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Soundscape analysis using eco-acoustic indices for the birds biodiversity assessment in urban parks (case study: Isfahan City, Iran)

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Abstract Biophony and anthrophony analysis as part of the urban soundscape is an efficient approach to bird biodiversity monitoring and to studying the impact of noise pollution in urban parks. Here, we analyzed the soundscape composition to monitor the diversity of birds using acoustic indices and machine learning in 21 urban parks of Isfahan, Iran, in spring 2019. To achieve this purpose four-step method was considered: (i) choosing parks and sampling of sound and bird species; (ii) calculated the six acoustic indices; (iii) calculated the six biodiversity indices; and (iv) statistical analysis for predicting biodiversity index from acoustic indices. Three regression models including support vector machine (SVM), random forest (RF), and elastic net regularization (GLM-NET) applied the acoustic indices with minimum and maximum recorded thresholds to feature extraction to measure biodiversity indicators. The optimization model was applied to reduce the independent variables. Generally, more than 18,000 samples were modeled for the dependent variables in each model. The regression results demonstrated that the highest R square was related to the songbird (0.93), evenness (0.92), and richness (0.9) indecies in the SVM model and the Shannon index (0.86) in the RF model. The results of acoustics analysis demonstrated that the Acoustic Entropy Index (H), Normalized Difference Soundscape Index (NDSI), Bioacoustics Index (BI), and Acoustic Complexity Index (ACI) indices were suitable because they could serve as proxies for bird richness and activity that reflect differences in habitat quality. Our findings offer using acoustic indicators as an efficient approach for monitoring bird biodiversity in urban parks.

Keywords Biodiversity indices · Biophony · Anthrophony · Songbird · SVM regression

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Introduction

In recent decades, population growth and urban development have led to the conversion of many natural areas into urban lands, which is a major threat

to the biodiversity (Li et al., 2022; Patankar et al., 2021). Urban parks have a significant role in conserving biodiversity from the perspective of ecologists (Bino et al., 2008; Lepczyk et al., 2017; Ofori et al., 2018; Tryjanowski et al., 2017). Parks and green spaces in urban areas provide several services and goods (Cilliers et al., 2013; Gámez & Harris, 2021; Iknayan et al., 2022; Song et al., 2020).

In recent years, studies on bird species in urban areas and suburbs have been considered as an indicator to assess the environmental quality within cities (Benocci et al., 2020b; Fuller et al., 2015; Gasc et al., 2018; Latifi et al., 2019; Morelli et al., 2021; Radan et al., 2017; Zhao et al., 2022). Birds are effective biological indicators of broad-scale habitat changes and ecological integrity (Egwumah et al., 2017; Fennici, 1989; Heggem et al., 1998; King et al., 2021; Šálek et al., 2022). Parks and urban green spaces are good places to attract different species of birds for various uses such as temporary rest (migration birds), reproduction, and nesting fields (Fernandez-Juricic & Jokimaki, 2001; Morelli et al., 2021). The development and management of urban green spaces can increase the biodiversity of birds, which has a considerable impact on the environmental quality (Waltert et al., 2004; Latifi et al., 2020) The type, size, and location of urban green spaces can also affect the production and diversity of natural sounds that require interdisciplinary sciences (architecture, green space, and ecology) (Aida et al., 2016; Hellstrom et al., 2014). Urban parks are places where you can hear and record natural sounds (Benocci et al., 2020a, 2021). Previous studies have shown that biodiversity can be measured using compute indices from the sound recorded in the environment (Denes et al., 2014).

A soundscape is the combination of different sounds (biophony or physical sounds) in a landscape. (Dröge et al., 2021; Jaszczak et al., 2021; Scarpelli et al., 2021). It is categorized into three categories of biophony (coming from living things), geophony (i.e., coming from non-living sources), and anthrophony (Farina et al., 2014). Ecoacoustics is the new field that focuses on the dynamics of biophony while regarding the acoustic environment in which sound is made (Farina & Gage, 2017; Servick, 2014; Sueur et al., 2014). Ecoecoustics can be applied to assess a wide range of plans such as diversity, richness, behavior, and dynamics in wildlife Fields (Ross et al., 2021; Sueur et al., 2014).

