



Modeling Trends of Acoustic Landscape Changes in Urban Parks Based on Time Series Analysis

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SUMMARY: *In this paper, continuous acoustic monitoring was conducted from July 5-9, 2024 at 10 sample points using City Park A in City B as the experimental sample site. Combined with the bioacoustic dominance degree, power spectral density, acoustic index and BFAST temporal analysis model, we systematically explored the changing trend of the city park acoustic landscape. The results show that: (1) the sound level spatial and temporal differentiation is significant, the cultural promenade, the south gate and the north gate are the noisy core area, and the highest proportion of the whole day exceeds 70 dB, while the sculpture garden and the ancient pavilion sound level is mostly lower than 65 dB. (2) in the subjective perception of the acoustic landscape, the artificial sound, the natural sound and the living sound accounted for 23.1%, 54.3%, and 22.6% respectively, and in the morning, due to the biological activities and the tourists' entry to the park, the cumulative value of the subjective perception reached the highest value of 1357.298. (3) The daily change of acoustic index is characterized by distinctive features, the BIO index dropped to the bottom in the early morning due to traffic disturbance, while the NDSI index reached the peak in the early morning. The AEI index was higher from 08:00-18:00, and the ACI index fluctuated between 9000-18000 during the day. (4) The BFAST model can decompose the temporal trend of the acoustic landscape efficiently, and it can identify more accurately the trend mutations.*

KEYWORDS: *urban park; soundscape; acoustic index; BFAST mutation model; time series analysis*

1 Introduction

For a long time, the research and design of landscape in urban parks have mostly pursued the principle of visual supremacy, focusing on its spatial form, functional layout, material texture, and color composition and other visual and use functions, studying the aesthetic experience of the environment through visual perception, but ignoring the auditory and other perceptions and experiences of the quality of the landscape [1-3]. Since the aesthetic experience of people on the environment is a synergistic completion of visual perception and auditory perception, the landscape with only visual factors lacks the sense of hearing, and the aesthetic mood of the landscape is incomplete, which can not give people a real dynamic effect [4-6]. With the acceleration of urbanization, the park as an important public leisure area, its soundscape is of great significance to the quality of life of urban residents [7, 8].

From the concept of soundscape, sound is not a simple physical quantity, but has rich social and cultural connotations. It not only contains physical characteristics such as sound pressure level, spectral analysis, reverberation time, etc., but also carries the significance of social,

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historical, environmental, etc., and is attached with different values and cultural meanings according to the individual differences of people [9-11]. The combination of individual sound elements to form an overall soundscape, its components should contain natural sound, artificial sound, life sound and associative sound [12]. However, the current urban park soundscape is in the stage of static analysis, and there is little exploration of the law of temporal and spatial changes, which is not conducive to the design optimization of the park soundscape. And temporal analysis is an important method for the study of temporal change trends by finding the relationship between the current value of a variable and its past value, thus revealing its vertical relationship [13].

In this paper, the soundscape of urban parks is taken as the research object, and Park A is selected as the research sample site. Combined with the results of field survey, suitable sample points are selected to collect data. The calculation method of soundscape characteristic index is proposed, and BFAST is used to detect the temporal change anomaly. Analyze the sound levels at each measurement point in Park A from both time and space dimensions, and evaluate the advantages and disadvantages of the sound environment in combination with the noise level. The temporal change characteristics of different categories of soundscapes in Park A were mined through subjective perception indicators. Four acoustic indices, BIO, NDSI, AEI and ACI, were used to quantitatively analyze the daily cycle change rules of the soundscape in Park A. Comparison experiments between BFAST and linear trend analysis are conducted to verify the superior performance of BFAST in trend prediction.

2 Content and methodology of the study

With the acceleration of urbanization, the acoustic landscape quality of urban parks, as the core space for residents to get close to nature, has a direct impact on public health and ecological experience. As an acoustic representation of the interaction between ecosystems and human activities, the acoustic landscape contains multidimensional information on the rhythms of biological activities, the quality of the environment, and the behavior of people. In recent years, the development of acoustic indices and time-series analysis methods has provided a new path for quantitative analysis of acoustic landscape. Taking Park A as the research object, this paper integrates acoustic data collection, index calculation and time-series decomposition modeling, aiming to reveal the time-series characteristics of the acoustic landscape in urban parks.

2.1 Overview of the study area

Park A was chosen as the experimental sample site for the application of the indicator, which is located inside the sixth ring road of City B, with a total planning area of 60.42 square kilometers in the northeastern direction, and is one of the most important forest parks in City B. Park A is connected to five different forested landscape areas by greenways, based on two rivers.

