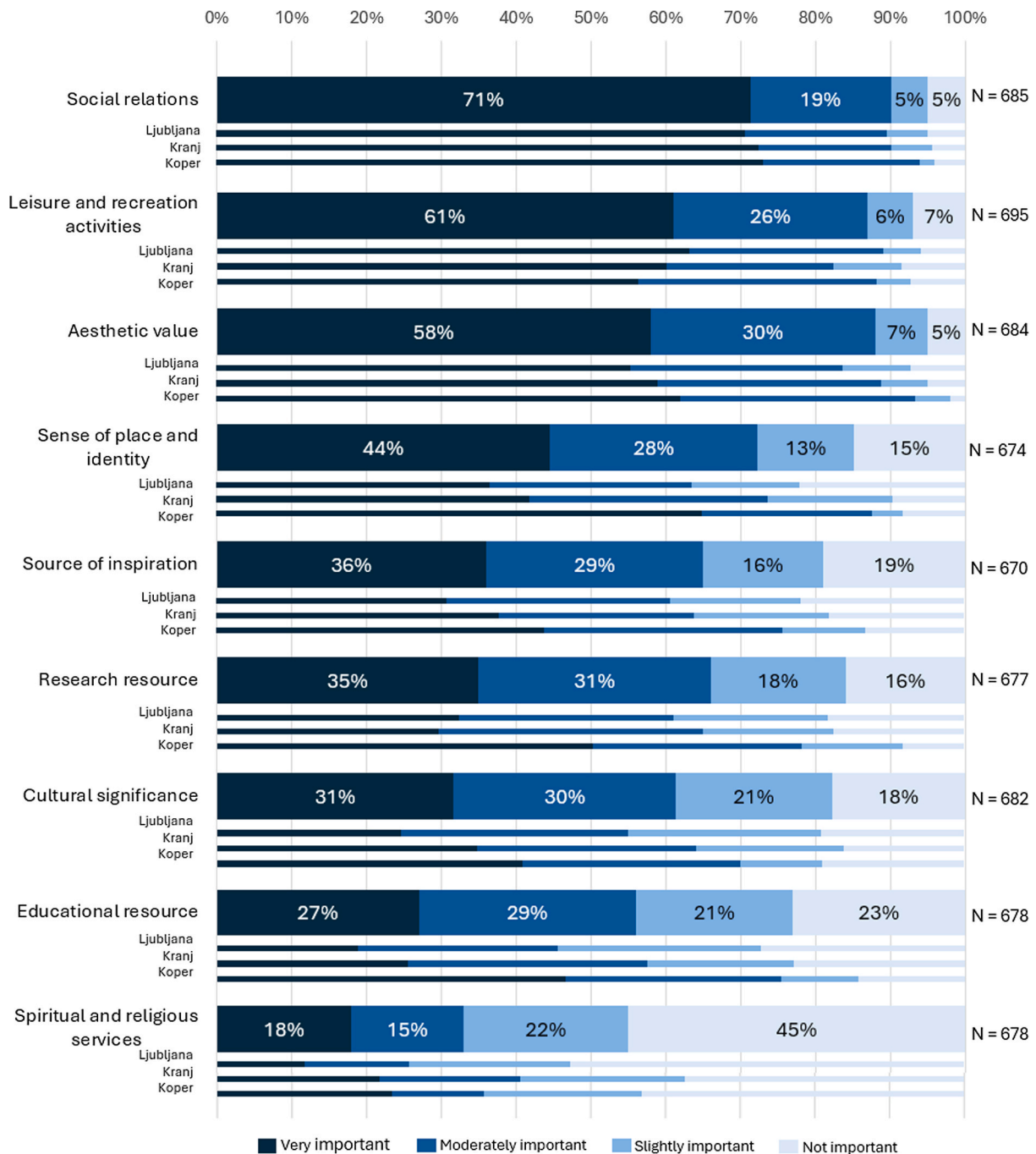


Fig. 3. Level of importance of each CES for survey respondents.

In Koper, the Škocjan Lagoon Nature Reserve emerged as a significant hotspot for five CES. Residential areas also showed higher significance compared to Ljubljana and Kranj. Coldspots were unevenly distributed, with larger areas identified around transport infrastructure and farmland used for fruit and olive cultivation.

The spatial distribution of CES **diversity**, measured by the weighted Shannon index, is shown in Fig. 6. In Ljubljana, the largest diversity hotspot was the Ljubljana Marsh, an area of mixed agricultural use under nature conservation and cultural heritage protection regimes. Other key areas included forested hills and a lake, whereas diversity coldspots were found on the city's outskirts and along transport corridors. In Kranj, hotspots primarily included agricultural areas, lakes, and Brdo Castle estate (a protected cultural heritage site), and coldspots

appeared near major transport routes. In Koper, diversity hotspots included the Škocjan Lagoon Nature Reserve and village cores, differing from the patterns seen in Ljubljana and Kranj.

#### 3.4. Relationship between the provision potential and perceived importance

##### 3.4.1. Relationship between geographical variables and CES

In response to Q3, we analyzed 1) expert data to assess the provision potential of geographical variables for CES, and 2) user data to understand how these variables are used for specific CES.

(1) Expert input provided average scores for each CES–geographical variable pair, weighted by confidence (Fig. 7). With a score above 2.15,

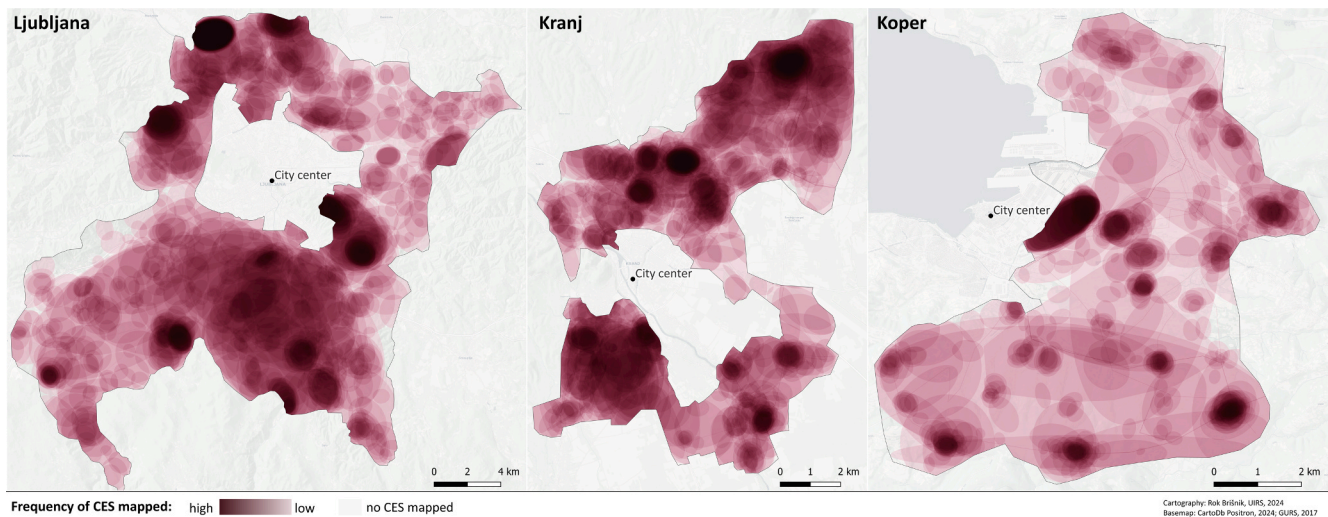


Fig. 4. Frequency distribution of all CES mapped in each study area.

‘forest’ and ‘nature conservation’ were identified as very favorable geographical variables for seven CES, whereas ‘cultural landscapes’ and ‘cultural heritage settlements’ were very favorable for six CES. *Spiritual and religious services* had no highly relevant geographical variables, and *social relations* were linked most strongly to ‘green space.’ The lowest score, (−2.33), indicated the negative role of ‘exclusive use’ in *aesthetic value*, which, together with ‘brownfield’, was the only geographical variable overall scored as very harmful.

(2) In the analysis of user survey data, we first calculated the percentage of twenty geographical variable classes across each study area (Appendix, Table A5). The variable ‘forest’ dominated the land cover, with ‘meadows, pastures, and grassland’ prevalent in Ljubljana, ‘arable land’ in Kranj, and ‘permanent crops’ in Koper. Urbanized land percentages were similar in Ljubljana and Koper but higher in Kranj due to the Brdo Castle estate being classified under ‘wider use.’ Protection regimes varied, with Ljubljana leading in nature conservation sites at over 50%.

As described in the data analysis, we determined perceived importance for each pair of CES–geographical variable classes, for each study area. We used hierarchical component analysis (HCA) with heatmap and dendrogram visualization to cluster CES and geographical variables (Fig. 8). The analysis showed that CES were consistently over-represented (had significantly positive z-scores) in artificial surface areas such as ‘residential,’ ‘mixed-use areas,’ and ‘green space’ across all study areas, likely due to respondents marking settlements as important CES locations. Interestingly, Koper also showed positive z-scores for ‘exclusive use’ areas, which were spatially more interlinked with other artificial uses than in Ljubljana or Kranj.

Protection regimes showed relatively strong positive associations in all cases, except in Kranj and Koper, where ‘cultural landscapes’ for most of CES did not have significantly positive z-scores. In Kranj, ‘cultural landscapes’ mostly covered areas of ‘arable land’ and ‘forest’, which had relatively negative z-scores for CES. For example, ‘arable land’ was only significant for CES *educational resource*. Negatively perceived geographical variables such as ‘transport infrastructure’ (between 30% and 40% of all routes are freeways, in all three cases) and ‘public infrastructure’, ‘brownfield’, ‘bare land’ and ‘exclusive use’ were generally underrepresented for CES locations. For instance, 20% of Koper’s area classified as ‘transport infrastructure’ belongs to the port, which was not selected as important for any CES. Although it is dominant in land cover, ‘forest’ was significantly underrepresented for all CES in both Kranj and Koper, and in Ljubljana for *cultural significance* and as *educational resource*. Water showed inconsistent importance

across the study areas. In Ljubljana, the locations of all CES, except *spiritual and religious services*, were overrepresented in ‘water’ areas. In Kranj, although positive, the associations were not statistically significant, and in Koper, *spiritual and religious services* and *sense of place and identity* were even negatively associated with water areas. *Leisure and recreation activities* and *aesthetic value* were scored similarly across all geographical variables in all study areas except Koper, where only *aesthetic value* was underrepresented in ‘bare land’ and ‘transport infrastructure’ areas.

