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Molecular & Cellular Biomechanics 2025, 22(4), 1593.
https://doi.org/10.62617/mcb1593

Article

Public perception of cultural ecosystem services in Dalian Xijiao Forest Park: A biomechanical perspective

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CITATION

Duan Y, Yang C, Zhang Q, Cheng J. Public perception of cultural ecosystem services in Dalian Xijiao Forest Park: A biomechanical perspective. Molecular & Cellular Biomechanics. 2025; 22(4): 1593. https://doi.org/10.62617/mcb1593

ARTICLE INFO

Received: 17 February 2025
Accepted: 10 March 2025
Available online: 17 March 2025

Abstract: Forest parks constitute one of the crucial types of urban green spaces. Studying cultural ecosystem services (CESs) in forest parks is critical for ecological conservation and human well-being. Taking Xijiao Forest Park (XFP) in Dalian, Liaoning Province, as the study area, the Latent Dirichlet Allocation (LDA) model was applied to extract latent topic classifications from web text data. An evaluation system was established by integrating the public participation geographic information system (PPGIS) and the social values for ecosystem services (SolVES) model, which is a spatially explicit tool that quantifies perceived social values through participatory mapping and environmental variable integration. This approach was used to analyze the spatial distribution of the value of its CESs and to identify the environmental factors influencing these values. The results indicate the following: (1) Public perception encompasses 28 topic levels, which incorporate seven value dimensions: Aesthetics, recreation and ecotourism, social relationships, wellness, education, cultural heritage, and inspiration. (2) The values of diverse CESs within the park (XFP) exhibit considerable spatial heterogeneity, depicting a pattern where high values occur in the north and south and low values occur in the east and west. The aesthetic, recreation and ecotourism, social relationship, and wellness values are relatively highly favored by the public. (3) The three environmental factors, namely, scenic spots, water bodies, and roads, have a more pronounced effect on the CES value. This study uses the novel approach of constructing models for web text data to evaluate the CES value.

Keywords: forest park; culture ecosystem services; PPGIS; SolVES model; LDA topic model

1. Introduction

Cultural ecosystem services (CESs) are the nonmaterial benefits that humans obtain from ecosystems, mainly encompassing spiritual gratification, cognitive advancement, aesthetic encounter, and leisure and recreation [1] emphasizing the interactive experience between humans and nature. Forest parks, as a type of urban green space, have multiple CES functions. They not only regulate the climate, purify the environment, and safeguard biodiversity but also play a crucial role in ecology, leisure and recreation, and physical and mental health [1–3]. With respect to urban territorial spatial planning and territorial spatial restoration and construction, the government places great importance on the contribution of forest park CESs to human well-being and prioritizes its role in enhancing human well-being. Hence, it is of great significance for the development of forest parks to effectively assess the CESs of forest parks, clarify the relationship between the construction of forest parks and human well-being, and conduct planning services and management practices in accordance with local conditions. The study objects of CESs are predominantly concentrated on forests [4], wetlands [5], and urban green spaces [6]. In particular, research on the

CESs of urban green spaces is relatively abundant, focusing on aspects such as value assessment models, perception and selection preferences, human well-being, and stakeholder involvement. Recreational accessibility, multi-source data, and potential indicators are employed to evaluate the supply and demand for CESs in urban parks and to provide recommendations for optimizing park planning [7]. To examine the diverse behavioral responses of urban residents across various locations, gain insights into their perceptions and preferences, and provide a novel perspective on how urban residents' interaction with nature influences their social lives and psychological behaviors [8]. To explore the differences in value demand and acquisition among residents from the perspective of the landscape spatial environment and to highlight the varying demands of different stakeholders for urban park CESs and their relationship with the landscape spatial environment [9]. With respect to assessment methods, the commonly adopted approaches are biological, value, and model assessments. In the early stage of value assessment, monetized value assessment methods such as travel cost [10,11], contingent valuation [12,13], and willingness-to-pay [12,14] were commonly used. However, the nonmaterial nature and other inherent characteristics of CESs impose methodological constraints on monetary valuation approaches [15–17]. Consequently, previous assessments have struggled to adequately capture the spatial features of these services.

In recent years, owing to the integration of knowledge from various related disciplines such as ecology, geography, and sociology, value assessment studies at home and abroad have placed greater emphasis on online location photography methods (utilizing social media platforms such as Twitter, Flickr, and Instagram) [5,18,19], as well as questionnaires, interviews [20,21], web text [4,17], and public participation geographic information system (PPGIS), which can to a certain extent exhibit the spatial distribution of CESs. Nevertheless, online location photography methods are restricted to presenting the recreational services and aesthetic value of images and fail to depict the diversity of CESs, whereas the questionnaires, interviews, and web text lack an in-depth description of the relationship between service functions and environmental variables.

To sum up, research on CESs is predominantly conducted from the policy decision-making management perspective [22]and the natural resource protection and utilization viewpoint [23]. Most current studies rely on single-value assessment or model simulation methods, overlooking the importance of public perception in the evaluation of CESs. This study aims to address these gaps and provide a more comprehensive assessment framework. Furthermore, existing studies generally lack longitudinal data on CESs, particularly regarding long-term changes, limiting a thorough understanding of their spatiotemporal variations [24]. Additionally, current assessment methods have yet to establish a framework effectively linking ecosystem functions to service provision, which may result in evaluations that do not fully capture the true value of CESs. Hence, there is an urgent need to explore ways to enhance the depth, breadth, and efficacy of CES assessment models, allowing a more scientifically rigorous assessment of forest parks.

The social values for ecosystem services (SolVES) model provides a comprehensive assessment, quantification, and mapping of CES values, such as aesthetics, recreation, and wellness [25]. In addition, it can position the CES value

index perceived by the public in a specific space in a graphical manner [26,27], allowing the public to accurately and clearly comprehend its CES value index. The maximum entropy model (MaxEnt) embedded in this model can generate a robust model that explains the relationship between the CES value and environment variable [27]. Spatial pattern analysis of social values using the SolVES model facilitates accurate and targeted resource assessment, planning, and management of forests and other ecosystems [25]. CESs, as carriers of intangible cultural values for humans, require quantification through public perception data. The Latent Dirichlet Allocation (LDA) topic model, a natural language processing technique, is applied to extract semantic topics from fragmented web reviews, facilitating the identification of public perception dimensions of CESs from unstructured data [28]. The PPGIS integrates geographic information system (GIS) technology with public participation, collecting public perceptions and spatial preferences through map-based marking and surveys to support environmental management and planning decision-making [29]. The SolVES model, a spatial analysis tool based on the MaxEnt algorithm, quantifies the relationship between public perception data and environmental variables. It subsequently translates the intangible values of CESs, such as aesthetics and wellness, into visualized heatmaps, thereby revealing their spatial distribution characteristics and environmental influencing factors [27]. Therefore, we employ PPGIS and SolVES to accentuate the spatial visualization of forest park CESs and conduct an in-depth analysis of the influence of environmental variables on CESs. This precisely addresses the current predicament where people have an unclear understanding of the CES value in forest parks and the absence of evidence-based management and protection [26,30].This study employs web-based text data from six social media platforms (Dianping, Mafengwo, Ctrip, Weibo, Xiaohongshu, and TikTok) to derive semantic information on CESs [31,32] Nevertheless, web text data are typically fragmented, and user comments and other information are scattered and unorganized, making it challenging to systematically depicting and analyzing the overall panorama of CESs. The LDA topic model [33,34] is a generative statistical model that can identify potential topics from a vast amount of text data and discern the main topics and trends discussed by users. These topics can represent the diverse perceptions and demands of the public for CESs and play a crucial role in identifying the categories of CESs and assessing their value. Simultaneously, they can lower the data acquisition cost and enhance the assessment efficiency.