With recent advancements in recording, processing, and data-storage technology, the application of acoustic indices is increasing in various studies (Sánchez-Giraldo et al., 2020). Acoustic indices are a useful tool for analyzing the sound of the urban landscape (Buxton et al., 2018). Denes et al. (2014) used sounds recorded to monitor the biodiversity of marine mammals (Denes et al., 2014). Elsewhere, Liu et al. (2014) investigated the modification of soundscape at spatial and time variations, (Liu et al., 2014). Acoustic indices can be used in many studies for investigating habitat quality (Yang & Kang, 2005), population density and distribution, and species invasion (Krause & Farina, 2016), acoustic dynamics and diversity (), and acoustic interactions and connection to the landscape (Farina et al., 2014; Joo et al., 2011; Tucker et al., 2014), predict noise pollution (Schulte-Fortkamp, 2002; Yang & Kang, 2005). Ross et al. (2021) utilized acoustic indices for ecological monitoring in complex sonic environments. Their results demonstrated the ability of acoustic indices as indicators for rapid biodiversity monitoring and management of the natural soundscapes (Ross et al., 2021). In this respect, acoustic indices can provide an appropriate background for assessing biodiversity changes (especially birds) in urban parks and natural habitats (Fairbrass et al., 2017; Gasc et al., 2015; Sueur et al., 2014). For example, Fairbrass et al. (2017) showed that the Acoustic Complexity Index (ACI), Normalized Difference Soundscape Index (NDSI), and Bioacoustic Index (BI) can be effective indices for urban areas (Fairbrass et al., 2017). Factors affecting acoustic indices include parameters concerning the flora and the shape of parks (Liu et al., 2014). These factors can have a significant impact on the biodiversity of parks and, thus, the soundscape (Farina et al., 2014). Morelli et al. (2021) selected bird species as high environmental quality for monitoring different European cities and offer a framework to study the spatial distribution of high environmental quality areas within the cities (Morelli et al., 2021).

Isfahan city has provided habitats for different species of birds through various parks in terms of vegetation (forest to grassland) and topographic zone that is considered in the field of biodiversity by ecologists. Therefore, the study aims to assess 21 parks in Isfahan with different structures and locations to measure the biodiversity of birds in the urban green space using acoustic and biodiversity indicators. The three most important steps in this regard are as follows:

1. Calculation of biodiversity indicators
2. Calculation of acoustic indicators from sound samples
3. Use of regression methods to arrive at the best estimate of biodiversity indices by using ecoacoustic indices.

Materials and methods

Study area

Isfahan is an Iranian city located between 51°39′40″ E and 32°38′30″ N coordinates in the lush plain of the Zayanderood River with 15 urban districts (Fig. 1). Isfahan city has a height above sea level of 1575 m and has a semi-arid climate. The annual average temperature is 16.7 °C, with a minimum of 10.6 °C in winter to a maximum of 40.6 °C in summer (Esmaeili & Moore, 2012). It is the third metropolitan city in Iran, with 1.9 million population. Urban development, population growth, and industrial expansion caused Isfahan's environmental quality has deteriorated. Isfahan has the highest per capita urban green space (26 m²) compared to other metropolises in Iran. The total area of Isfahan parks is 3700 hectares. Three types of urban green spaces are designed in Isfahan, including urban open spaces, regional parks, and pocket parks (They are small parks that are commonly accessible to the public). Plane, Morus, and Ulmus species are more common than other tree species in the Isfahan parks. The information of the parks is mentioned in Table 1.
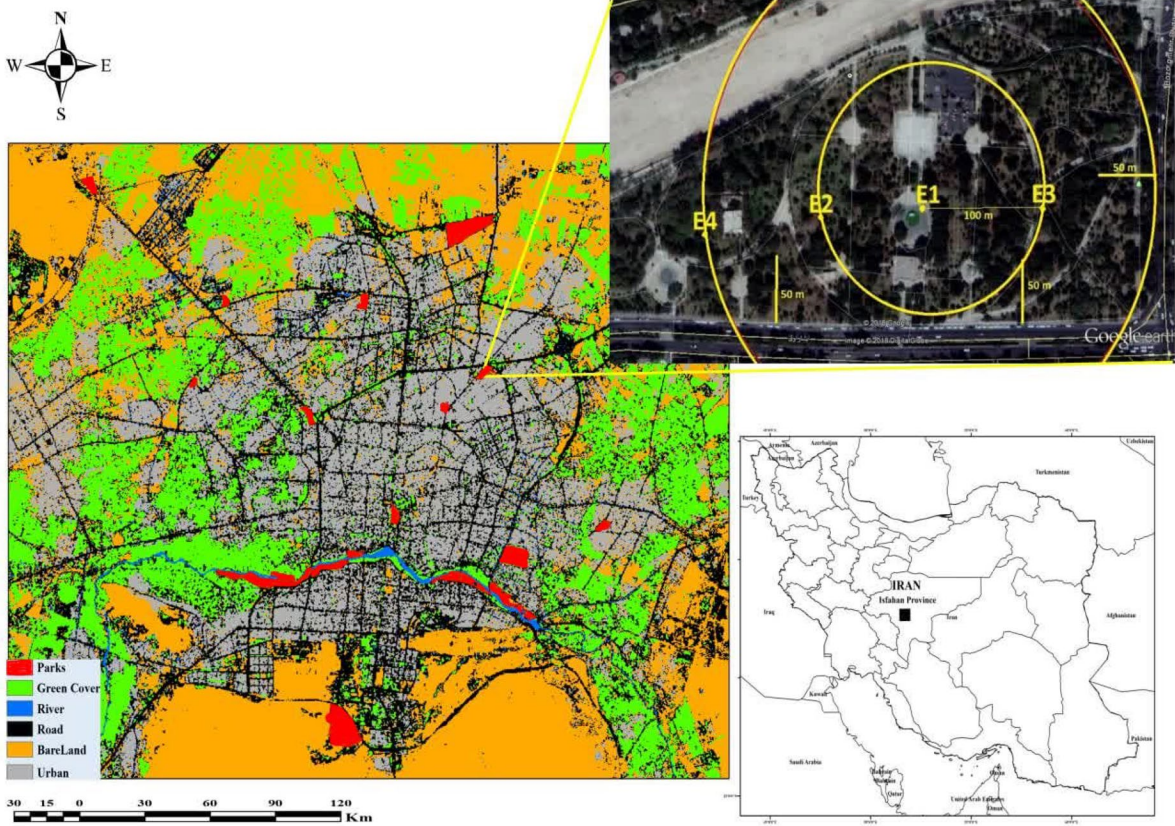
Fig. 1 Location of the Isfahan urban parks and location of sample stations inside the park distinguished by concentric circles