Through hierarchical clustering, we identified similar clusters of CES across all study areas, specifically *leisure and recreation activities* and *aesthetic value*, as well as *sense of place and identity* and *social relations*. However, the clusters of other CES such as *educational resource* and *spiritual and religious services* were not consistent across the three areas, showing clustering only in Kranj and Ljubljana. Geographical variable clustering generally grouped heavily altered geographical variables such as ‘transport infrastructure’ and ‘brownfield’ separately from natural geographical variables such as ‘water’, ‘green space’ and ‘wetlands.’ Interestingly, ‘residential’ and ‘mixed-use’ areas clustered with natural-like variables in all study areas, whereas ‘forest’ did not cluster with other natural variables, requiring further investigation into this discrepancy.

#### 3.4.2. Spatial distribution of CES provision potential versus perceived importance

We modeled the experts’ values and respondents’ mapping results to compare CES provision potential and perceived importance. Fig. 9 shows the overlay of these results. Survey hotspots are concentrated in hilltop landscapes and lake areas, rated highly by experts, whereas agricultural landscapes and settlements were less favorable. However, respondents emphasized village cores. Coldspots generally aligned with the areas experts deemed harmful. Interestingly, industrial and commercial zones were not identified as coldspots by respondents but were considered harmful by experts. Forested areas, valued by experts, were largely insignificant or coldspots for respondents, particularly near state roads or difficult-to-access areas.

#### 3.4.3. Provision potential and perceived importance of CES in peri-urban landscapes in relation to geographical variables

In response to Q4, we incorporated the previously obtained results (see Fig. 7 and Fig. 8) into Fig. 10 to enable comparison of experts’ estimations of the provision potential and perceived importance for each CES–geographical variable pair.



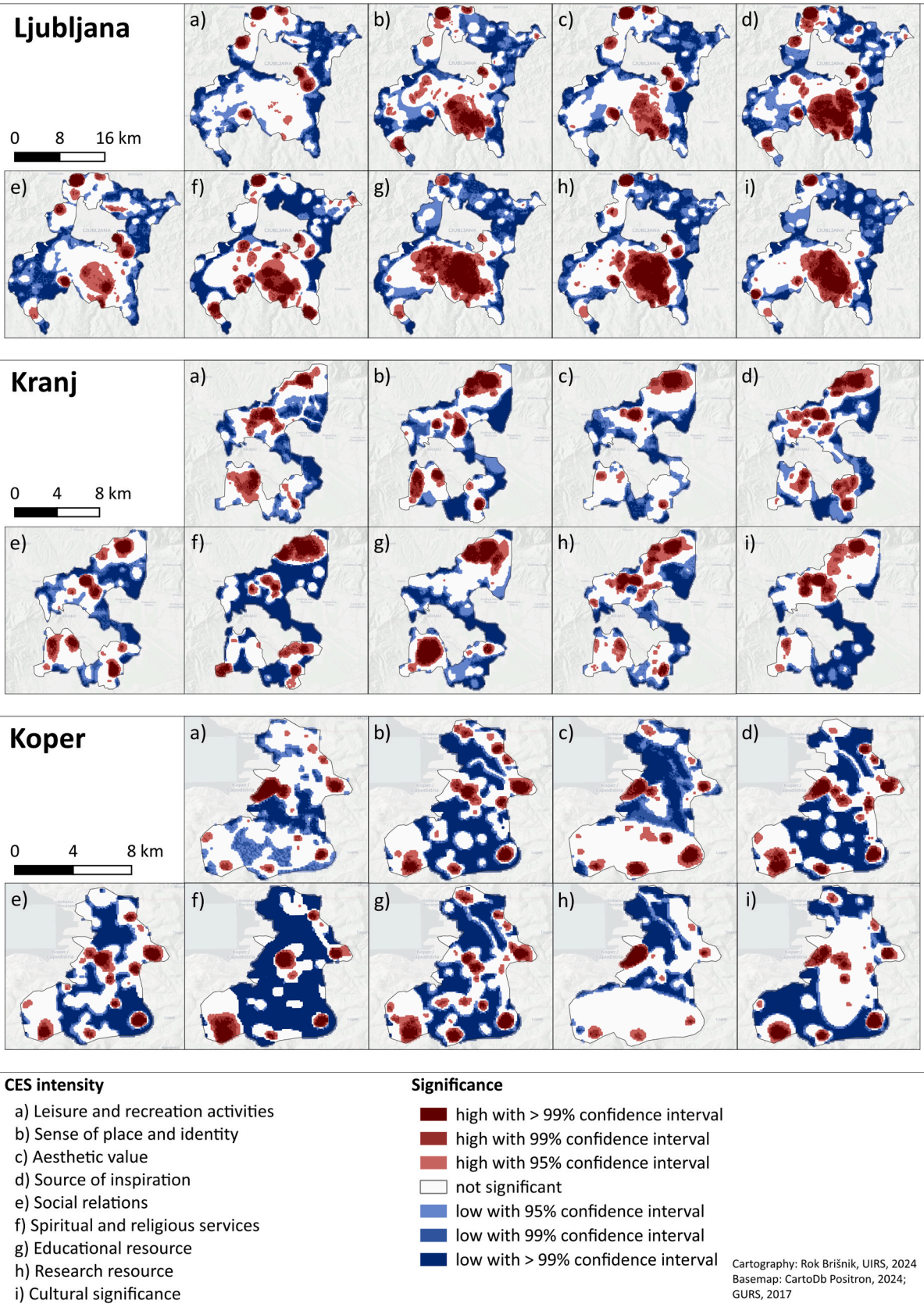


Fig. 5. Statistically significant CES intensity hotspots and coldspots across the study areas.