The Xijiao Forest Park (XFP) in Dalian, Liaoning, relies on the distinctive ecosystem between the mountains and waters in the western suburbs and is a unique urban cultural and ecological resource integrating ecological tourism, leisure and entertainment, and cultural experience. With XFP as the study area, web text data is utilized to extract the perceived dimensions of CESs through the LDA topic model, facilitating the classification of CES categories and the identification of key service types of public concern. Furthermore, the spatial distribution patterns of CESs are visualized through spatial mapping based on the PPGIS method. The SolVES model is applied to quantify the influence of environmental variables on CESs, elucidating the spatial mechanisms by which different environmental variables affect the value of specific CESs. This approach not only compensates for the shortcomings of traditional questionnaires in data acquisition but also offers a novel method to assess CESs in

forest parks.

2. Study area and data sources

2.1. Study area

The Xijiao Forest Park (38°43′–40°10′ N, 120°58′–123°31′ E) encompasses a total area of 5958 hm^2 (**Figure 1**). This park has a core with an original ecological style; adheres to the notion of sustainable development; boasts abundant animal, plant, and water body resources; and is a leisure tourism resort integrating leisure and entertainment, popular science education, and sightseeing. As an important component of natural protected areas, it is among the most crucial places for the public nature and experience the forest CESs.

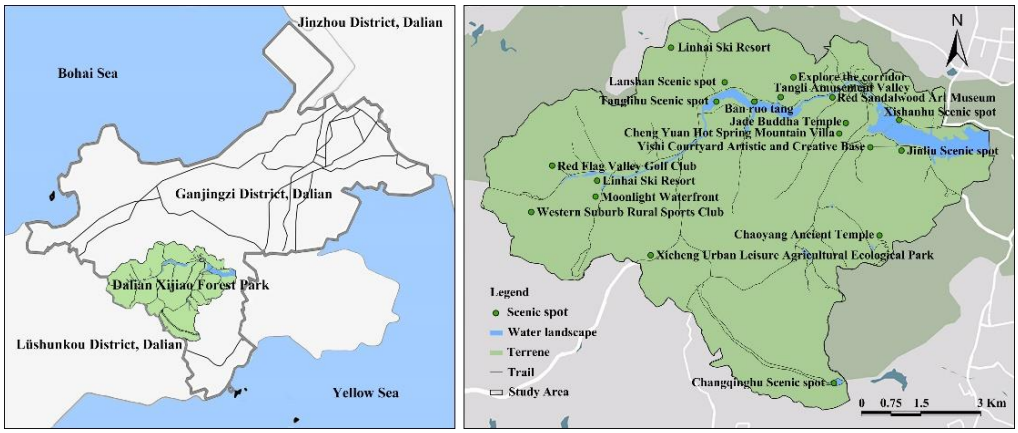

Figure 1. Location of the study areas.

2.2. Methodological flow

Using XFP as the search keyword and employing web crawler tools, relevant web text data from social media platforms are collected and preprocessed using the Jieba word segmentation tool. The LDA topic model is then utilized to identify public perception preferences and, in conjunction with the specific features of XFP, to determine the value types of its CESs. Subsequently, the perceptual topics derived from the LDA topic model are mapped to the corresponding CES categories. Building upon this, an evaluation system for CES values is established, with evaluation indicators incorporated into the PPGIS questionnaire. Based on the data provided by users, spatial clustering and environmental impact factor analyses of CES values are conducted (**Figure 2**). In accordance with ethical requirements, user names in the PPGIS questionnaire and web text data have been removed, and geographical locations are generalized to the city or regional level to ensure the protection of privacy.

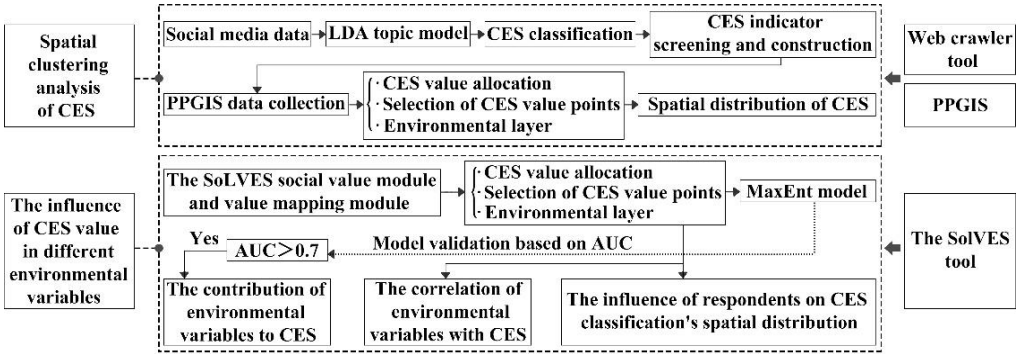

Figure 2. Method flow chart.

2.3. Data source and processing

2.3.1. Web text data processing

This study selected six platforms, namely Dianping, Mafengwo, Ctrip, Weibo, Xiaohongshu, and Tiktok, as data sources. These platforms combine social media attributes with comprehensive life service functionalities. They have a large user base and broad coverage, providing multimodal review data, including text, images, and videos. Additionally, they grant access to users' basic information and multidimensional event attributes, such as geographic coordinates, ratings, review content, and timestamps, thereby meeting the requirements for user behavior analysis.

A total of 4092 web-based textual data entries were collected using "XFP" as the keyword through web scraping tools (we collected data from all available time periods). To ensure data quality and validity, low-value content was manually eliminated, followed by data cleaning, Chinese word segmentation, and stop-word removal. The specific processing steps were as follows: (1) Duplicated comments, short comments with fewer than five characters, and invalid texts (e.g., emoticons, garbled codes) were removed; (2) the Jieba word segmentation tool was employed, and a dictionary of proper nouns was compiled based on relevant literature [35] and incorporated into the segmentation library to enhance segmentation accuracy; (3) the stop-word lists from Sichuan University and Harbin Institute of Technology were adopted to filter non-informative words (e.g., pronouns, conjunctions). The latest version of the Harbin Institute of Technology stop-word list was applied to further refine the data, thereby enhancing the accuracy of topic extraction. Ultimately, 3986 comments were retained.

The LDA topic model can accurately capture topic diversity and structural patterns from large volumes of text, making it particularly advantageous for handling the implicit complex structures in long-text data, while also demonstrating high effectiveness and applicability. The preprocessed web text data were analyzed using the LDA topic model to identify and extract latent perceptual topic words. When the number of topics is set to 28 (K = 28), the topic coherence score reaches its optimal value. Therefore, the number of topics, K, is set to 28.