2.2 Data acquisition

Preliminary field surveys were conducted for sample site selection, and footsteps and observations were made throughout the park, and surveys and recordings were made, and a total of 10 sample sites were selected to hang audio recorders at, and sound recordings were made for 5 consecutive days from July 5 to July 9, 2024, for the next step of the analytical study.

One sound collector was placed at each sample site, and clear and windless weather was selected to conduct the process, and all sample plot measurements were ensured to be synchronized. The sound collector should be placed in the center of the sample plot, when there is a tree in the sample plot, choose a tree with a diameter at breast height of about 15cm and

good growth, and fix the instrument at a position of about 1.5m from the ground by using a dark-colored fixed rope and cover it appropriately to prevent human damage; if the sample plot is a structure of shrubs and grasses, choose to place an experimental box on the ground or in the bushes in the center of the sample plot, and place the recorder in it with the purpose and unit of the sample plot to prevent human damage. The tape recorder will be placed in the box, labeled with its purpose and organization to prevent human damage.

2.3 Data quantification methods

(1) Bioacoustic dominance degree based on acoustic events (BioDomin)

Based on the identification of biological acoustic events (BioE) and artificial acoustic events (AntE) in the audio, we calculated the acoustic time-based BioAcoustic Dominance Degree to measure the overall situation of the acoustic landscape, which is calculated as follows:

$$BioDomin = (BioE - AntE) / (BioE + AntE) \quad (1)$$

The value of Bio Domin is between -1 and +1, the closer the value is to +1, the more biological sound dominates, and vice versa, the more artificial sound dominates.

(2) Power Spectral Density (PSD)

Sounds emanating from ecosystems can be broadly categorized as biological, anthropogenic and geophysical. The classification of sounds occurring in ecosystems includes: biological sounds - biological sounds produced by living organisms, usually at mid to high frequencies (2-11kHz); human sounds produced by man-made objects, usually at lower frequencies (1-2kHz); and seismic sounds produced by geophysical processes (e.g., winds and rainfall) that may extend beyond the entire soundscape spectrum (1-11kHz). Indices corresponding to these soundscape components are derived and used to measure changes in the soundscape over time and many details of acoustic community composition and change. The power spectral density PSD is an efficient method for quantitative analysis of each frequency interval and is implemented through the soundscapes function in the seewave package, and the PSD values obtained from the quantization are normalized to facilitate comparisons of PSD differences between different localities. In addition, in addition to calculating the nPSD values for each 1kHz frequency interval, the total soundscape power ($\sum 1-11kHz$), the artificial sound power (1-2kHz), and the biological soundscape power ($\sum 2-11kHz$) were also included.

(3) Calculation of acoustic indices

Acoustic indices can realize the rapid assessment of acoustic community dynamics, and have shown a correlation with acoustic community diversity in some studies, but due to the acoustic community composition in different environments has a great deal of difference, making the acoustic characteristics of bioacoustic change, in order to find the acoustic index suitable for use in urban ecosystems in Beijing, this paper will be the quantitative processing of the four acoustic indices commonly used at present. The four acoustic parameters selected in this paper include: bioacoustic index (BIO), bioacoustic dominance degree (NDSI), acoustic evenness index (AEI), and acoustic complexity index (ACI). The calculation of acoustic indices were all done in the R language platform. The batch calculation of acoustic indices of sound files was realized by autonomous programming through tuneR, seewave and soundecology packages with the following parameter settings.

BIO calculates the area under each frequency curve greater than the minimum db value, which is accomplished through the bioacoustic_index function in the soundecology program package, setting the minimum frequency threshold for the calculation to 2 kHz, the maximum frequency threshold to 11 kHz, and the rest of the parameters to default values.

NDSI estimates the soundscape level of anthropogenic interference by calculating the ratio of the sound energy of artificial to biological sounds found in sound samples collected in the field. The index is calculated by using the `soundscapepec` function in the `seewave` package to calculate the PSD values for the biological sound frequency interval 2-11kHz and the artificial sound frequency interval 1-2kHz, respectively, and then normalized by an exponent between -1 and +1, which is similar to `BioDomin`, where the closer to +1 the more dominant the biological sound is, and the opposite is the more dominant the artificial sound is. The opposite is true for the dominance of artificial sound.