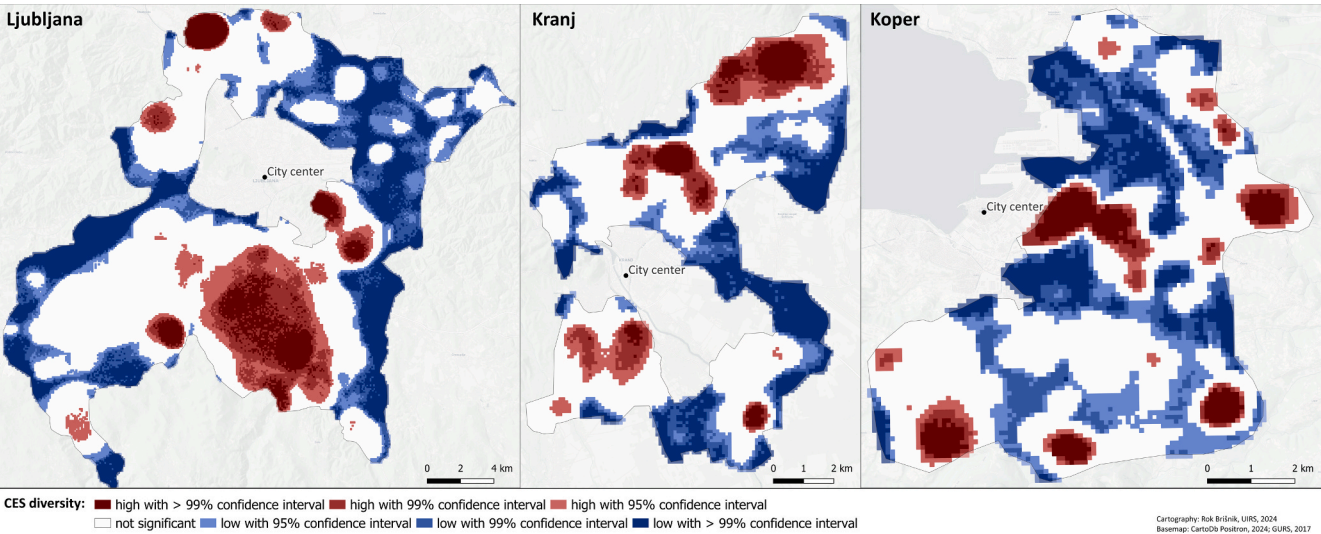


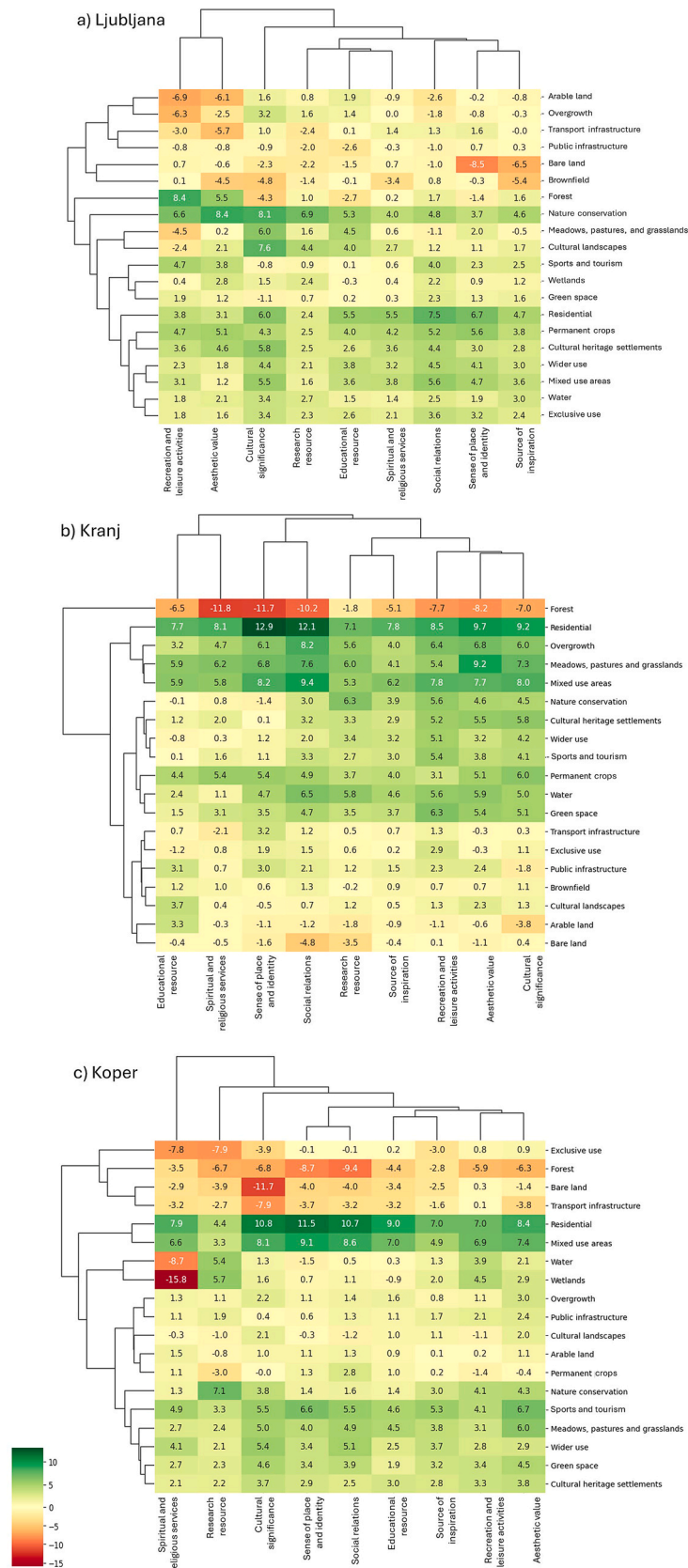
Fig. 6. Statistically significant CES diversity hotspots and coldspots across the study areas.

|                                                                                                                                                                                                                              | Arable land | Permanent crops | Meadows, pastures, and grasslands | Forest | Water | Wetlands | Overgrowth | Bare land | Transport infrastructure | Public infrastructure | Brownfield | Exclusive use | Wider use | Green space | Sports and tourism | Residential | Mixed-use areas | Nature conservation | Cultural landscapes | Cultural heritage settlements |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-----------------|-----------------------------------|--------|-------|----------|------------|-----------|--------------------------|-----------------------|------------|---------------|-----------|-------------|--------------------|-------------|-----------------|---------------------|---------------------|-------------------------------|
| Leisure and recreation activities                                                                                                                                                                                            | 1.31        | 1.87            | 2.15                              | 2.74   | 2.81  | 1.68     | 0.65       | 0.12      | -0.86                    | -1.74                 | -1.29      | -1.84         | -0.95     | 2.81        | 1.78               | 0.33        | 0.56            | 2.37                | 2.54                | 2.01                          |
| Sense of place and identity                                                                                                                                                                                                  | 1.74        | 2.52            | 1.84                              | 2.40   | 2.65  | 2.42     | -0.05      | -0.23     | 0.11                     | -0.90                 | -1.49      | -1.38         | -0.53     | 2.21        | 1.30               | 1.24        | 1.04            | 2.16                | 2.63                | 2.72                          |
| Aesthetic value                                                                                                                                                                                                              | 1.85        | 2.60            | 2.24                              | 2.45   | 2.91  | 2.29     | 0.08       | -0.37     | -0.96                    | -1.77                 | -2.21      | -2.33         | -1.41     | 2.14        | 0.87               | 0.62        | 0.21            | 2.36                | 2.64                | 2.68                          |
| Source of inspiration                                                                                                                                                                                                        | 1.49        | 2.28            | 1.88                              | 2.63   | 2.70  | 2.48     | 0.49       | -0.12     | 0.11                     | -1.11                 | -1.10      | -1.30         | -0.90     | 1.64        | 0.99               | 0.28        | 0.28            | 2.34                | 2.66                | 2.48                          |
| Social relations                                                                                                                                                                                                             | 0.39        | 0.89            | 1.29                              | 1.93   | 2.08  | 0.73     | 0.37       | 0.08      | -0.08                    | -1.32                 | -1.13      | -1.33         | 1.79      | 2.63        | 2.31               | 1.27        | 1.80            | 1.61                | 1.58                | 2.18                          |
| Spiritual and religious services                                                                                                                                                                                             | 0.05        | 0.46            | 0.58                              | 1.34   | 1.54  | 0.48     | -0.05      | 0.15      | -0.94                    | -1.28                 | -1.00      | -1.17         | -0.38     | 0.81        | 0.47               | 0.52        | 0.72            | 1.04                | 1.89                | 1.82                          |
| Educational resource                                                                                                                                                                                                         | 2.03        | 2.22            | 2.08                              | 2.44   | 2.14  | 2.38     | 0.91       | 0.30      | 0.94                     | 0.92                  | 0.90       | 0.74          | 1.26      | 2.03        | 1.26               | 0.81        | 1.10            | 2.66                | 2.58                | 2.51                          |
| Research resource                                                                                                                                                                                                            | 1.77        | 2.00            | 2.36                              | 2.69   | 2.70  | 2.70     | 1.99       | 1.08      | 0.07                     | 0.24                  | 0.88       | -0.05         | 0.17      | 1.59        | 0.97               | 0.93        | 0.81            | 2.84                | 2.08                | 1.48                          |
| Cultural significance                                                                                                                                                                                                        | 2.00        | 2.35            | 2.38                              | 2.35   | 2.44  | 2.44     | 1.00       | 0.23      | -0.53                    | -1.10                 | -0.82      | -1.08         | -0.76     | 1.59        | 0.60               | 0.61        | 0.23            | 2.44                | 2.56                | 2.37                          |
| Legend: very favorable = 3.00 to 2.13; favorable = 2.14 to 1.25; slightly favorable = 1.25 to 0.40; no connection = 0.40 to -0.45; slightly harmful = -0.45 to -1.30; harmful = -1.3 to -2.14; very harmful = -2.15 to -3.00 |             |                 |                                   |        |       |          |            |           |                          |                       |            |               |           |             |                    |             |                 |                     |                     |                               |

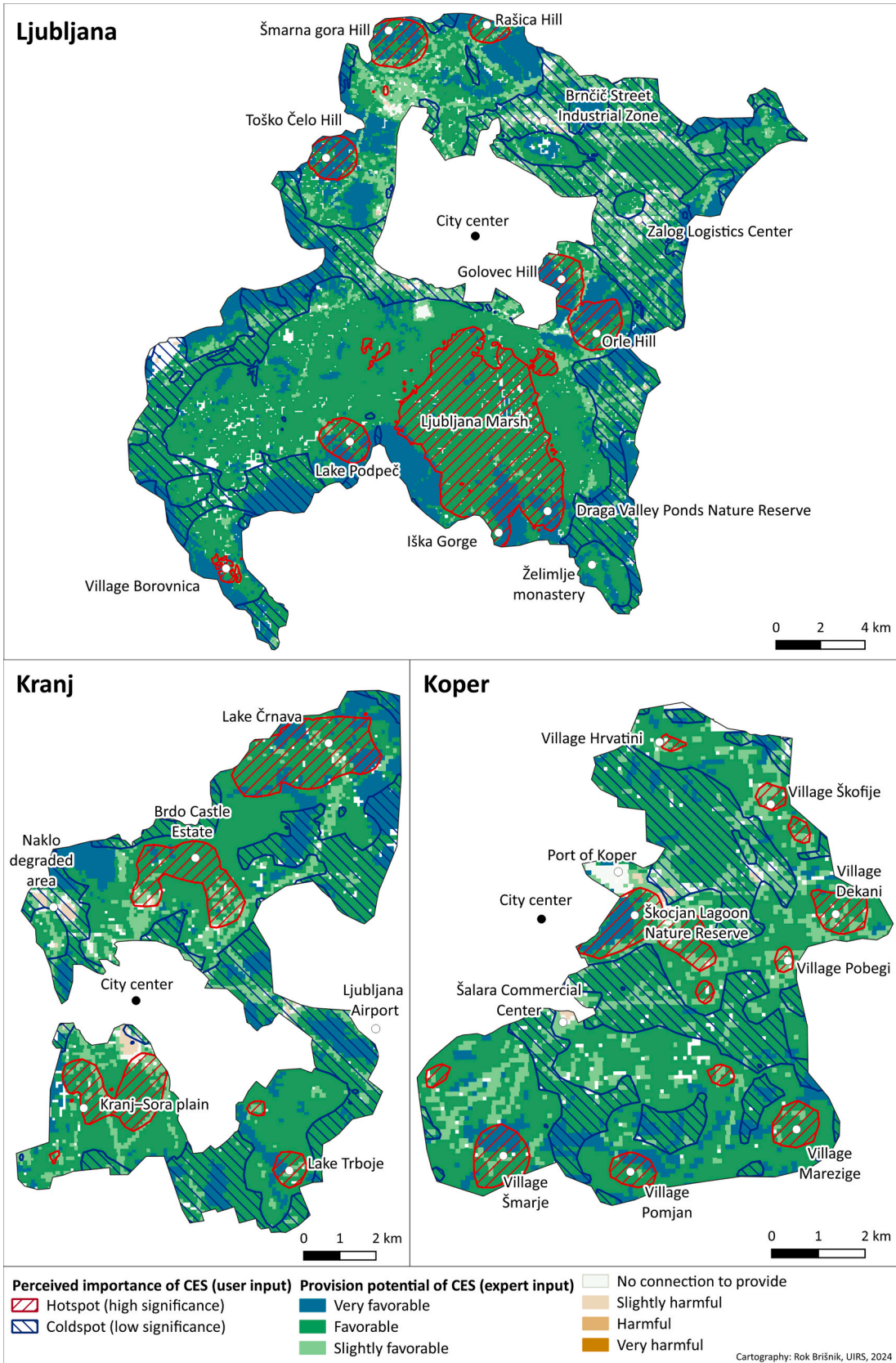
Fig. 7. Aggregated mean scores provided by experts, weighted by their confidence level and colored according to the scale (+3 is the highest and - 3 is the lowest possible score).