The 28 generated topics are categorized into natural landscape and human landscape classes (**Figure 3**). The natural landscape class encompasses Topic8, Topic9, Topic12, Topic15, Topic19, and Topic26. The related topics words are "beautiful scenery", "rich vegetation", "the time corridor", "nine islands of wetland",

"forest landscape", "quiet and secluded environment", "plant configuration", "plant seasonal changes", "waterscape", "wonderful view", "natural green lung", and "landscape diversity", among others. These topics reflect the public's aesthetic experience within the natural ecosystem, thereby attaining a landscape perception experience of harmonious coexistence between humans and nature. Human landscape topics comprise Topic1, Topic2, Topic3, Topic4, Topic5, Topic6, Topic7, Topic10, Topic11, Topic13, Topic14, Topic16, Topic17, Topic18, Topic20, Topic21, Topic22, Topic23, Topic24, Topic25, Topic27, and Topic28. Among them, the topic words in Topic1, Topic4, Topic5, Topic7, Topic10, Topic14, and Topic23 encompass "Tanglihu scenic spot", "stroll", "entertainment recreation", "outdoor activities", "lawn", "camping", "leisure", "Xishan lake scenic spot", "picnic", "children's playground", "an attractive spot", "fresh air", "Changqinghu scenic spot", "nature conservation area", etc. These topics indicate the resources and activities such as entertainment, leisure, and diversion offered by the natural ecosystem to the public and are categorized as types of leisure and ecotourism. The topic words in Topic2, Topic11, Topic18, and Topic25 cover "children", "parent-child activity", "walk with the kids", "family outing", "lively and noisy", "friend gathering", "team building", "social interaction", etc. These topics indicate scenes in which family and friends enhance emotional bonds and unwind through various forms of communication and activities. The topic words in Topic3, Topic20, Topic24, and Topic28 are "basking in the sun", "comfortable", "exercise", "eliminate fatigue", "natural oxygen bar", "healing", "agritainment", "picking", etc. These topics cover activities that are conducive to physical and mental health, as well as leisure and enjoyment for the public in natural environments. Topic21 and Topic22 focus on topic words such as "Chaoyang Ancient Temple", "have a long history", "hot spring water", "temple", etc. These topics incorporate cultural, historical, and spiritual experiences, presenting the cultural heritage and spiritual purification perceived by the public in the place. The topic words in Topic13, Topic16, and Topic27 are "nature education", "popularization of science", "spreading knowledge", "flora and fauna", "experiences", "observations", etc. These topics indicate educational and experiential activities in ecological environments, allowing the public to acquire rich knowledge and sensory experiences, thereby enhancing their comprehension and awareness of nature and cultural conservation. Topic6 and Topic17 contain elements such as "artistic conception", "color", "inspiration", "hand painting", etc. These topics integrate natural landscapes and artistic creation, aiming to stimulate public creativity and artistic inspiration by depicting and experiencing natural elements, and further disclose the unique value of natural landscapes in cultural creation and artistic experience.

Figure 3. LDA-perceived topic words.

Note: The word clouds for 28 topics are arranged in descending order based on their probability distribution. For each topic, the word cloud displays the top 20 words with the highest probabilities, with the size of each word indicating its occurrence probability within the respective topic.

2.3.2. Participatory mapping survey data

The perceived topics extracted using the LDA topic model are associated with CES categories. In accordance with relevant literature [29,36,37] and the specific characteristics of XFP, seven value types, namely, aesthetics, recreation and ecotourism, social relationships, wellness, education, cultural heritage, and inspiration, are selected as the criterion layer indicators for the CES assessment system of this park. Based on the distribution of LDA topic words and the study conducted by Boyd et al. [38–41], the connotations of these seven types of CESs are defined, and the LDA topic words are subsequently matched to these specific value types, as shown in **Table 1**.

Table 1. Description of CES value.

CES value types	Description of CES value	Example of topic words	Topics included
Aesthetic	A place of scenic beauty.	Beautiful scenery, rich vegetation, etc.	Topics 8, 9, 12, 15, 19, and 26
Recreation and ecotourism	Conduct entertainment, recreational, and ecotourism activities.	Picnicking, camping, going boating, etc.	Topics 1, 4, 5, 7, 10, 14, and 23
Social relationship	The natural place for activities with friends, family, etc.	Parent-child activities, family outing, social interaction, etc.	Topics 2, 11, 18, and 25
Wellness	Places for sports, relaxation, etc., which allow people to have a better psychological and physiological experience.	Healing, eliminate fatigue, pick, etc.	Topics 3, 20, 24, and 28
Education	A place for the accretion of natural and humanistic knowledge.	Popularization of science, knowledge, experience, etc.	Topics 13, 16, and 27
Cultural heritage	Containing cultural and historical values.	Chaoyang Ancient Temple, hot spring, etc.	Topics 21 and 22
Inspiration	Offer inspiration for artistic creation.	Paint, creativity, landscape, etc.	Topics 6 and 17

Based on the acquisition of the value perception classification of CESs in the XFP from web text data, the value classification of CESs domestically and internationally, landscape assessment indicators, and current national standards as the starting points. After the value classification of CESs is determined, an assessment system appropriate for the CES value of this park is established, and specific weights are assigned using the expert grading method, as shown in **Table 2**.

Table 2. Value indicators of CESs.

CES value types	Indicator
Aesthetic B1 (0.2731)	Topographic form diversity C1 (0.0136) [42], plant seasonal phase changes C2 (0.0718) [42], plant configuration C3 (0.0718) [43], road pavement C4 (0.0267) [44], architectural landscape C5 (0.0429) [45], integration between plants and surrounding landscape C6 (0.0742) [44], water landscape C7 (0.0444) [46], guide the aesthetics of the signage system C8 (0.0316) [45,46], aesthetics of recreational service facilities C9 (0.0288) [45,46], landscape composition levels C10 (0.0718) [42]
Recreation and ecotourism B2 (0.2731)	Accessibility C1 (0.0279) [47], recreational open space within the forest C2 (0.0628) [42], diversity of recreational spaces C3 (0.0341) [45], diversity of recreational activity types C4 (0.0628) [45], interesting aspects of recreational activities C5 (0.0341) [42,47], under forest activity space C6 (0.0628) [42], recreational service facilities C7 (0.0628) [46,48], scenic spot interpretation, and guidance information facilities C8 (0.0628) [45,46], coverage degree of network signal C9 (0.0299) [45], accessible routes and information accessibility C10 (0.0628) [45,46]
Social relationship B3 (0.1722)	Family activities C1 (0.3873) [49], friend gatherings C2 (0.1698) [48], organized activities C3 (0.4429) [49]
Wellness B4 (0.1272)	Static recreational activities C1 (0.0719) [49], entertainment C2 (0.3034) [50], outdoor exercise C3 (0.3034) [50], comfortable environment C4 (0.3213) [48]
Education B5 (0.0512)	Geographic environment knowledge C1 (0.0791) [51], knowledge of flora and fauna C2 (0.3070) [51], sociocultural knowledge C3 (0.2877) [51], popular science publicity facilities C4 (0.3262) [51]
Cultural heritage B6 (0.0619)	Art exhibition C1 (0.1429) [52], historical architecture C2 (0.4286) [52], folk custom C3 (0.4286) [52]
Inspiration B7 (0.0412)	Photography Inspiration C1 (0.2500) [50], artistic inspiration enlightenment C2 (0.7500) [50]