The AEI is calculated by first dividing the spectrogram into frequency bands (default 10) and calculating the proportion of bands above the threshold (default -50 dBFS) in each band. The AEI is further calculated by applying the Gini index, which is accomplished using the `acoustic_diversity` and `acoustic_evenness` functions in the `soundecology` package. Evenness functions in the `soundecology` package, with all parameters set to default values.

The ACI index measures the variability of sound intensity in recordings by examining short time average changes in acoustic energy over frequency intervals to quantify complex biological sounds. It is done with the `acoustic_complexity` function in the `soundecology` package, setting the minimum frequency threshold for the calculation to 2kHz, the maximum frequency threshold to 11kHz FFT=1024, and the rest of the parameters are set to default.

2.4 Timing change anomaly detection method

BFAST is an automatic decomposition and then iterative fitting of segmented linear trend and seasonal models. BFAST iteratively evaluates the timing and number of sudden changes in a time series and characterizes the changes in their magnitude and direction. BFAST has a wide range of applications, not only for the analysis of long time series remote sensing data, but also for other problems that require the treatment of seasonal or non-seasonal time series. In addition, the algorithm has been extended to applications such as detecting label change information.

The decomposition model of BFAST is as follows:

$$Y_t = T_t + S_t + e_t, t = 1, \dots, n \quad (2)$$

where Y_t is the observation at moment t , T_t is the trend term, S_t is the seasonal term, and e_t is the residual term. Assuming that T_t is segmented, if T_t consists of $m+1$ distinct segments, there are m jump points $\tau_{t-1}, \dots, \tau_m$ in T_t .

$$T_t = \alpha_i + \beta_i t (\tau_{i-1} < t < \tau_i) \quad (3)$$

where $i = 1, \dots, m$ and defining $\tau_0 = 0$ and $\tau_{m+1} = n$, the magnitude of the jumping point M can be found from the parameters α and β of the linear model T_t that differs between τ_{i-1} and τ_i as follows:

$$M = (\alpha_{i-1} - \alpha_i) - (\beta_{i-1} - \beta_i)t \quad (4)$$

Similarly, the seasonal terms between jump points are fixed, but the seasonal model is different for each segment, and also the timing of the jump points in the seasonal terms can be different from the timing of the jump points in the trend terms. Assuming that there are jump points $\tau_{p1}, \dots, \tau_{pp}$ in the seasonal terms, defining $\tau_0 = 0$ and $\tau_{p+1} = n$, and assuming that the

S_t of each segment is a harmonic model, $\tau_{j-1} < t < (j=1, \dots, p)$, K is the number of harmonic models

$$S_t = \sum_{k=1}^K \alpha_{jk} \sin\left(\frac{2\pi kt}{f} + \delta_{jk}\right) \quad (5)$$

where the amplitude α_{jk} and phase δ_{jk} of the segmented seasonal model are unknown quantities, and f is a known frequency (if there are 365 observations in a year, then $f = 365$), Eq. (4) emphasizes the harmonic composition, which can be determined by the coefficients $\gamma_{jk} = \alpha_{jk} \cos(\delta_{jk})$ and $\theta_{jk} = \alpha_{jk} \sin(\delta_{jk})$ into linear harmonic regression models

$$S_t = \sum_{k=1}^K \left[\gamma_{jk} \sin\left(\frac{2\pi kt}{f}\right) + \theta_{jk} \cos\left(\frac{2\pi kt}{f}\right) \right] \quad (6)$$

At frequencies of f/k amplitude and phase can be passed:

$$\alpha_{jk} = \sqrt{\gamma_{jk}^2 + \theta_{jk}^2} \quad (7)$$

$$\delta_{jk} = \tan^{-1}\left(\theta_{jk} / \gamma_{jk}\right) \quad (8)$$

Finding.

The BFAST mutation detection method has the following advantages: (1) it is suitable for vegetation disturbance identification using remotely sensed data; (2) there is no need to select a specific reference period; (3) there is no need to set a threshold value in advance; and (4) there is no need to define a change track in advance.