We found both consistencies and discrepancies between expert assessments and user perceptions, which underscores the subjective nature of CES and the challenges experts face in interpreting place-based values. Experts rated the variables ‘permanent crops’ and ‘meadows, pastures, and grasslands’ positively, aligning with Kranj’s respondents only. In Ljubljana, users found ‘permanent crops’ significantly important, whereas respondents in Koper appreciated ‘meadows, pastures, and grasslands’, reflecting an inverse relationship with their local abundance. Both experts and users across all areas agreed on the positive value of the variables ‘residential’, ‘mixed-use areas’, ‘nature conservation’, and ‘cultural heritage settlements’, even though experts rated

‘residential’ and ‘mixed-use areas’ lower than users. Positive associations were also found for ‘green spaces’ and for ‘sports and tourism’ areas, highlighting their importance for the categories *social relations*, *leisure and recreation activities*, *aesthetic value* and *source of inspiration*. However, Ljubljana’s respondents did not recognize their cultural significance, despite expert assessments indicating high CES potential. A major discrepancy emerged with ‘forest.’ Experts gave ‘forest’ the highest ratings for CES provision, users in Ljubljana found it insignificant, and respondents in Koper and Kranj found it significantly less important compared to its distribution in the area. A similar, less pronounced divergence appeared for ‘cultural landscapes.’ In contrast,



**Fig. 8.** HCA represented with heatmaps and dendrograms visualizing the clustering of CES categories (columns) and geographical variables (rows). The numbers in each cell are z-scores, showing proportional relationships based on survey respondents' locations marked in each case study. Z-scores above 1.96 show significantly overrepresented geographical variable for a specific CES category, and z-scores below -1.96 show significantly underrepresented geographical variable for that category. Geographical variables not present or without any locations marked intersections are excluded from the figure. Color scale is continuous and represents varying degrees of variables' representation to visually assess the results.



**Fig. 9.** Provision potential and perceived importance of CES. The solid-colored areas represent the combined results of nine CES layers across the three study areas, showing spatial variation in provision potential based on expert scores and GIS data. The hatched areas highlight the hotspots and coldspots of perceived CES importance, calculated by merging frequency, intensity, and diversity indices from participatory mapping data.



| ID | CES category<br>Geographical variable | Leisure and recreation activities | Sense of place and identity      | Aesthetic value                   | Source of inspiration             | Social relations                 | Spiritual and religious services | Educational resource             | Research resource                 | Cultural significance             |
|----|---------------------------------------|-----------------------------------|----------------------------------|-----------------------------------|-----------------------------------|----------------------------------|----------------------------------|----------------------------------|-----------------------------------|-----------------------------------|
| 1  | Arable land                           | Experts+<br>LJ—<br>KR—<br>KP+     | Experts+<br>LJ—<br>KR—<br>KP+    | Experts+<br>LJ—<br>KR—<br>KP+     | Experts+<br>LJ—<br>KR—<br>KP+     | Experts+<br>LJ—<br>KR—<br>KP+    | Experts+<br>LJ—<br>KR—<br>KP+    | Experts+<br>LJ—<br>KR++<br>KP+   | Experts+<br>LJ+<br>KR—<br>KP—     | Experts+<br>LJ+<br>KR—<br>KP—     |
| 2  | Permanent crops                       | Experts+<br>LJ++<br>KR++<br>KP—   | Experts++<br>LJ++<br>KR++<br>KP+ | Experts++<br>LJ++<br>KR++<br>KP+  | Experts++<br>LJ++<br>KR++<br>KP+  | Experts+<br>LJ++<br>KR++<br>KP+  | Experts+<br>LJ++<br>KR++<br>KP+  | Experts++<br>LJ++<br>KR++<br>KP+ | Experts+<br>LJ++<br>KR++<br>KP—   | Experts++<br>LJ++<br>KR++<br>KP—  |
| 3  | Meadows, pastures, and grasslands     | Experts++<br>LJ—<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP++  | Experts++<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ—<br>KR++<br>KP++   | Experts+<br>LJ—<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ++<br>KR++<br>KP++ | Experts++<br>LJ+<br>KR++<br>KP++  | Experts++<br>LJ++<br>KR++<br>KP++ |
| 4  | Forest                                | Experts++<br>LJ++<br>KR—<br>KP—   | Experts++<br>LJ—<br>KR—<br>KP—   | Experts++<br>LJ++<br>KR—<br>KP—   | Experts++<br>LJ+<br>KR—<br>KP—    | Experts+<br>LJ+<br>KR—<br>KP—    | Experts+<br>LJ+<br>KR—<br>KP—    | Experts++<br>LJ—<br>KR—<br>KP—   | Experts++<br>LJ+<br>KR—<br>KP—    | Experts++<br>LJ—<br>KR—<br>KP—    |
| 5  | Water                                 | Experts++<br>LJ+<br>KR++<br>KP+   | Experts++<br>LJ+<br>KR++<br>KP—  | Experts++<br>LJ+<br>KR++<br>KP+   | Experts++<br>LJ+<br>KR++<br>KP+   | Experts+<br>LJ+<br>KR++<br>KP—   | Experts+<br>LJ+<br>KR+<br>KP—    | Experts++<br>LJ+<br>KR++<br>KP+  | Experts++<br>LJ+<br>KR++<br>KP+   | Experts++<br>LJ++<br>KR++<br>KP+  |
| 6  | Wetlands                              | Experts+<br>LJ+<br>KR<br>KP++     | Experts++<br>LJ+<br>KR<br>KP+    | Experts++<br>LJ+<br>KR<br>KP++    | Experts++<br>LJ+<br>KR<br>KP+     | Experts+<br>LJ+<br>KR<br>KP+     | Experts+<br>LJ+<br>KR<br>KP—     | Experts++<br>LJ+<br>KR<br>KP—    | Experts++<br>LJ+<br>KR<br>KP++    | Experts++<br>LJ+<br>KR<br>KP+     |
| 7  | Overgrowth                            | Experts+<br>LJ—<br>KR++<br>KP+    | Experts—<br>LJ—<br>KR++<br>KP+   | Experts+<br>LJ—<br>KR++<br>KP++   | Experts+<br>LJ—<br>KR++<br>KP+    | Experts+<br>LJ+<br>KR++<br>KP+   | Experts+<br>LJ+<br>KR++<br>KP+   | Experts++<br>LJ+<br>KR++<br>KP+  | Experts++<br>LJ++<br>KR++<br>KP+  | Experts++<br>LJ++<br>KR++<br>KP++ |
| 8  | Bare land                             | Experts+<br>LJ+<br>KR+<br>KP+     | Experts—<br>LJ—<br>KR—<br>KP—    | Experts—<br>LJ—<br>KR—<br>KP—     | Experts—<br>LJ—<br>KR—<br>KP—     | Experts+<br>LJ—<br>KR—<br>KP—    | Experts+<br>LJ+<br>KR—<br>KP—    | Experts+<br>LJ—<br>KR—<br>KP—    | Experts+<br>LJ—<br>KR—<br>KP—     | Experts+<br>LJ—<br>KR+<br>KP—     |
| 9  | Transport infrastructure              | Experts—<br>LJ—<br>KR+<br>KP+     | Experts+<br>LJ+<br>KR+<br>KP—    | Experts—<br>LJ—<br>KR—<br>KP—     | Experts+<br>LJ+<br>KR+<br>KP—     | Experts—<br>LJ+<br>KR+<br>KP—    | Experts—<br>LJ+<br>KR—<br>KP—    | Experts+<br>LJ+<br>KR+<br>KP—    | Experts+<br>LJ+<br>KR+<br>KP—     | Experts—<br>LJ+<br>KR+<br>KP—     |
| 10 | Public infrastructure                 | Experts—<br>LJ—<br>KR++<br>KP++   | Experts—<br>LJ—<br>KR++<br>KP++  | Experts—<br>LJ—<br>KR++<br>KP++   | Experts—<br>LJ—<br>KR+<br>KP+     | Experts—<br>LJ—<br>KR++<br>KP+   | Experts—<br>LJ—<br>KR+<br>KP+    | Experts+<br>LJ+<br>KR++<br>KP+   | Experts—<br>LJ—<br>KR—<br>KP+     | Experts—<br>LJ—<br>KR—<br>KP+     |
| 11 | Brownfield                            | Experts—<br>LJ+<br>KR+<br>KP—     | Experts—<br>LJ—<br>KR+<br>KP—    | Experts—<br>LJ—<br>KR+<br>KP—     | Experts—<br>LJ—<br>KR+<br>KP—     | Experts—<br>LJ+<br>KR+<br>KP—    | Experts—<br>LJ—<br>KR+<br>KP—    | Experts+<br>LJ—<br>KR+<br>KP—    | Experts+<br>LJ—<br>KR+<br>KP—     | Experts—<br>LJ—<br>KR+<br>KP—     |
| 12 | Exclusive use                         | Experts—<br>LJ+<br>KR+<br>KP+     | Experts—<br>LJ+<br>KR+<br>KP—    | Experts—<br>LJ+<br>KR+<br>KP+     | Experts—<br>LJ+<br>KR+<br>KP—     | Experts—<br>LJ+<br>KR+<br>KP+    | Experts—<br>LJ+<br>KR+<br>KP—    | Experts+<br>LJ+<br>KR—<br>KP+    | Experts+<br>LJ+<br>KR+<br>KP—     | Experts—<br>LJ+<br>KR+<br>KP—     |
| 13 | Wider use                             | Experts—<br>LJ++<br>KR++<br>KP++  | Experts—<br>LJ++<br>KR+<br>KP++  | Experts—<br>LJ+<br>KR++<br>KP++   | Experts—<br>LJ+<br>KR++<br>KP++   | Experts+<br>LJ++<br>KR++<br>KP++ | Experts—<br>LJ++<br>KR+<br>KP++  | Experts+<br>LJ++<br>KR—<br>KP++  | Experts+<br>LJ++<br>KR++<br>KP+   | Experts+<br>LJ++<br>KR++<br>KP++  |
| 14 | Green space                           | Experts++<br>LJ+<br>KR++<br>KP++  | Experts++<br>LJ+<br>KR+<br>KP++  | Experts++<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP++   | Experts++<br>LJ+<br>KR++<br>KP++ | Experts+<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP+    | Experts+<br>LJ—<br>KR++<br>KP++   |
| 15 | Sports and tourism                    | Experts+<br>LJ++<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR+<br>KP++   | Experts+<br>LJ+<br>KR++<br>KP++   | Experts+<br>LJ+<br>KR++<br>KP++   | Experts++<br>LJ+<br>KR++<br>KP++ | Experts+<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP++   | Experts+<br>LJ—<br>KR++<br>KP++   |
| 16 | Residential                           | Experts+<br>LJ++<br>KR++<br>KP++  | Experts+<br>LJ++<br>KR++<br>KP++ | Experts+<br>LJ++<br>KR++<br>KP++  | Experts+<br>LJ++<br>KR++<br>KP++  | Experts+<br>LJ++<br>KR++<br>KP++ | Experts+<br>LJ++<br>KR++<br>KP++ | Experts+<br>LJ++<br>KR++<br>KP++ | Experts+<br>LJ++<br>KR++<br>KP++  | Experts+<br>LJ++<br>KR++<br>KP++  |
| 17 | Mixed-use areas                       | Experts+<br>LJ+<br>KR+<br>KP++    | Experts+<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP++   | Experts+<br>LJ+<br>KR++<br>KP++   | Experts+<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP++  | Experts+<br>LJ+<br>KR++<br>KP++   | Experts+<br>LJ+<br>KR++<br>KP++   |
| 18 | Nature conservation                   | Experts++<br>LJ++<br>KR++<br>KP++ | Experts++<br>LJ++<br>KR—<br>KP+  | Experts++<br>LJ++<br>KR++<br>KP++ | Experts++<br>LJ++<br>KR++<br>KP++ | Experts+<br>LJ++<br>KR++<br>KP++ | Experts+<br>LJ++<br>KR+<br>KP+   | Experts++<br>LJ++<br>KR++<br>KP+ | Experts++<br>LJ++<br>KR++<br>KP++ | Experts++<br>LJ++<br>KR++<br>KP++ |
| 19 | Cultural landscapes                   | Experts++<br>LJ—<br>KR+<br>KP+    | Experts++<br>LJ+<br>KR—<br>KP+   | Experts++<br>LJ+<br>KR+<br>KP++   | Experts++<br>LJ+<br>KR+<br>KP+    | Experts+<br>LJ+<br>KR+<br>KP—    | Experts+<br>LJ+<br>KR+<br>KP+    | Experts++<br>LJ+<br>KR++<br>KP+  | Experts+<br>LJ+<br>KR+<br>KP+     | Experts++<br>LJ+<br>KR+<br>KP++   |
| 20 | Cultural heritage settlements         | Experts+<br>LJ++<br>KR++<br>KP++  | Experts++<br>LJ++<br>KR+<br>KP++ | Experts++<br>LJ+<br>KR++<br>KP++  | Experts++<br>LJ+<br>KR++<br>KP++  | Experts++<br>LJ+<br>KR++<br>KP++ | Experts+<br>LJ+<br>KR+<br>KP++   | Experts++<br>LJ+<br>KR++<br>KP++ | Experts+<br>LJ+<br>KR++<br>KP+    | Experts++<br>LJ+<br>KR++<br>KP++  |