Before conducting the formal investigation, a preliminary field survey was

conducted in the study area, followed by the development of a questionnaire in accordance with the previously established CES value assessment system. The questionnaire is categorized into three parts. Part 1 concerns the visiting characteristics and feelings of the respondents. For Part 2, formulated labels in accordance with the definitions of aesthetic, recreation and ecotourism, social relationships, wellness, education, cultural heritage, and inspiration values. Respondents would match one to three scenic spots for each type of CES value based on the map within the questionnaire and assign a score (i.e., monetary allocation) to these CES value types, with a total expenditure limit of 100 RMB. Part 3 involves the basic information of the respondents. From July to August 2023, face-to-face survey data collection was conducted in XFP, acquiring a total of 300 valid questionnaires.

2.3.3. Data related to natural environmental elements

Using ArcGIS 10.5, maps of XFP and the survey data of PPGIS were separately digitized to acquire the boundary layer of the study area and the value point layer of CESs. In accordance with the environmental characteristics of XFP and relevant literature [26], the elevation and slope elements were extracted from the DEM data of the study area. In addition, Euclidean distance analysis was conducted on the four types of elements, namely, scenic spots, water bodies, roads, and vegetation, to yield the corresponding six single-variable environmental layers, namely, distance to water (DTW), distance to roads (DTR), distance to vegetation (DTV), distance to scenic spots (DTSS), elevation (ELEV), and slope (SLOPE), and the comprehensive variable (DTR-DTW-DTV-DTSS-ELEV-SLOPE), amounting to seven environmental layers, as the natural resource conditions of the study area.

3. Results

3.1. Social demographic characteristics: Analysis of the radiation population of XFP

A statistical analysis of the collected PPGIS survey information was conducted. The results reveal that 52.7% of the respondents were male and 47.3% were female, with a nearly equal gender ratio. The age group of the tourists is predominantly young and middle-aged, with 75.4% of the respondents being under 65 years and 24.6% being the elderly (over 65 years). The respondents have various occupations and high educational attainment, with 56.8% having a college degree or above.

3.2. Spatial clustering analysis

3.2.1. Spatial distribution of CES value

The spatial distribution density of the CES value points can, to a certain extent, reflect the public's perception and preference for the scenic spots within the forest park (**Figure 4**). The value spatial distribution of CESs in the XFP considerably varies, with high-density clustering observed in the Tanglihu scenic spot and Lanshan scenic spot in the north, Changqinghu scenic spot in the south, and Xishanhu scenic spot in the northeast. By contrast, the public perception in the western and eastern areas is relatively low. The scenic spots in these high-density areas are preferred by the public

owing to their beautiful natural landscape, and diverse ecological environment, and comprehensive facilities. This preference suggests that the public favors scenic spots that provide a holistic experience and a rich variety of amenities when selecting tourist sites.

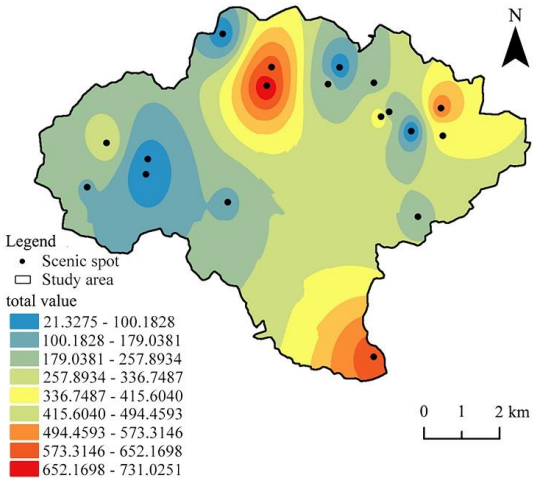

Figure 4. Spatial distribution of CES value.

3.2.2. Spatial clustering analysis on the CES value

The SolVES model employed the average nearest neighbor tool of ArcGIS to analyze the value of seven CESs in XFP. These findings indicate that the spatial distribution of the seven CES types within the park exhibited a spatial aggregation pattern ($R < 1$). In addition, the importance of the seven CES types, as determined by the Maximum Value Index (MVI), is ranked as follows: aesthetic value > recreation and ecotourism value > social relationship value > wellness value > educational value > cultural heritage value > spiritual value. The MVI of these seven CES types varies to a certain extent under different environmental modes. However, these MVI values associated with educational, cultural heritage, and inspirational is identical. Thus, this study selects four value types, namely, aesthetic, recreation and ecotourism, social relationship, and wellness, that are of relatively higher importance as targets for further discussion (**Table 3**).

A density analysis of the top four ranked CES values in XFP, namely, aesthetic, recreation and ecotourism, social relationship, and wellness, was conducted to precisely recognize the spatial agglomeration relationships of the CES value points of the park. As shown in **Figure 5**, from the density analysis, the aesthetic and recreation and ecotourism values are most highly aggregated in the north (Tanglihu and Lanshan scenic spots), south (Changqinghu scenic spot), and northeast (Xishanhu scenic spot). These scenic spots are adjacent to water bodies, featuring dense vegetation and enchanting scenery. They offer not only excellent visual enjoyment but also a variety of activities to the public, such as sightseeing, camping, picnicking, boating, and other recreational activities. Social relationship value is concentrated in the north (Tanglihu and Lanshan scenic spots), the west (Red Flag Valley Golf Club), and the northeast (Xishanhu scenic spot, Chengyuan Hot Spring Mountain Villa). These areas supply ample facilities and venues for diverse social activities such as parent–child activities, family outings, and friend gatherings, making the park an important center for social

relationships. The high-value points of wellness value are distributed in the north (Tanglihu and Lanshan scenic spots), the northeast (Xishanhu scenic spot, Chengyuan Hot Spring Mountain Villa), the south (Changqinghu scenic spot), the west (Red Flag Valley Golf Club), and the southwest (Xicheng Urban Ecological Leisure Agriculture Park). These areas provide fitness trails, fruit and vegetable picking, and other wellness facilities, which are natural oxygen bars for relieving fatigue and nurturing the body and mind.

Table 3. MVI and spatial clustering of CES value.