3 Findings

3.1 Objective analysis of the soundscape

3.1.1 Sound level magnitude

Ten marked locations in Park A were selected for sound level measurements at various times of the day, and the results are shown in Table 1. The changes and distribution of the soundscape in Park A have a great relationship with the surrounding environment and the living habits of park users. 8:00-10:00 a.m. each point is different, fitness plaza and cultural promenade because of dancing sound, exercise activities sound, sound level is larger, are above 70dB, up to 76dB. south gate and north gate for the main entrance to the park, vendors are many, the flow of people is large, the sound of traffic, shouting and talking noisy, the sound level for the size of the sound at about 70dB, while the other measurement points are below 65dB. 10:00-12:00 time period, fitness plaza due to the morning exercise, dancing sound reduction, the activities of visitors at this time are mostly playing table tennis, badminton and exercise using fitness equipment, the number of activities has also been reduced, the sound level is reduced to 68dB. cultural promenade due to the number of tourists and the increase in recreational activities, such as singing, musical instruments, dancing and other activities to produce a larger sound level, up to 81dB. The children's playground is open from 10:00 to 20:00, at this time, due to the arrival of

children playing, the sound level of the children's playground increased to 67dB, and the sound level of each other measurement point increased due to the number of tourists and the increase in traffic in the vicinity. 12:00, the traffic flow becomes smaller, the park tourists go home and leave the park, the size of the sound level of the various measurement points at around 65dB, however, the south gate, the North Gate, the sound level still is 70dB or more because of the influence of traffic. Although the number of visitors to the Cultural Promenade decreased, the activities did not stop, and the sound level reached 90dB. 14:00, the sound level of some places reached the highest in the region throughout the day, such as the Sculpture Garden, Four Seasons Plaza. 18:00, due to the increase in the number of young people and children who come to play after work and school, the number of visitors reached the highest peak of the day, especially in the Cultural Promenade, the Kite Square, where small and medium-sized activities are often held, the number of people reached the highest peak, especially the Cultural Promenade and the Kite Square, which are often held in small and medium-sized activities. Plaza, where small and medium-sized activities are often held, are very lively and the sound level reaches the highest peak of the day.

Table 1: Results of sound level measurement at each time period (dB)

Measuring point	8:00~10:00	10:00~12:00	12:00~14:00	14:00~16:00	16:00~18:00	18:00~20:00
Fitness plaza	76	68	64	67	65	67
Cultural corridor	73	81	90	82	77	78
Sculpture garden	60	63	58	67	65	64
Children's playground	61	67	64	68	71	75
Kite square	64	68	66	73	78	77
Four seasons plaza	64	68	67	70	68	67
Ancient pavilion	62	65	63	64	67	66
Water promenade	55	64	60	68	70	76
South gate	71	73	70	66	70	73
North gate	70	74	71	70	66	71
Mean value	65.6	69.1	67.3	69.5	69.7	71.4

3.1.2 Noise level

Noise level is an important indicator for evaluating the overall acoustic environment of a park, and the statistics of the number of times when the sound level is greater than 70dB at each observation point (No. X1~X10) in Park A are shown in Fig. 1. The noisiest point in Park A is the Cultural Promenade, with all the time periods greater than 70dB, which is the largest number of time periods greater than 70dB among all the measurement points. This is followed by the South Gate and the North Gate, both of which have five, and these three points are affected by high sound levels throughout the day. This is because the Cultural Promenade often gathers tourists to sing, play musical instruments and dance here, and these behaviors are continuous activities, which exist throughout the day and have high sound levels, while the South Gate and the North Gate are affected by the main traffic roads. Moreover, there are three times when the sound level at Kite Square is higher than 70dB, which is mainly caused by the gathering activities of tourists - playing chess, storytelling and dancing. Other measurement points, such as Fitness Plaza, Children's Playground, Four Seasons Plaza, Water Promenade, etc., there are only 1 or 2 periods above 70dB, and the rest of the time is relatively quiet. People's activities in these venues are basically based on individual spontaneous activities, with high mobility and fewer organized collective activities. Sculpture Garden and the ancient pavilion all day sound level are below 65dB, the overall environment is more quiet and overflow, only slight chatting sound, footsteps, but not enough to cause noise pollution.

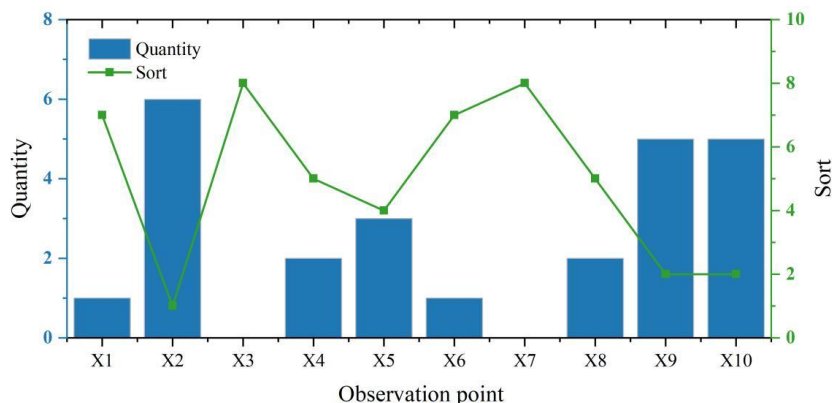


Figure 1: Statistical results of sound level number time at each observation point