**Fig. 10.** Summary of mean values for experts and the proportional relationships between CES and geographical variables. LJ = Ljubljana respondents, KR = Kranj respondents, KP = Koper respondents. “++” or “—” indicates a significant positive or negative association ( $z > 1.96$  or  $z < -1.96$ ,  $p \leq 0.05$  for users; averages  $> 2.14$  or  $< -2.14$  for experts). “+” or “-” indicates a non-significant positive or negative association ( $z < 1.96$  or  $z > -1.96$ ,  $p > 0.05$  for users; averages  $< 2.14$  or  $> -2.14$  for experts). Shading denotes significance across all three cases (dark green = significantly positive z-value in all cases, red = significantly negative z-value in all cases, yellow = divergence in significance). Light green = three significant scores among three cases and experts, a pink border = divergence in significance between experts and the three cases.

‘wider use’ was rated negatively by experts but was deemed significantly more important by users in all areas. Experts rated ‘overgrowth’ positively, but users, particularly in Ljubljana, expressed little appreciation for its CES, especially regarding *leisure and recreation activities*, *aesthetic value*, and *social relations*. Users in both Koper and Ljubljana did not find it important for CES *educational resource*, and *spiritual and religious services*.

We found no clear pattern for the variables ‘arable land’, ‘exclusive use’, or ‘transport infrastructure’, even though the latter two were generally rated negatively. ‘Brownfield’ was rated negatively by experts and were rated unimportant by users in Ljubljana and Koper, but not by those in Kranj.

#### 4. Discussion

Peri-urban landscapes, blending urban, rural, and natural features, provide a unique context for analyzing CES. The case studies presented varied in terms of nature and cultural heritage protection, as well as land cover diversity. Despite these differences, consistent land use and cover patterns emerged across the landscapes, reflecting shared characteristics. Understanding CES distribution and its link to provision potential is essential for effective policy-making and spatial planning (Crouzat et al., 2022; IPBES, 2019). This study explored the spatial relationships between CES and geographical variables by comparing expert assessments of CES provision potential with user-reported experiences. Insights were gained through three comparative analyses: between various peri-urban cases, expert assessments versus perceived importance, and CES distribution relative to geographical variables. The following subsections address Q5.

##### 4.1. CES values and their spatial distribution patterns in peri-urban landscapes

Our study highlights the importance of peri-urban landscapes in providing CES such as *leisure and recreation activities*, *aesthetic value*, and *social relations*. These findings align with previous research that identified these services as important for human wellbeing (Brown & Raymond, 2007; Fagerholm et al., 2019; Zaman et al., 2022; Zwierchowska et al., 2018). Notably, *sense of place and identity* also emerged as a significant CES in users’ survey, indicating a gap in expert assessments and highlighting the need for more attention to this under-researched service (Hausmann et al., 2016). This study links sense of place to natural environments, such as green spaces, arable land, and nature conservation sites, highlighting its relevance in the context of environmental stewardship (Žlender & Gemin, 2020). In contrast, *spiritual and religious services* were less frequently valued by users, which may reflect an underappreciation of these intangible benefits. This observation is consistent with findings by Zaman et al. (2022), but our study found stronger links of these services to residential and mixed-use areas rather than nature conservation and cultural heritage sites.

Our findings are consistent with previous studies that emphasize the importance of proximity to home for CES appreciation (Cusens et al., 2022; Fagerholm et al., 2019; Kirby et al., 2023; Plieninger et al., 2013). While ‘forest’ was rated as having high CES in terms of potential by experts in our study, they were underutilized in all three cases, possibly due to accessibility barriers. Previous studies have also reported forests as popular for leisure activities (Ko & Son, 2018; Žlender & Ward Thompson, 2017), which supports their recognized relevance. This discrepancy highlights that perceived CES potential does not necessarily translate into actual use, and that accessibility plays a key role in

maximizing CES benefits, because ease of access encourages greater use (Fagerholm et al., 2019).

CES often overlapped spatially, reflecting their interconnected and bundled nature (e.g., Cusens et al., 2022; Plieninger et al., 2013). This suggests that peri-urban landscapes offer a multidimensional experience, with places serving several functions simultaneously. Comparative analysis revealed that each peri-urban landscape had unique features contributing to CES supply, despite shared land uses such as logistic centers and shopping malls. Ljubljana’s peri-urban hills and Lake Podpeč were valued for *leisure and recreation activities* and *aesthetic value*, and Kranj’s Brdo Castle estate and its surrounding agricultural areas supported CES such as *sense of place and identity*, *research resource*, and *educational resource*, which may arise from symbolic or historical connections beyond direct use. In Koper, village cores and the Škocjan Lagoon Nature Reserve were key CES hotspots. However, areas with limited physical access, such as dense olive groves and fruit orchards, were less commonly associated with CES that depend on direct engagement, reinforcing the importance of access. Similar findings regarding accessibility were reported by Muñoz et al. (2020). However, as shown in Fig. 5, the spatial extent of individual CES categories varied considerably, which suggests that factors beyond access also influence their distribution. This warrants further investigation.

Interestingly, the perceived value of CES *leisure and recreation activities* showed little variation across sites, aligning with findings by Biedenweg et al. (2019) that recreation is perceived as a ubiquitous and accessible value that varies little across spatial contexts. *Aesthetic value* and *social relations* are also typically tied to collective experiences that are valued universally, which may explain the lack of significant spatial differentiation in Ljubljana and Kranj. In contrast, services with deeper cultural meanings varied more significantly, highlighting sensitivity to local environmental and social contexts (Crouzat et al., 2022). Dense urban areas, such as the city of Ljubljana, may create a disconnect from peri-urban spaces, reducing the perceived CES value compared to more open, accessible areas such as Koper. These findings underscore the need to consider both universal and context-dependent aspects when assessing CES in peri-urban landscapes.