CES value types	Environment variable													
	DTR		DTW		DTV		DTSS		ELEV		SLOPE		Comprehensive variables	
	MVI	*R*	MVI	*R*	MVI	*R*	MVI	*R*	MVI	*R*	MVI	*R*	MVI	*R*
Aesthetic	9	0.0811	10	0.0811	10	0.0811	10	0.0811	10	0.0811	9	0.0811	10	0.0811
Recreation and ecotourism	7	0.0750	8	0.0750	7	0.0750	8	0.0750	8	0.0750	8	0.0750	8	0.0750
Social relationship	6	0.0901	7	0.0901	6	0.0901	7	0.0901	7	0.0901	6	0.0901	7	0.0901
Wellness	5	0.0882	6	0.0882	5	0.0882	6	0.0882	6	0.0882	6	0.0882	6	0.0882
Education	5	0.0808	5	0.0808	5	0.0808	5	0.0808	5	0.0808	5	0.0808	5	0.0808
Cultural heritage	5	0.0667	5	0.0667	5	0.0667	5	0.0667	5	0.0667	5	0.0667	5	0.0667
Inspiration	3	0.0884	3	0.0884	3	0.0884	3	0.0884	3	0.0884	3	0.0884	3	0.0884

Note: $R < 1$ representing clustering; $R = 1$ representing randomness; $R > 1$ representing dispersion.

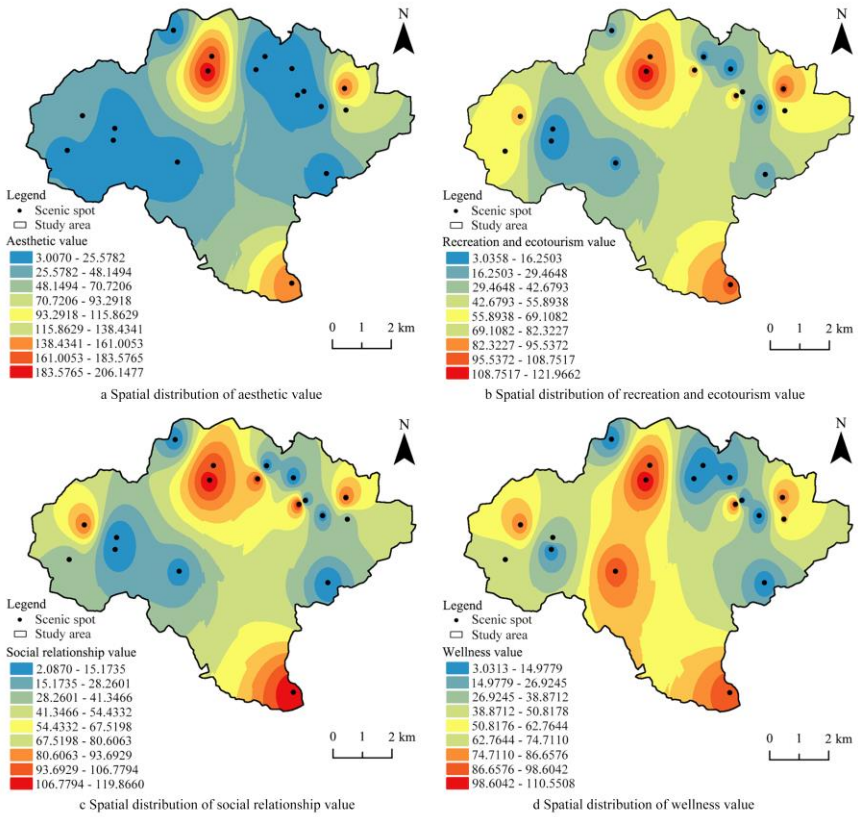

Figure 5. Spatial distribution of values of different CES types: **(a)** aesthetic value; **(b)** recreation and ecotourism value; **(c)** social relationship value; **(d)** wellness value.

3.3. Assessment of the CES values under different environmental variables

To explore the effect of various environmental factors on the CES values in XFP, six individual environmental variables (DTR, DTW, DTV, DTSS, ELEV, and SLOPE) and a suite of comprehensive environmental variables (DTR-DTW-DTV-DTSS-ELEV-SLOPE) were successively imported into the SolVES model to analyze their spatial clustering impacts and extent of contribution to the CES values in the park.

3.3.1. Impact of univariate factors on the CES value

(a). Impact of DTW on the CES value

When DTW is the sole environmental variable (**Figure 6**), the aesthetic value increases to its highest value (MVI = 10) within the range of 0–15 m and subsequently declines. This indicates that within the close proximity, water bodies can efficaciously augment the aesthetic allure through visual focus, color contrast, and spatial layering. Nevertheless, as the distance augments, its influence wanes. The values of recreation and ecotourism, social relationship, and wellness respectively peak within the intervals of −375–0 m, 0–15 m, and 0–62.5 m with the corresponding MVIs of 8, 7, and 6, respectively. This indicates that water bodies can not only heighten the attractiveness of recreational activities but also furnish an ideal milieu for the establishment and interaction of social relationships. Simultaneously, owing to the exquisite landscapes and favorable ecological conditions surrounding them, water bodies effectively enhance the wellness experience. However, in the regions distant from the core, owing to the enhancement of landscape diversity or the reduction of human interference, the values of these three CESs experience a slight increase. It is likely that the public acquires additional utility by exploring new areas or evading crowds.

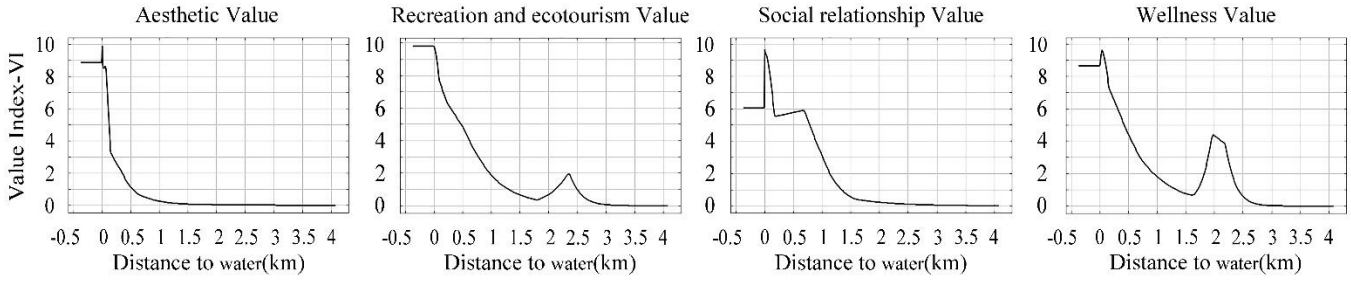

Figure 6. Distance to water and value index fitted relationships.

(b). Impact of DTR on CES value

When the DTR functions as the sole environmental variable (**Figure 7**), the aesthetic and social relationship values peak at a distance of 6 m from the road, with the corresponding MVI being 9 and 6, respectively. This distance furnishes the public with the optimal landscape perception experience and establishes ideal environmental conditions for social activities. The values of recreation and ecotourism peaked at 12 m from the road (MVI = 8), which effectively mitigates the interference of the road, offering the public a more immersive recreational experience. By contrast, the wellness value is predominantly concentrated within the range of −125–0 m from the road, revealing that areas closer to the road, owing to their convenience and accessibility of transportation and facilities, are ideal options for wellness activities.

Evidently, the public has a propensity to select areas closer to the road when engaging in wellness-related activities to guarantee the convenience of the activities and acquire a higher-quality wellness experience.