Table 1 The area and edge effect of the studied parks. (a) and (b) show the forest parks and mountain parks type respectively. Some of the parks have woodland and grassland habitat types (Tashakor et al., 2013)

Urban district	Park names	The location of the park relative to the city	Area (m2)	Perimeter (M)	Edge effect
District 1	Kodak	Downtown	65904	1306	0.019
District 2	Ghalamestan	Edge of the city	89945	1542	0.017
District 3	Moshtagh	Downtown	158578	2481	0.015
	Hashtbehesht	Downtown	97146	1828	0.018
District 4	Bagh Ghadir	Edge of the city	367156	2574	0.007
	Polesharestan	Edge of the city	102813	2420	0.023
District 5	Saadi	Downtown	166100	2863	0.017
	Mirzakochakkhan (a)	Edge of the city	185985	3543	0.019
	Soffeh (a) (b)	Edge of the city	912597	3977	0.004
District 6	Khabarnegar	Downtown	154299	2562	0.016
	Isargaran	Downtown	116229	2289	0.019
District 7	Fadak (a)	Edge of the city	680127	4248	0.006
	Baghoshkhane	Edge of the city	45230	1330	0.029
District 8	Golmohamadi	Edge of the city	91222	1399	0.015
District 9	Nazhvan Shomali (a)	Edge of the city	107741	2047	0.018
District 10	Lale	Edge of the city	117180	1885	0.016
District 11	Emam Reza	Edge of the city	35369	790	0.022
District 12	Ghods	Edge of the city	44384	984	0/022
	Mahmodabad (a)	Edge of the city	100,106	1663	0.016
District 13	Nazhvan Shomali (a)	Edge of the city	320271	4118	0.012
District 15	Kosar	Edge of the city	70067	1241	0.017

Selected parks and green spaces

Two conditions were considered for selecting urban parks, which include (1) the park area must be more than 3000 ha; (2) the vegetation of the park should be trees. In addition, we estimated the edge effects for each park (Table 1). As a geometric concept, the edge effect refers to the ratio of the perimeter to the area in a habitat. Increasing this ratio increases the perimeter or edge per unit area, bringing the interior portions of the habitat closer to the edge in texture. Overall, 21 urban parks in 14 districts of the city were chosen for sampling. Park names are abbreviated as follows: ES: Isargaran, KH: Khabarnegar, SO: Soffeh, MK: Mirzakochakkhan, SA: Saadi, PS: Polesharestan, BG: Bagh Ghadir, HB: Hashtbehesht, MO: Moshtagh, GH: Ghods, KO: Kodak, KS: Kosar, NJ: Nazhvan Jonobi, MA: Mahmodabad, GO: Golmohamadi, ER: Emam Reza, LA: Lale, NS: Nazhvan Shomali GM: Ghalamestan, BK: Baghoshkhane, and FA: Fadak.