3.2 Subjective analysis of soundscape

Park A has convenient transportation and many tourists, so the soundscape of Park A is relatively rich, which is mainly divided into the following three kinds: artificial sound, natural sound and living sound. To sort out the types of soundscape, it can be classified as traffic sound, music sound, radio sound, wind sound, leaf sound, bird sound, insect sound, water sound, song sound, footsteps, conversation sound, and children's sound. The cumulative percentage of subjective perception of various soundscape composite sounds in Park A over a 5-day period was counted, and the statistical results are shown in Figure 2. Bird chirping and insect chirping among the natural sounds were the two types of sounds with the highest percentage, accounting for 23.3% and 23.9%, respectively. Traffic sounds in artificial sounds come next, accounting for 20.4%. Conversation and footsteps among the living sounds accounted for 10.7% and 10.1% respectively. All other sound elements accounted for less than 3%. It can be seen that the sound elements that account for more than 10% of the total may be the main acoustic landscape in Park A, which is the main component of the sound field and the main factor affecting people's overall feeling of the acoustic environment, and should be the foreground sound in the acoustic environment. The other sound elements with a ratio of 3% or less are the elements that constitute the background sound (keynote sound) in the park.

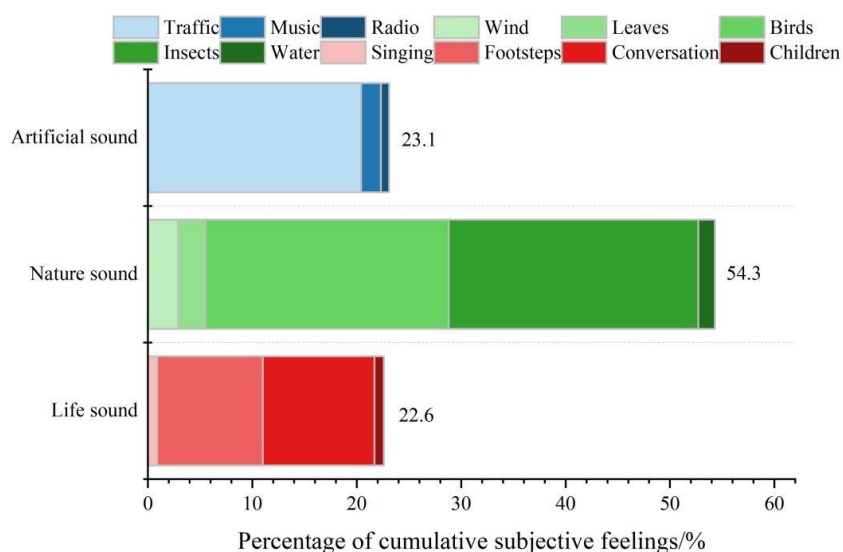


Figure 2: Percentage of cumulative values of subjective feelings

8:00~12:00, 12:00~14:00, 14:00~18:00, and 18:00~20:00 are divided into morning, noon,

afternoon, and evening, respectively, and the results of the comparative analysis of the cumulative values of the integrated sound subjective perception indexes of the soundscape in different time periods are shown in Figure 3. From the data trend, the cumulative value of comprehensive sound subjective perception in the morning time is at a higher level, which is consistent with the gradual active activities of tourists in this time, and the characteristics of the interweaving of natural and artificial sounds are enhanced. On the one hand, bird activities are frequent from early morning to morning. As the natural sound elements with the highest proportion, the subjective perception indexes of bird chirping and insect chirping reached 300.225 and 306.998 respectively, which were more prominent in this period. On the other hand, as visitors entered the park one after another, artificial and living sounds such as traffic sounds, conversations and footsteps were gradually superimposed to form a richly layered sound field, which strengthened the overall perceptual intensity. The cumulative value at noon shows a significant decrease, which is presumed to be related to the decrease in activity due to the rest of some visitors at noon. At this time, the subjective perception index of natural sounds remained around 700, but the intensity of artificial sounds and living sounds decreased. The cumulative value in the afternoon shows a rebound again, and the overall subjective perception index reaches 1206.306, which may be related to the fact that the tourists concentrate their activities again in the afternoon. In addition to the continuous contribution of natural sounds, the artificial sounds such as music and broadcasting increased due to the arrangement of activities in the park. The cumulative value in the evening is relatively moderate, maintaining at about 1000, when the intensity of natural sounds such as bird chirping and insect singing decreases due to the reduction of activities such as birds returning to their nests, and the sound of traffic gradually decreases with the departure of tourists from the park. However, the artificial sound of radio or music is still played, combined with a small amount of residual life sound, together constitute a relatively soft sound field.