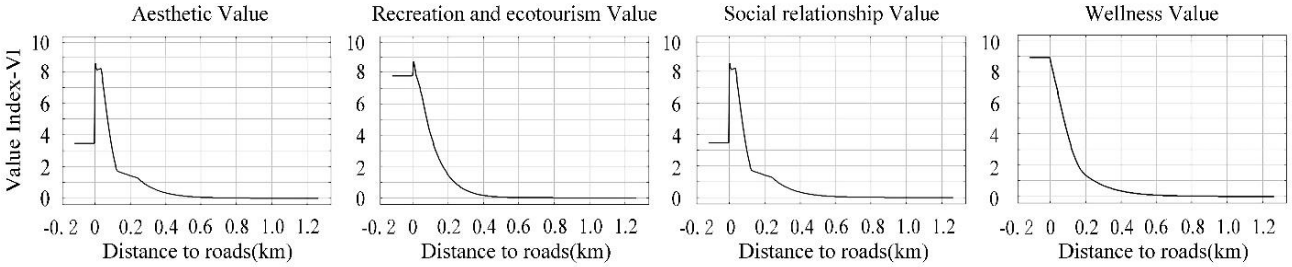

Figure 7. Distance to roads and value index fitted relationships.

(c). Impact of DTV on CES value

With respect to vegetation, being an essential landscape element of the XFP, the analysis result (**Figure 8**), with DTV as the sole environmental variable, indicates that the aesthetic and the social relationship values gradually ascend within the range of 25–400 m and 0–700 m, respectively. The peaks are positioned at 400 m (MVI = 10) and 225–700 m (MVI = 6), respectively, suggesting that an appropriate distribution of vegetation can effectively enhance the aesthetic charm of the park landscape and facilitate public interaction. In addition, the value of recreation and ecotourism moderately increases between 25 and 125 m and attains the highest value (MVI = 7) within the range of 125–400 m. Within this distance range, vegetation can enhance the allure of recreational and ecotourism activities; however, this value gradually declines after more than 400 m. Meanwhile, the wellness value rapidly escalates to the peak (MVI = 5) within the range of 0–12 m from the vegetation, suggesting that the superior landscape and ecological attributes presented by the close-range vegetation environment can efficaciously enhance the wellness experience. Subsequently, as the distance expands, this value gradually reduces but rises again from 150 to 218 m, which might be attributed to the quiet environment, less human flow, better air circulation, open vision, and activity space. Furthermore, some individuals may choose to stay away from vegetation for wellness activities owing to certain allergens such as pollen.

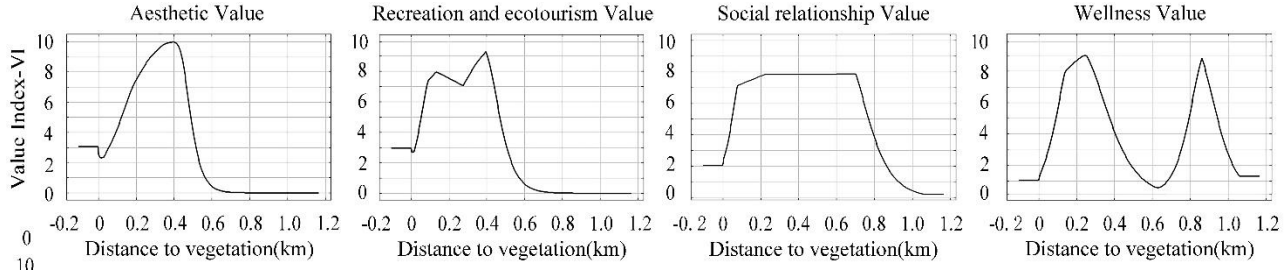

Figure 8. Distance to vegetation and value index fitted relationships.

(d). Impact of DTSS on the CES value

The scenic spots of XPF are the notable manifestations of its CES value. When the DTSS is the sole environmental variable (**Figure 9**), the aesthetic, recreation and

ecotourism, social relationship, and wellness values attain their highest values within the ranges of −375–0 m, 312.5–0 m, −312.5–0 m, and −312.5–0 m, respectively. The corresponding MVIs are 10, 8, 7, and 6, respectively, suggesting that the areas adjacent to the scenic spots can conspicuously enhance the public's aesthetic perception and recreational experience and furnish a favorable social, interactive, and wellness environment. Subsequently, all CES values exhibit a downward trend, which can be attributed to the reduced landscape attractiveness and environmental functionality upon departure from the core areas of scenic spots. However, within the range of 625–1375 m, the social relationship value undergoes a marginal increase once again. Although distant from the core area of the scenic spots, the public can still acquire certain social relationship utilities through low-density social activities within a specific distance range. This resurgence in utility may be associated with the serene environment, open space, and increased sparsity of the crowd resulting from being away from the core area.

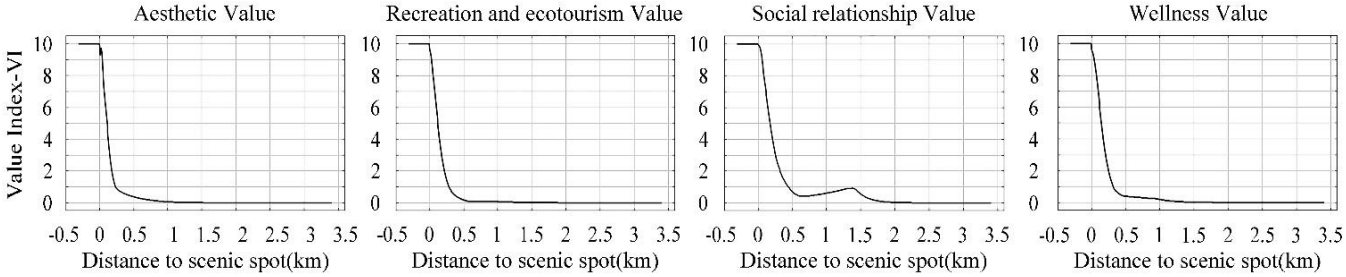

Figure 9. Distance to scenic spot and value index fitted relationships.

(e). Impact of ELEV on CES value

The analytical finding (**Figure 10**), with ELEV as the sole environmental variable, indicates that the aesthetic value escalates gradually between the altitudes of 44 m and 75 m and attains the pinnacle (MVI = 10) at 75 m, signifying that the landscape vista and vegetation configuration at this altitude positively influence the aesthetic value. The value related to recreation and ecotourism fluctuates between 50 m and 94 m, attaining the highest value (MVI = 8) at 70 m, indicating that it is markedly affected by the altitude and might be associated with the openness of the landscape and the diversity of vegetation. The social relationship and the wellness values increase within the altitude span of 44–65 m and 50–75 m, respectively, with the peak values positioned at 65 m (MVI = 7) and 62–75 m (MVI = 6). Subsequently, these two types of values gradually decrease within the range of 65–68 m and 75–1500 m; however, in the higher altitude brackets (68–94 m and 150–218 m) the values marginally increase again. This can be attributed to the enhancements in landscape openness, air quality, and environmental tranquility.