##### 4.2. Assessing CES provision potential and user needs

Our model of CES provision in peri-urban landscapes, based on expert scores, did not align with the perceived importance in all three study areas. The discrepancy between the provision potential and perceived importance is a key finding, although it should be interpreted with caution as it is partly related to the methodological approach used, and is further discussed in Section 4.4. Experts tend to value landscapes broadly, often rating semi-natural areas such as forest and cultural landscapes high due to their capacity to support diverse CES. Users, however, prioritize landscapes they can easily access for recreation, socialization, and inspiration (Crouzat et al., 2022; Fagerholm et al., 2019).

A major divergence was seen in the perceived value of ‘forest’. Experts consistently rated ‘forest’ high across all CES, recognizing its multifunctionality. However, particularly in Koper and Kranj, users used ‘forest’ less than expected, contradicting its well-established recreational and aesthetic roles (Brown, 2013). Agricultural variables such as ‘meadows, pastures, and grasslands’, and ‘permanent crops’ also showed mixed responses. Experts rated ‘meadows, pastures, and grasslands’, and ‘permanent crops’ high for CES, whereas user preferences varied. This aligns with previous studies (e.g., Plieninger et al., 2013; Brown, 2013) that also noted variable perceptions of agricultural areas. In contrast,

human-modified areas such as ‘residential areas’, ‘mixed-use areas’, and ‘wider use’, and ‘public infrastructure’ were rated lower by experts but were appreciated by users across all cities, highlighting the importance of such spaces in delivering CES (Crouzat et al., 2022). Similarly, the variables ‘brownfield’, ‘exclusive use’, and ‘transport infrastructure’ showed divergent results, with users in some cities (e.g., Ljubljana) favoring them more than experts. These discrepancies point to the importance of user engagement in CES assessment and management, but also suggest the influence of cognitive mechanisms such as substitutional bias, where responders may attribute value to CES while prioritizing other dimensions, including heritage, historical meaning or built environment characteristics. This is evident in high valuation of village cores, where the role of natural capital remains unclear. Emotional attachment of framing effects may further shape responses, meaning that what is captured as CES may partly reflect non-ecological values. This issue should be considered when designing interdisciplinary methods associated with the ES approach, as noted by Tengberg et al. (2012). The partial alignment between expert and user assessments indicates that experts can approximate user priorities where landscape features are clearly multifunctional or culturally embedded. However, they may overestimate CES supply in ecologically valuable areas that lack accessibility, visibility or opportunities for direct interaction. While expert-based assessments provide a valuable baseline, integrating user perspectives is essential to fully capture the relational and experiential dimensions of CES, particularly in urban and peri-urban contexts where landscape values are highly contextual and shaped by local use patterns.

Both experts and users agreed on the importance of ‘green space’, ‘sports and tourism’, and ‘nature conservation’ and cultural heritage sites. Although discrepancies existed regarding the value of certain geographical variables, those within protected areas greatly enhanced CES. For instance, ‘arable land’ was found significantly less important by respondents in Ljubljana compared to its general distribution in the area. However, the Ljubljana Marsh, a protected area with abundant arable land, was identified as a notable hotspot in the spatial analysis, indicating a significantly higher importance than expected. This finding suggests that protection regimes can enhance the value of specific geographical variables such as ‘arable land’ in providing CES. This aligns with previous studies (Brown et al., 2014; Zaman et al., 2022), indicating that CES depend on more than just biophysical elements. Other factors, including geographical diversity, multifunctionality, accessibility in terms of trail quality, tourism marketing, and socioeconomic influences, are also crucial for effective management of protected areas (e.g., Crouzat et al., 2022; Karimi & Raymond, 2022; Ridding et al., 2018).

#### 4.3. Implications for spatial planning and policy in peri-urban landscapes

Integrating CES into spatial planning and policy is vital for the sustainable management of peri-urban landscapes, which often face competing demands from agriculture, urban expansion, and recreational needs. This study outlines key implications for planners and policy-makers aiming to enhance CES benefits in these transitional areas.

First, accessibility and proximity to CES-rich areas significantly maximize the benefits provided by these landscapes. Our findings show that areas close to urban settlements, particularly those protected under nature and cultural heritage regimes, offer the highest CES value. This supports broader studies emphasizing the importance of keeping green spaces and culturally significant areas easily accessible to the public (Fagerholm et al., 2020; Filyushkina et al., 2022; Ridding et al., 2018). Therefore, spatial planning for peri-urban landscapes must prioritize preserving and developing green infrastructure near urban centers.

Incorporating CES mapping into the urban nature plans (UNPs) (European Commission, 2021) as part of the EU Biodiversity Strategy 2030 (European Commission, 2020) can ensure biodiversity while enhancing the social and cultural wellbeing of local communities and improving ecological resilience.

Second, effective management of protected areas is crucial for CES delivery, especially in rapidly changing landscapes. Peri-urban spaces often serve as ecological corridors and cultural sites that require careful protection. Our results indicate that protected areas, such as the Ljubljana Marsh and the Škocjan Lagoon Nature Reserve, act as CES hotspots, offering a range of services, from recreation to aesthetic value. In Slovenia, over 40% of land falls under Natura 2000 and other protective regulations (Smrekar et al., 2020), reflecting the country’s commitment to biodiversity and conservation of cultural landscapes. However, this introduces challenges in high-demand peri-urban areas, particularly in reference to the recently adopted Nature Restoration Law (Regulation 2024). This law requires farmers to allocate 4% of their arable land to non-productive uses and reduce the use of fertilizers. These regulations have sparked protests among European farmers, including those in Slovenia (J. K., 2023), who argue that they threaten their livelihoods and impose excessive bureaucracy. For now, the Slovenian government has conceded to the farmers’ demands, but pressures from the EU and dissatisfaction among nature conservationists remain (Prijetelj Videmšek, 2024). Planners must find ways to mediate these conflicts, emphasizing collaborative landscape governance that integrates various sectors and land-use interests (Primdahl, 2024). Furthermore, establishing and implementing measures such as collaborative landscape strategies (Kristensen & Primdahl, 2020) that promote multifunctional land use (Plieninger et al., 2013; Primdahl, 2024; Xia et al., 2023) and management plans for protected areas (Smrekar et al., 2020) may foster place-making over conflict management while meeting both conservation and economic goals.

Third, bridging the gap between the potential provision and perceived importance of peri-urban landscapes for CES remains a challenge. Our spatial and proportional analyses show that some areas identified by experts as having high CES potential were not recognized as important by users, indicating differences in how CES are perceived, experienced, and valued. However, these differences should be interpreted with caution, as the expert- and user-based assessments were derived from non-equivalent spatial methods and levels of detail. Consequently, the observed gap should not be understood as a direct mismatch between expert and resident views alone, but rather as a preliminary indication of possible divergences that merits further investigation. Future research should seek to integrate both perspectives through more methodologically aligned frameworks that combine expert knowledge with participatory mapping at comparable spatial scales. Previous studies have highlighted the need to clarify the relationships between knowledge, landscape values, and geographical variables (Zaman et al., 2022). Engaging local stakeholders in participatory mapping and decision-making processes is crucial, because this enhances CES visibility and supports inclusive strategies and capacity building (Cusens et al., 2022; Plieninger et al., 2015).

#### 4.4. Evaluation of the methodological approach

This study employed a mixed-methods framework to provide a comprehensive understanding of CES mapping. By integrating data from experts and users through a matrix model and participatory mapping, this approach highlights both strengths and limitations. The matrix model allows for rapid implementation and provides a general overview of CES trends. However, it may yield variability in scores due to differing



perspectives and levels of expertise (Kopperoinen et al., 2014; Žlender, 2024). Moreover, the method was based on scoring generalized land uses and protection regimes, which may not adequately reflect context-dependent local characteristics. Scoring based on landscape units or specific landscape elements (Kostanjšek & Golobič, 2023) or at least acknowledging the role of landscape configuration and context, as stressed by Vallés-Planells et al. (2014) might better reflect such nuances. This limitation is particularly evident in assessing CES, where the matrix method, relying on generalized land cover classes and expert judgment, struggles to account for the wide range of individual and collective perceptions, experiences, and meanings associated with specific CES categories. These values are inherently location-specific, shaped by local knowledge, practices, and cultural contexts. When applied solely to land use and protection regimes, the method proves less appropriate, being overly reductive and risking misinterpretation of key CES. While its basic framework of grading relevant themes and aggregating values could be useful, further adaptation is necessary to include locally grounded and socially informed variables, to meaningfully assess CES. Without such changes, however, the approach captures only part of their complexity.

To address this gap, we utilized a paper-based PPGIS survey, despite challenges such as the time required to digitize data and limitations in zooming into smaller areas. This approach enables participants to engage directly with the physical landscape, yielding more accurate representations of their spatial experiences. PPGIS often captures singular points (Brown & Fagerholm, 2015), whereas individuals typically interact with larger, complex areas. Our integration of points, polygons, and lines aimed to produce a more holistic spatial dataset, enhancing our understanding of user interaction with peri-urban landscapes (Bressan, 2021; Ramirez-Gomez et al., 2013). This comprehensive mapping facilitates precise matching between CES and geographical variables. Moreover, on-site data collection minimizes biases associated with digital tools, such as access disparities and technological familiarity, which was also highlighted by previous studies (Brown & Fagerholm, 2015; Ridding et al., 2018). Engaging local users through surveys makes it possible to gather detailed, context-specific insights into how services are perceived, valued, and utilized, thus validating model outputs and incorporating socio-cultural dimensions, which are in purely spatial models often overlooked (Brown & Fagerholm, 2015). On this point, it should be stressed that the importance of evenly distributed data collection points in the whole area is crucial due to the problem of spatial discounting (Brown, 2017). Despite our efforts to achieve this, we did detect some tendency in our collected spatial data to mark locations close to where respondents live or where the data collection took place.