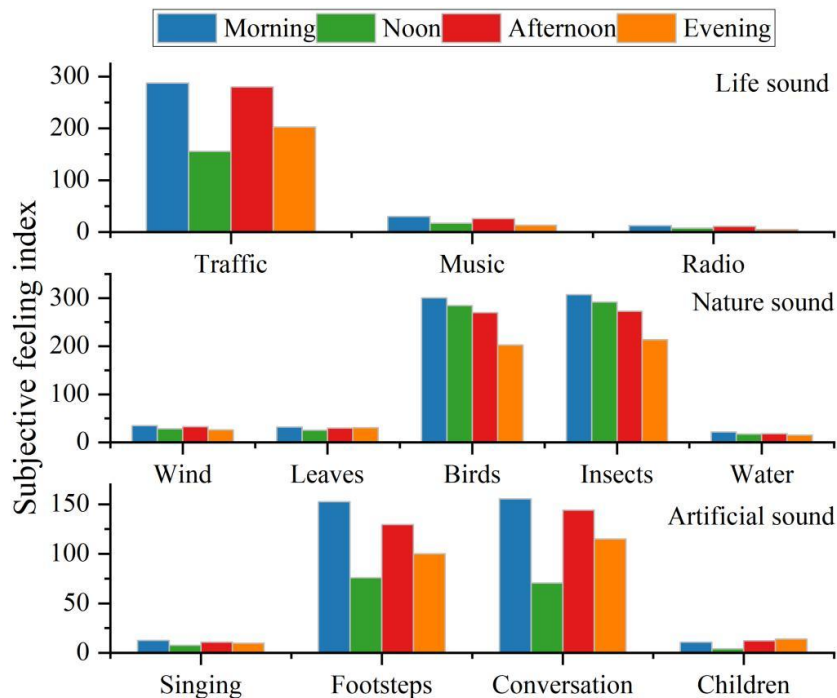


Figure 3: Comparison results of cumulative values of indicators in different periods

3.3 Soundscape Index Analysis

The BIO index reflects the activity of biosound in the soundscape, and the daily variation curve

of the BIO index is shown in Figure 4. Early in the morning around 8:00 a.m., the BIO index dropped to the bottom, and the sudden increase in traffic noise masked some of the biosound. Between 10:00 a.m. and 18:00 a.m. the BIO index rebounded and remained at a moderate level, and then around 20:00 a.m., the activities of birds and insects gradually leveled off, and the BIO index finally tended to a lower level.

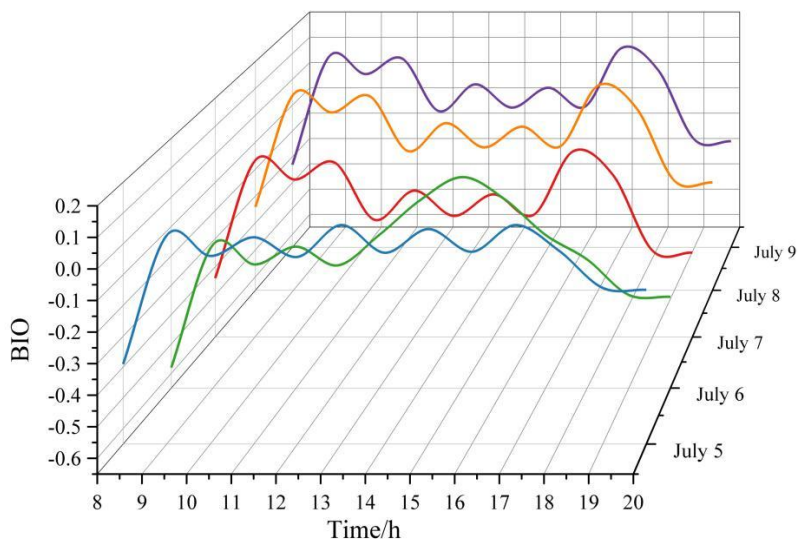


Figure 4: Diurnal variation curve of BIO index

NDSI reflects the proportion of sound generated by human activities in the soundscape, and the daily variation curve of NDSI is shown in Figure 5. It can be found that the NDSI index reaches the peak of NDSI in the early morning around 8:00 a.m., and the NDSI is more stable between 10:00 a.m. and 18:00 a.m., after which there is a slight decrease with time. The change of the NDSI indicates that the peak of the traffic flow in the early morning caused a reduction of the proportion of the biogenic sound production, which brought about the obvious road noise, and the morning peak value of the NDSI is more obvious at all the sampling locations.