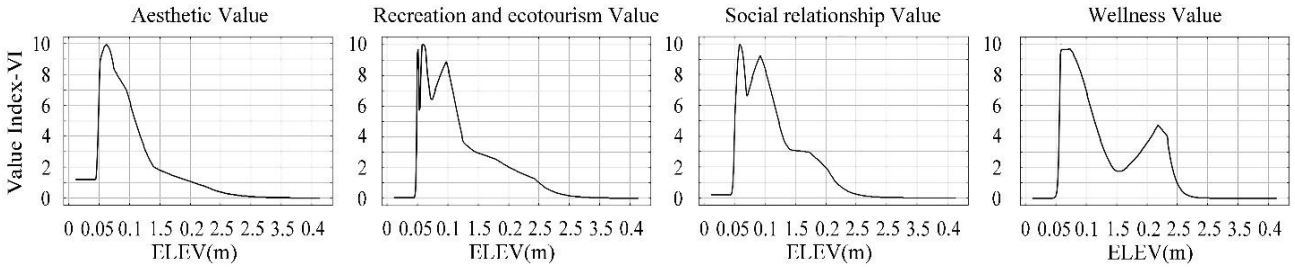

Figure 10. ELEV and value index fitted relationships.

(f). Impact of SLOPE on CES value

When the SLOPE is the sole environmental variable (**Figure 11**), the aesthetic and social relationship values attain their peaks at 3.7° and 4.4°, respectively, with the corresponding MVI being 9 and 6, respectively. Subsequently, they gradually decrease within the intervals ranging from 3.7° to 12.5° and 4.4° to 20°, respectively, but present a slight increase within the intervals ranging from 12.5° to 21.25° and 20° to 26.3°. A gentle slope notably enhances these two types of values, whereas a larger slope may trigger their rebound owing to landscape diversity and specific environmental characteristics. The recreation and ecotourism and the wellness values reach their peaks at a slope of 2.6° (MVI = 8) and 5.6° (MVI = 6), respectively, indicating that the slope within the intervals of 0°–2.6° and 0°–5.6° is conducive to enhancing the recreational experience and wellness effect. However, as the slope increases further, the values of both types of CESs gradually decline, potentially because a larger slope reduces the accessibility and safety of activities. Therefore, the slope within the intervals of 0°–2.6° and 0°–5.6° is an ideal option for recreational and healthcare activities, whereas an excessive slope is not conducive to the implementation and effectiveness of these activities.

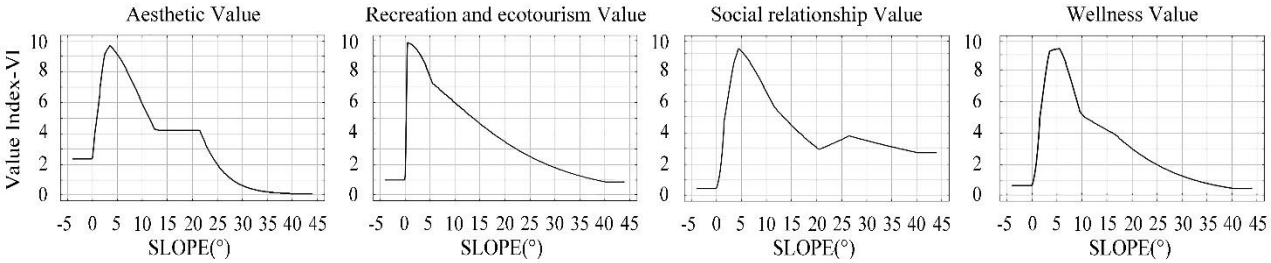

Figure 11. SLOPE and value index fitted relationships.

3.3.2. Impact of comprehensive variables on CES value

When DTR-DTW-DTV-DTSS-ELEV-SLOPE is analyzed as a cluster of environmental variables, the results exhibit relatively minor disparities from those of each individual environmental variable. This can be attributed to the fact that the effect of each factor on the CES value is relatively independent within specific ranges. For instance, DTW or DTSS can boost aesthetic and recreation and ecotourism values within a particular scope without overly relying on the interactions among other factors. In addition, the landscape traits and environmental structure of the study area might be relatively homogeneous, which could result in a stronger explanatory force of a single factor on the value of CESs, making the analysis results of comprehensive

variables not significantly superior to those of individual variables.

The consistency of the landscape features of the park creates a unified and harmonious environmental atmosphere, facilitating management and maintenance, ensuring ecological stability, and promoting CES benefits such as recreation and education. However, within this consistent environment, introducing more diverse landscapes and ecological characteristics could strengthen ecosystem resilience and enhance the capacity of the park to adapt to external environmental changes. Simultaneously, diversifying the landscape features may better satisfy the preferences of varied publics, enrich the depth and fulfillment of the public experience, and consequently increase the overall appeal and competitiveness of the park.

The MaxEnt, functioning as a significant verification instrument of the SolVES model, utilizes the jackknife approach during model operation to examine the extent to which each environmental variable in the study area corresponds to the values of diverse CESs (**Table 4**). The statistical findings indicate that DTSS holds the highest contribution ratio to the four values of aesthetic, recreation and ecotourism, social relationship, and wellness, attaining 65.2%, 89.6%, 70.2%, and 78.4%, respectively. Apart from DTSS, the contribution of DTW to aesthetic value exceeds that of environmental layers such as ELEV, DTW, and SLOPE, with a contribution ratio of 24.6%. Moreover, the contribution ratio of DTR to recreation and ecotourism value is considerably higher than that of the other three CES values, with a contribution ratio of 3.1%. DTR makes the most significant contribution (12.2%) to social relationship value. With respect to the wellness value, ELEV ranks immediately after DTSS, with a contribution ratio of 8.2%. Generally, DTW ranks second regarding contribution to these four values.

Table 4. Statistics on the contribution rate of environmental variables to the value of different CESs.

CES value types	Contribution rate					
	DTW	**DTR**	**DTV**	**DTSS**	**ELEV**	**SLOPE**
Aesthetic	24.7	3.1	2.8	65.2	1	3.2
Recreation and ecotourism	2.2	3.1	1	89.6	2.8	1.4
Social relationship	9.7	12.2	1.9	70.2	3.5	2.5
Wellness	4.2	2.6	5.4	78.4	8.2	1.2

4. Discussion

4.1. Accuracy of the assessment results

The SolVES model is a qualitative and quantitative coupled analytical method that evaluates the CES value in the study area via the established statistical model. The accuracy of the results is, to a certain degree, contingent upon the performance of the established statistical model. Consequently, in this study, the receiver operating characteristic curve (ROC) of the MaxEnt model was selected to verify the reliability of the assessment results of the SolVES model (**Table 5**). The statistical models established for the four CES values indicate that the area under the curve (AUC) calculated via ROC analysis is all greater than 0.9, suggesting that the assessment

results obtained by the SolVES model employed in this study are highly feasible and can effectively mirror the spatial distribution characteristics of different types of CES values in the study area. This further validates the practicability and accuracy of the SolVES model to assess the value of CESs, providing reliable data support for the subsequent management and decision-making of the ecosystem.

Table 5. AUC parameter for the CES value.