The combined analytical approach that integrates spatial and statistical data proves effective for landscape assessments and provides valuable insights for exploratory analyses (Bieling & Plieninger, 2013). However, there is still room for improvement, particularly regarding proportional analysis, in which imprecise marking may significantly impact results. Also, while expert assessments enabled identification of both CES favorable and harmful areas, user-generated maps typically lack explicit absence data. We identified areas significantly less frequently marked by participants as user-defined coldspots. These should be interpreted cautiously, as lower marking density reflects lower prioritization, not necessarily negative perception. Future studies should enhance PPGIS implementation alongside other methods such as modeling approaches (Cusens et al., 2022), and explore demographic

influences (Dou et al., 2021) or the perceived value of more tangible CES (Biedenweg et al., 2019) to improve CES mapping capabilities.

## 5. Conclusion

This study contributes to research on CES in peri-urban landscapes in three ways. First, it improves the understanding of the relationships between landscapes, CES, benefits, and beneficiaries. The study highlights how users' appreciation of CES is strongly influenced by accessibility, proximity to home, and the multifunctionality of everyday landscapes, particularly residential, mixed-use areas, and nature conservation and cultural heritage sites. These findings suggest that people's interactions with peri-urban landscapes are shaped as much by lived experience and access as by biophysical attributes, emphasizing the relational nature of cultural benefits. Second, the study offers evidence-based recommendations for integrating CES into spatial planning and landscape management. The results support the prioritization of accessible green infrastructure, recognition of user-valued but underappreciated spaces, and the development of collaborative governance frameworks. These recommendations align with ongoing policy efforts such as the EU Biodiversity Strategy 2030 and the implementation of urban nature plans, reinforcing the relevance of CES in contemporary land-use planning. Third, it advances methods for mapping and assessing CES by integrating expert-based scoring with participatory public mapping. This mixed-methods approach allowed for the identification of both provision potential and perceived importance, revealing spatial patterns that would be overlooked by using either method alone. The inclusion of both spatial and non-spatial data provides a more holistic understanding of CES distribution and values.

In future research, we suggest building on this mixed-methods foundation by incorporating demographic dimensions, digital participatory tools, and modeling approaches to better capture the diversity of CES perceptions and their spatial variability across broader contexts. This will further support the mainstreaming of CES in planning for sustainable, inclusive, and multifunctional peri-urban landscapes.

## CRediT authorship contribution statement

**Vita Žlender:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Rok Brišnik:** Writing – original draft, Software, Investigation, Formal analysis, Data curation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix

**Table A1**

Information on the CES used in this study.

| No. | Category                          | Reason for selection                                                                                                                                                                                                                                                                                                                                 | Description for experts                                                                                                                                                                                                | Description for users                                                                                                                                                                        |
|-----|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Leisure and recreation activities | Peri-urban landscapes often serve as vital recreational areas for nearby urban populations. This category acknowledges the importance of leisure activities in enhancing human wellbeing and fostering a connection to nature in a peri-urban landscape.                                                                                             | Such activities refer to walking, hiking, cycling, climbing, relaxing, enjoying attractive views, and escaping from stress in the peri-urban landscape.                                                                | These are places that are important to me because of the recreational opportunities they offer.                                                                                              |
| 2   | Sense of place and identity       | A peri-urban landscape typically exhibits a unique blend of urban and rural characteristics, contributing to a distinct sense of place and local identity. Exploring this category allows for an understanding of how individuals perceive and relate to their surroundings, thereby influencing community cohesion and attachment to the landscape. | Sense of place ( <i>genius loci</i> ) refers to natural and built elements that are part of the ecosystem and encourage a complex emotional bond between people and place such as attachment, belonging, and identity. | These are places that are important to me because here I feel connected to the local place.                                                                                                  |
| 3   | Aesthetic value                   | The aesthetic qualities of peri-urban landscapes shape public perceptions and preferences; examining these values helps identify visual aspects that enhance landscape appreciation.                                                                                                                                                                 | Aesthetic value is the interaction of people with the environment in relation to natural beauty based on human perceptions and evaluations.                                                                            | These are places that are important to me because of the attractive scenery, smells, sights, sounds, etc.                                                                                    |
| 4   | Source of inspiration             | Understanding the inspirational qualities of peri-urban landscapes can provide insights into the cultural significance and symbolic meanings attributed to them by various social groups.                                                                                                                                                            | A source of inspiration for providing new thoughts, ideas, and creative expression                                                                                                                                     | These are places that are important to me because they are a source of inspiration for new thoughts, ideas, and creativity.                                                                  |
| 5   | Social relations                  | This category emphasizes the role of the landscape in fostering social cohesion, recreational gatherings, and cultural events, thereby promoting social wellbeing and inclusivity.                                                                                                                                                                   | Providing a place to spend time with friends and family, and facilitating social interactions and community engagement                                                                                                 | These are places that are important to me because here I can hang out with friends and family.                                                                                               |
| 6   | Spiritual and religious services  | Investigating this category sheds light on the spiritual connections and cultural practices associated with peri-urban landscapes, underscoring their importance beyond ecological and recreational values.                                                                                                                                          | These are spiritual experiences, religious ceremonies, and religious community events.                                                                                                                                 | These are places that are important to me because they provide a spiritual experience / they are suitable for religious ceremonies.                                                          |
| 7   | Educational resource              | Peri-urban landscapes provide educational opportunities in ecology, agriculture, history, and traditional land uses, serve as outdoor classrooms for experiential learning, and thus foster environmental literacy for children and adults.                                                                                                          | Refers to the acquisition of various types of knowledge developed by various cultures; for example, traditional and expert knowledge that comes from living in a certain area.                                         | These are places that are important to me because here I can learn about the way of life here (e.g., land cultivation or extraction of raw materials).                                       |
| 8   | Research resource                 | Peri-urban landscapes offer research opportunities in ecological processes, land-use dynamics, and human–environment interactions. Viewing them as research resources highlights their scientific value.                                                                                                                                             | Providing biodiversity research about the flora and fauna of the area.                                                                                                                                                 | These are places that are important to me because here I can learn about different plants and animals.                                                                                       |
| 9   | Cultural significance             | Peri-urban landscapes hold cultural heritage, stories, and traditions. Recognizing their cultural significance is key to promoting conservation amid urbanization pressures.                                                                                                                                                                         | Refers to the contribution to the diversity of the landscape (cultural landscape) or to landscape-specific plant and animal species.                                                                                   | These are places that are important to me because of their cultural value (e.g., archaeological sites, parks, traditional landscapes, castles, monuments, historical village centers, etc.). |

| 10. In this area, there are places that are important to me ...<br>(for each activity or experience, choose one statement)                          |                          |                          |                          |                          |  On the map, mark in PINK the places you have identified as <b>important</b> , and assign a number as indicated below. |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                                                                     | Not important            | IMPORTANT                |                          |                          |                                                                                                                                                                                                           |
|                                                                                                                                                     |                          | Slightly important       | Moderately important     | Very important           |                                                                                                                                                                                                           |
| because of the recreational opportunities they offer.                                                                                               | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <b>1</b>                                                                                                                                                                                                  |
| because of the attractive scenery, smells, sights, sounds, etc.                                                                                     | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <b>2</b>                                                                                                                                                                                                  |
| because of their cultural value (e.g., archaeological sites, parks, traditional landscapes, castles, monuments, historical village centers., etc.). | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <b>3</b>                                                                                                                                                                                                  |
| because here I feel connected to the local place.                                                                                                   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <b>4</b>                                                                                                                                                                                                  |
| because here I can learn about different plants and animals.                                                                                        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <b>5</b>                                                                                                                                                                                                  |
| because here I can learn about the way of life here (e.g., land cultivation or extraction of raw materials).                                        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <b>6</b>                                                                                                                                                                                                  |
| because here I can hang out with friends and family.                                                                                                | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <b>7</b>                                                                                                                                                                                                  |
| because they provide a spiritual experience / they are suitable for religious ceremonies.                                                           | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <b>8</b>                                                                                                                                                                                                  |
| because they are a source of inspiration for new thoughts, ideas, and creativity.                                                                   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <b>9</b>                                                                                                                                                                                                  |
| Other: _____                                                                                                                                        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <b>10</b>                                                                                                                                                                                                 |

**Fig. A1.** Survey question on the perceived importance of CES in peri-urban landscapes of Ljubljana, Kranj, and Koper. Respondents marked important locations on a map using pink color and corresponding numbers.

**Table A2**

List of geographical variables and their descriptions.

| No. | Variable                          | Description                                                                                         | Data source* and data set dates                  |
|-----|-----------------------------------|-----------------------------------------------------------------------------------------------------|--------------------------------------------------|
| 1   | Arable land                       | Agricultural areas, constantly tilled surface without permanent crops (e.g., fields)                | Ministry of Agriculture, Forestry and Food, 2023 |
| 2   | Permanent crops                   | Areas covered by perennial crops such as greenhouses, vineyards, orchards, and olive groves         | Ministry of Agriculture, Forestry and Food, 2023 |
| 3   | Meadows, pastures, and grasslands | Areas used for mowing and grazing                                                                   | Ministry of Agriculture, Forestry and Food, 2023 |
| 4   | Forest                            | Areas covered by forest                                                                             | Ministry of Agriculture, Forestry and Food, 2023 |
| 5   | Water                             | Natural and artificial surface waters (rivers, lakes, the sea)                                      | Slovenian Water Agency, 2021                     |
| 6   | Wetlands                          | Bogs, wetlands, salt marshes                                                                        | Ministry of Agriculture, Forestry and Food, 2023 |
| 7   | Overgrowth                        | Areas overgrown with forest trees                                                                   | Ministry of Agriculture, Forestry and Food, 2023 |
| 8   | Bare land                         | Undeveloped, mostly natural land with little or no vegetation (beaches, dunes, gravel areas, scree) | Ministry of Agriculture, Forestry and Food, 2023 |

(continued on next page)