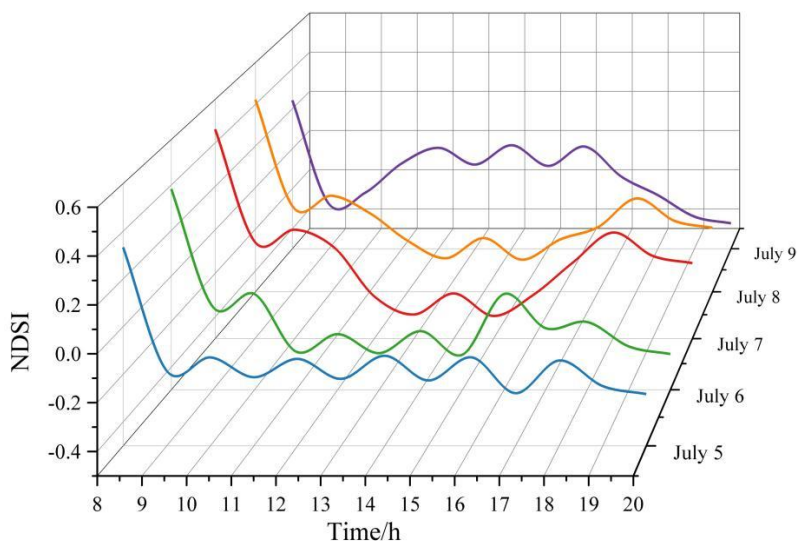


Figure 5: Diurnal variation curve of NDSI index

The daily cycle of AEI is also more obvious, and the daily variation curve of AEI index is shown in Fig. 6. The lower AEI index from 12:00 to 16:00 indicates that the acoustic diversity

is lower at this time, when both human and biological activities are less active. The AEI index varies less during the day and gradually decreases after 18:00 at night.

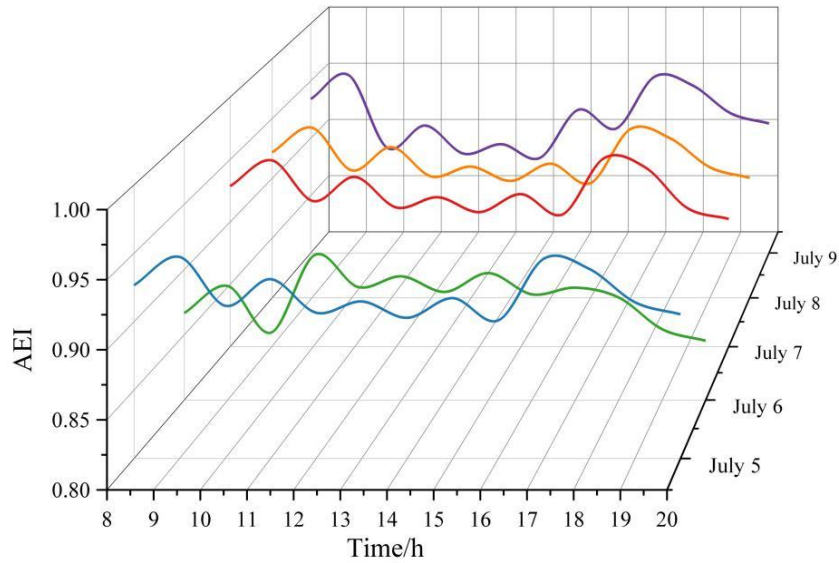


Figure 6: Diurnal variation curve of AEI index

The daily variation curve of the ACI index is shown in Figure 7. Since the ACI calculation process selects a 1-minute period to calculate the acoustic landscape index, the randomness is greater and the periodicity is more ambiguous than other indices. Around 8:00 a.m., the ACI index shows a significant increase, and it is hypothesized that the surge in the ACI index may be produced due to the concentration of bird calls in the morning. During the daytime the ACI index fluctuates more between 9,000-18,000, representing the activity and song of birds during the day. The ACI index was lower at night from 18:00 to 20:00, which is the time of low-frequency bird activity.