AUC parameters	Aesthetic	Recreation and ecotourism	Social relationship	Wellness
Training AUC parameters	0.951	0.938	0.928	0.945
Test AUC parameters	0.950	0.939	0.923	0.941

4.2. Advantages of assessment methods in planning and management

CESs are widely regarded as an entirely novel means to elucidate the relationship between humans and the environment. The integration of CES functions into landscape planning and management facilitates a deeper understanding of the diverse values and implications of landscapes among the public while also revealing their preferences and demands for landscapes. This integration modality not only enhances the maintenance of high-value areas of CESs but also empowers us to identify which specific landscape features or functions are the most favored, stimulates the utilization of multiple landscape functions, and thereby more effectively responds to and satisfies the public's needs in planning and management. This study presents a supplementary approach to applying CES functions and natural capital to environmental management and landscape planning. The LDA topic model analysis and PPGIS methods under natural language processing furnish new means of obtaining public perception and demand, which effectively constructs the process of public participation, thereby enhancing the scientific and sustainable nature of planning and decision-making. Moreover, special attention was paid to the complexity and specificity of forest ecosystems, and an environmental raster dataset was established for the environmental characteristics of forest parks, such as DTV, DTW, DTR, DTSS, ELEV, and SLOPE, to guarantee that the assessment results of the SolVES model are more comprehensive. This study method can effectively identify priority management areas, promote sustainable development and environmental protection practices, and provide a practically feasible means to achieve multiple CESs as management objectives.

4.3. Optimization measures for enhancing CESs of forest parks

This study, founded on public perception analysis, further investigates the spatial attributes of the CES value and the influence of environmental factors on the CES value. Evidently, regions with high MVI of environmental variables exhibit high CES values, particularly in areas adjacent to scenic spots, water bodies, and roads. In addition, the aesthetic, recreation and ecotourism, and social relationship values are especially prominent, further validating the significant role of environmental factors in enhancing the CES value. Nevertheless, in some areas where the CES value is relatively low, owing to the absence of support from crucial environmental factors, the public's awareness of the value of their CESs is comparatively limited. Hence, proposing feasible optimization measures to facilitate the overall enhancement of

CESs in forest parks has become an urgent issue that needs to be addressed.

The public holds a considerable recognition of the aesthetic value of Tanglihu and Lanshan scenic spots, particularly with respect to plant arrangement and seasonal alterations. Owing to the vast space and irregular shape of forest parks, road design should organically orchestrate landscape segments to generate a dynamic effect of "step-by-step, different scenery". Plant landscape planning centers on natural vegetation, creating a stratified and seasonal landscape through terrain and color factors, thereby strengthening the construction of natural environmental areas and elevating the aesthetic value of forests. Based on the assessment indicators of CESs regarding recreation and ecotourism value and the traits of hotspot areas, diversified recreational spaces are established. Intriguing activity areas such as rock climbing and bicycle paths are tailored for children; camping, picnic, and viewing platforms are devised for middle-aged people; accessibility facilities and healing gardens and other social spaces are offered for the elderly. A public space abundant in regional characteristics and with comprehensive functions is built to fulfill the public's needs and services, thereby enhancing the value of forest recreation. Tanglihu scenic spot, Xishanhu scenic spot, Changqinghu scenic spot, Lanshan scenic spot, Chaoyang Ancient Temple, and Jade Buddha Temple showcase considerable advantages in education and historical culture. In these areas, popular science facilities and interactive experience devices are being constructed, such as forest museums and parent–child interactive handicraft activities. Combined with sculptures and story scene wall facilities, they exhibit regional culture and history and enhance the value of forest education. In accordance with the high-scoring assessment indicators of wellness value and the characteristics of hotspot scenic spots, they integrate the endowed resources and comprehensively contemplate the age, health status, and hobbies of the public. The park can be partitioned into multiple functional areas, namely, static leisure, leisure agriculture, and outdoor sports, and installed with accessible facilities to fulfill the demands of various groups of people, thereby promoting the forest wellness value.

Given that the forest parks in China are extensively distributed and the existence of marked disparities in the ecological environment, resource endowment, cultural and historical background, and public demands, during the optimization and upgrading of forest parks, it is critical to integrate the uniqueness of the region and employ the assessment findings of the value of CESs to ensure the continuous and effective enhancement of the CES functions of forest parks.

5. Conclusion

As the public's economic and cultural levels increase, the demand for a quality life is escalating by the day, and the construction of diverse and inclusive park environments is attracting growing attention. Forest parks not only boast functions such as optimizing urban ecology and improving the quality of the landscape but also supply public spaces for rest, sightseeing, leisure, and sports activities in the public's daily life. With XFP taken as the study area, based on web text data and utilizing the LDA topic model, 28 topics were extracted to profoundly explore the public's perception and experience within the park. These topics encompass diverse aspects

such as natural scenery, leisure and entertainment, social interaction, cultural heritage, and outdoor sports, profoundly disclosing the public's perception and demand for the XFP. Therefore, seven value types, namely, aesthetics, recreation and ecotourism, social relationships, wellness, education, cultural heritage, and inspiration, were selected as the value classification of CESs in XFP, and a set of indicators appropriate for the CES evaluation in XFP were screened and established, such as the richness and diversity of plant seasonal and chromatic variations and the diversity of recreational activities.

By utilizing the PPGIS and SolVES analysis methods, the characteristics of public perception were spatially processed to analyze the spatial distribution heterogeneity of CES value and the influence of environmental conditions on CESs. The findings of the study suggest that the value indices of aesthetic, recreation and ecotourism, social relationships, and wellness values are relatively high and are highly favored by the public. The ranking of importance is aesthetic value > recreation and ecotourism value > social relationship value > wellness value, and a distinct spatial aggregation distribution is manifested, with the northern and southern regions being the hotspot areas. Scenic spots, water bodies, and roads have considerable impacts on the CES value, particularly in the areas surrounding water bodies and scenic spots. The statistical results of MaxEnt disclose that DTSS is the factor with the greatest contribution to the four types of value of CESs: aesthetic, recreation and ecotourism, social relationship, and wellness values. Its contribution rates are 65.2%, 89.6%, 70.2%, and 78.4%, respectively, and the AUC values under the ROC curve are all greater than 0.9.

To sustainably reap the benefits that ecosystems bestow upon humanity, we explored and investigated the public's perceived preferences regarding forest parks, as well as the threshold range that influences the value of CESs in forest parks. During the construction of landscapes to boost the value of CESs, we also deliberated on how to minimize the negative impact of CESs. This study aims to provide evidence-based guidance for the planning, construction, and restructuring of forest parks, as well as more precise information for design practices targeting human well-being, health, and sustainable cities.

Author contributions: Conceptualization, YD and CY; methodology, YD and CY; software, YD; validation, YD and CY; formal analysis, YD; investigation, YD and JC; resources, CY; data curation, YD; writing—original draft preparation, YD; writing—review and editing, CY and QZ; visualization, YD; supervision, CY; funding acquisition, CY. All authors have read and agreed to the published version of the manuscript.

Funding: We gratefully thank the National Natural Science Foundation of China [Grant numbers 32071831] and Research Project on Economic and Social Development in Liaoning Province [Grant numbers 2022lsljdwzzkt-009] for their financial support of this research.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

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