**Table A2** (continued)

| No. | Variable                      | Description                                                                                                                                           | Data source* and data set dates                                                                                                                                                                   |
|-----|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9   | Transport infrastructure      | Roads (highways, main roads, parking), railways, airports, ports                                                                                      | Surveying and Mapping Authority of the Republic of Slovenia, 2022                                                                                                                                 |
| 10  | Public infrastructure         | Energy production areas (power plants of all kinds), waste management areas, power lines, etc.                                                        | Ministry of Natural Resources and Spatial Planning, 2023; Surveying and Mapping Authority of the Republic of Slovenia, 2022                                                                       |
| 11  | Brownfield                    | Degraded, abandoned, and exposed areas due to human activity (gravel pits, mines)                                                                     | Ministry of Natural Resources and Spatial Planning, 2023; Surveying and Mapping Authority of the Republic of Slovenia, 2022                                                                       |
| 12  | Exclusive use                 | Non-residential large built-up areas for exclusive use (industrial, logistics, military areas)                                                        | Ministry of Natural Resources and Spatial Planning, 2023                                                                                                                                          |
| 13  | Wider use                     | Large non-residential built-up areas for wider use (campuses, shopping centers, hospitals)                                                            | GmbH, OpenStreetMap Contributors, 2023; Ministry of Natural Resources and Spatial Planning, 2023;                                                                                                 |
| 14  | Green space                   | Maintained green areas and associated infrastructure for public use (parks, children's playgrounds, leisure facilities, hiking trails, bicycle paths) | GmbH, OpenStreetMap Contributors, 2023; Ministry of Natural Resources and Spatial Planning, 2023;                                                                                                 |
| 15  | Sports and tourism            | Maintained green areas and associated infrastructure for sports and tourism (stadiums, golf courses, racecourses, camp sites)                         | GmbH, OpenStreetMap Contributors, 2023; Ministry of Natural Resources and Spatial Planning, 2023; Slovenian Water Agency, 2021; Surveying and Mapping Authority of the Republic of Slovenia, 2022 |
| 16  | Residential                   | Areas of predominantly houses and/or residential–agricultural compounds                                                                               | Ministry of Natural Resources and Spatial Planning, 2023                                                                                                                                          |
| 17  | Mixed-use areas               | Areas of predominately mixed use (housing, public services, shops, tourism, etc.)                                                                     | Ministry of Natural Resources and Spatial Planning, 2023                                                                                                                                          |
| 18  | Nature conservation           | Protected natural areas of national or wider importance (Natura 2000 sites, landscape parks, etc.)                                                    | Slovenian Environment Agency, 2010, 2015, 2018                                                                                                                                                    |
| 19  | Cultural landscapes           | Historically and culturally important landscapes and their parts, such as archaeological sites, heritage, monuments, outstanding landscapes           | Ministry of Culture, 2021                                                                                                                                                                         |
| 20  | Cultural heritage settlements | Culturally valuable settlements and their parts (historical village cores, traditional village patterns)                                              | Ministry of Culture, 2021                                                                                                                                                                         |

\*Data source URL:

- GmbH, OpenStreetMap Contributors: <https://www.openstreetmap.org>- Ministry of Agriculture, Forestry and Food: <https://www.gov.si/teme/register-kmetijskih-gospodarstev-in-evidenca-dejanske-rabe/>- Ministry of Culture: <https://www.gov.si/teme/register-kulturne-dediscine/>- Ministry of Natural Resources and Spatial Planning: <https://www.gov.si/novice/2021-12-13-evidenca-stavbnih-zemljisc-zelite-graditi-pa-ne-veste-kje/>- Slovenian Environment Agency: <https://www.arso.gov.si/>- Slovenian Water Agency: <https://www.gov.si/drzavni-organi/organi-v-sestavu/direkcija-za-vode/>- Surveying and Mapping Authority of the Republic of Slovenia: <https://www.e-prostor.gov.si/podrocja/gospodarska-javna-infrastruktura/zbirni-kataster-gji/>.**Table A3**

Number of locations by CES category marked on maps by respondents across the three study areas (note: one location marked could represent more than one CES category.).

| No. | CES category                      | No. of locations marked | Ljubljana    | Kranj        | Koper      |
|-----|-----------------------------------|-------------------------|--------------|--------------|------------|
| 1   | Leisure and recreation activities | 1,202                   | 621          | 383          | 198        |
| 2   | Sense of place and identity       | 522                     | 232          | 176          | 114        |
| 3   | Aesthetic value                   | 864                     | 408          | 295          | 161        |
| 4   | Source of inspiration             | 464                     | 219          | 164          | 81         |
| 5   | Social relations                  | 784                     | 374          | 261          | 149        |
| 6   | Spiritual and religious services  | 294                     | 141          | 92           | 61         |
| 7   | Educational resource              | 461                     | 202          | 146          | 113        |
| 8   | Research resource                 | 563                     | 262          | 180          | 121        |
| 9   | Cultural significance             | 520                     | 249          | 159          | 112        |
|     | <b>Total</b>                      | <b>2,929</b>            | <b>1,200</b> | <b>1,142</b> | <b>586</b> |

**Table A4**

Results of Kruskal-Wallis tests and post-hoc pairwise comparisons for CES categories across the three study areas.

| CES category                      | Kruskal-Wallis <i>p</i> | Decision     | Post-hoc pairwise comparisons (Mann–Whitney <i>U</i> , Bonferroni-adjusted $\alpha = 0.0167$ )*                                                                                                                                                                                                                                                                                                                                                       |
|-----------------------------------|-------------------------|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Leisure and recreation activities | 0.335                   | Retain $H_0$ | —                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Sense of place and identity       | < 0.001                 | Reject $H_0$ | Ljubljana ( $M = 299.11$ ) vs. Koper ( $M = 414.05$ ), $U = 14,093.000$ , $p < 0.001$<br>Kranj ( $M = 337.64$ ) vs. Koper ( $M = 414.05$ ), $U = 13,160.000$ , $p < 0.001$<br>Kranj ( $M = 337.64$ ) vs. Ljubljana ( $M = 299.11$ ), $U = 30,454.000$ , $p = 0.012$                                                                                                                                                                                   |
| Aesthetic value                   | 0.128                   | Retain $H_0$ | —                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Source of inspiration             | 0.006                   | Reject $H_0$ | Ljubljana ( $M = 313.83$ ) vs. Koper ( $M = 374.61$ ), $U = 16,949.000$ , $p = 0.001$                                                                                                                                                                                                                                                                                                                                                                 |
| Social relations                  | 0.750                   | Retain $H_0$ | —                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Spiritual and religious services  | < 0.001                 | Reject $H_0$ | Ljubljana ( $M = 306.56$ ) vs. Kranj ( $M = 370.86$ ), $U = 28,331.000$ , $p < 0.001$<br>Koper ( $M = 353.83$ ) vs. Ljubljana ( $M = 306.56$ ), $U = 18,405.500$ , $p = 0.012$<br>Kranj ( $M = 338.56$ ) vs. Koper ( $M = 421.70$ ), $U = 13,138.000$ , $p < 0.001$<br>Ljubljana ( $M = 299.17$ ) vs. Koper ( $M = 421.70$ ), $U = 13,697.500$ , $p < 0.001$<br>Ljubljana ( $M = 299.17$ ) vs. Kranj ( $M = 338.56$ ), $U = 30,883.000$ , $p < 0.015$ |
| Educational resource              | < 0.001                 | Reject $H_0$ |                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

(continued on next page)

Table A4 (continued)

| CES category          | Kruskal-Wallis <i>p</i> | Decision     | Post-hoc pairwise comparisons (Mann–Whitney U, Bonferroni-adjusted $\alpha = 0.0167$ )*                                                                  |
|-----------------------|-------------------------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Research resource     | < 0.001                 | Reject $H_0$ | Kranj (M = 322.30) vs. Koper (M = 401.39), U = 13,448.500, $p < 0.001$<br>Ljubljana (M = 321.19) vs. Koper (M = 401.39), U = 16,335.500, $p < 0.001$     |
| Cultural significance | 0.003                   | Reject $H_0$ | Koper (M = 374.13) vs. Ljubljana (M = 314.09), U = 17,773.500, $p = 0.002$<br>Kranj (M = 354.87) vs. Ljubljana (M = 314.09), U = 31,182.500, $p = 0.013$ |

Null hypothesis ( $H_0$ ): The distribution of responses across the three regions (Ljubljana, Kranj, Koper) is the same for each CES category.

\*Only significant pairs are reported.

Table A5

Percentage of individual geographical variables in each study area (%).

| No. | Geographical variable             | Ljubljana | Kranj | Koper |
|-----|-----------------------------------|-----------|-------|-------|
| 1   | Arable land                       | 14.99     | 24.20 | 6.26  |
| 2   | Permanent crops                   | 0.92      | 0.57  | 20.32 |
| 3   | Meadows, pastures, and grasslands | 24.86     | 13.59 | 7.77  |
| 4   | Forest                            | 34.52     | 29.48 | 24.14 |
| 5   | Water                             | 1.16      | 1.28  | 1.63  |
| 6   | Wetlands                          | 0.04      | N/A   | 0.49  |
| 7   | Overgrowth                        | 4.67      | 1.13  | 8.32  |
| 8   | Bare land                         | 0.00      | 0.02  | 0.02  |
| 9   | Transport infrastructure          | 0.16      | 0.11  | 0.24  |
| 10  | Public infrastructure             | 0.64      | 1.83  | 0.33  |
| 11  | Brownfield                        | 0.04      | 0.01  | 0.04  |
| 12  | Exclusive use                     | 0.21      | 0.98  | 1.10  |
| 13  | Wider use                         | 0.36      | 4.47  | 0.94  |
| 14  | Green space                       | 0.12      | 0.13  | 0.12  |
| 15  | Sports and tourism                | 0.35      | 0.54  | 0.19  |
| 16  | Residential                       | 5.07      | 4.84  | 5.30  |
| 17  | Mixed-use areas                   | 0.61      | 0.48  | 0.50  |
| 18  | Nature conservation               | 50.40     | 13.99 | 11.87 |
| 19  | Cultural landscapes               | 40.89     | 10.85 | 16.19 |
| 20  | Cultural heritage settlements     | 2.18      | 24.58 | 0.91  |

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