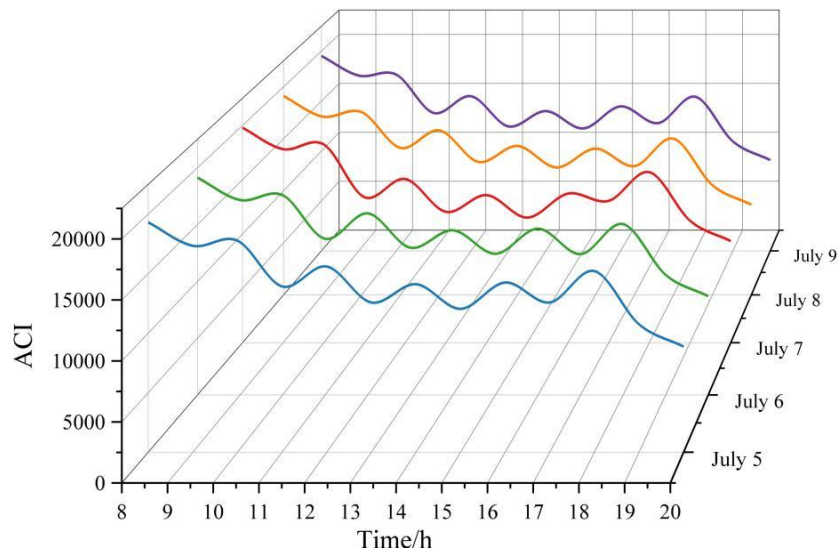


Figure 7: Diurnal variation curve of ACI index

3.4 Effectiveness of BFAST Timing Detection

In order to verify the effectiveness of the BFAST method on the detection of soundscape time

series in urban parks, the linear trend analysis method was selected as a comparison method to analyze the transformation of different trend types between the two. The transformation rate of the results obtained from the BFAST and linear trend analysis methods is shown in Table 2. There is a significant difference in the detection of soundscape trends between the linear trend analysis method and the BFAST nonlinear trend analysis method. Only 56.7% of the non-significant trends in the linear trend remained non-significant for the BFAST method, followed by 14.3% and 14.1% detected as interrupted increases and decreases to increases. On the other hand, only 34.8% of the significant degradation trends were defined as monotonic decrease by the BFAST method, which is the most transformed nonlinear trend type of the linear decrease trend, reflecting that acoustic landscapes are implicitly characterized by mutations that are not captured by the linear trend analysis method due to the interaction between natural and human behaviors. Meanwhile, among the nonlinear trend types with significantly improved trend transformations, although monotonic increase was the most frequent at 41.3%, interrupted increase and decreasing-to-increasing area were also as high as 22.6% and 16.5%, respectively. Thus, the BFAST method not only detects the overall trend of acoustic landscape transformations, but also includes mutations such as interruptions and transitions, which is not possible with ordinary linear regression methods.

Table 2: Results Conversion rate

		Linear trend		
		Non-significant trend	Significant degradation	Significant improvement
Nonlinear trend	Monotone increased	1.1	20.7	41.3
	Monotone decreased	0.2	34.8	3.6
	Interrupted increased	14.3	4.5	22.6
	Interrupted decreased	9.4	9.1	0.1
	From increase to decrease	4.2	5.5	2.7
	From decrease to increase	14.1	11.3	16.5
	Non-significant trend	56.7	14.1	13.2

4 Conclusion

In this paper, through multi-dimensional acoustic analysis and temporal modeling, the temporal and spatial variation rules of A park soundscape are systematically revealed.

(1) The sound landscape of the city park presents significant spatio-temporal differentiation characteristics. Artificial activity-intensive areas such as the cultural promenade, the south gate and the north gate are the core of high sound level, and the sound level of each measurement point is lower at noon time (12:00~14:00). Birds and insects in natural sounds, traffic sounds in artificial sounds, and conversations and footsteps in living sounds are the main components of the acoustic landscape, and their proportion directly affects the intensity of subjective feelings.

(2) The acoustic indices quantified the characteristics of the acoustic landscape from different dimensions; BIO and NDSI reflected the transition of the dominance of biological and artificial sounds; AEI index showed that the acoustic diversity was lower from 12:00 to 16:00; and ACI showed a stronger ability to explain biological sounds.

(3) The BFAST model was able to better capture the abrupt change characteristics of the acoustic landscape than the traditional linear trend method, which verified its applicability in acoustic landscape detection.

About the Author

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