The total area of urban green parks sampled in this research is 4028449 m^2, the largest area is the Soffe Park with an area of 912,597 m^2, and the smallest area of the park in this research belongs to Imam Reza Park with an area of 35,369 m^2. The only mountain park in the research is Soffe Park (Latifi et al., 2020) (Table 1).

Recorded sound samples and observed samples of birds

We used a Lender brand sound recorder (model PV4) and a Boya brand shotgun microphone to record natural sounds and birds' voices. The audio files were recorded in WAV format. In addition, due to the noise and false sounds in the environment, the noise reduction system of the device was activated and the machine was also equipped with a sound filter. The digital amplification was increased to 6 dB to record sounds with long-distance production sources.

Two time periods per day (from 7:30 AM to 12 PM and from 3 to 5 PM) were selected for sound sampling. The Cornell method was employed to indicate sample points and obliterate the edge effect of the parks (Moshtaghie & Kaboli, 2015). In this section, a 50-m distance was considered from the park's edge up to the sample point (Liddle, 1997). Then, concentric circles were made up to the edge of the park's center ranging from 50 to 250 m based on the shape, area, and distribution, and density of vegetation cover. We recorded six samples of 30 min from each park. At each station, the bird population, the number of species observed, and the number of songbirds was recorded to estimate the biodiversity of the birds (Fig. 2). Signs and

handbooks were used to identify the birds. For this purpose, binoculars and digital cameras were used at each station (Issa, 2019). Samples were entered into the software for analysis as 1-min files. Due to the singing activity of birds in the spring season, the biophony samples were collected during this season in 2019 (Pijanowski et al., 2011a, b).

In addition, the Bruel&Kjaer model 2239 sound meter was used to measure the sound level. To confirm the accuracy of the measurement by the sound meter, this device was initially calibrated.

The highest threshold (MAX) and the lowest threshold (MIN) of the sound in the environment were measured by this device.

Fig. 2 Bird sound recording in different habitat types (forest, mountainous, and grassland) in Isfahan urban parks

Analysis of recorded sounds and acoustic indices

Song Scope Bioacoustics Software 4.1 Documentation is a tool enabling the process of a great deal of acoustic data in a short time (Farina et al., 2014; Knight et al., 2017). This study measured the acoustic index in the anthrophony frequency ranging from 1000 to 2500 Hz and the biophony frequency ranging from 2500 to 11,000 Hz. Figure 3 shows most biophony ranges from 2500 to 7000 Hz or above, and anthrophony ranges from 1000 to 2500 Hz (Farina et al., 2014). Biophony is also detected in 2000 Hz in some cases, which is mainly associated with crows and pied crows (*Corvus albus*). However, they were excluded from the singing bird category, producing a single-sound pulse in all parks. The frequency range of biophony (bird songs) is created above 5500 Hz, and anthrophony (mobile sound) is recorded below 2000 Hz.

Calculated acoustic indices

The six acoustic indices include Acoustic Complexity Index (ACI), Acoustic Evenness Index (AEI), Acoustic Diversity Index (ADI), Bioacoustics Index (BI), Normalized Difference Soundscape Index (NDSI),

and Acoustic Entropy Index (H) were calculated after specifying the signed areas and recording sampling, using Seewave R-package (). Based on the review of sources, these indicators have been used in other studies in urban environments to monitor different species and biophonic sounds. Therefore, we also employed these indicators in this study. In addition, the indicators used in their calculations take into account the impact of human sounds and indicate the general situation of biophony sounds in the urban landscape. These six indices are described in Table 2.

Statistical analysis

Analysis of variance

Based on eco-acoustic indices, sampling with repetition on biophony in parks was used to compare Isfahan's urban parks. To determine the statistical preference of the parks, the one-way ANOVA was used based on the normality test of eco-acoustic indices. The ANOVA is an analysis tool used in statistics that splits an observed aggregate variability found inside a data set of factors (Edwards, 2005). One-way ANOVA is used to measure relationships between dependent and independent variables, without
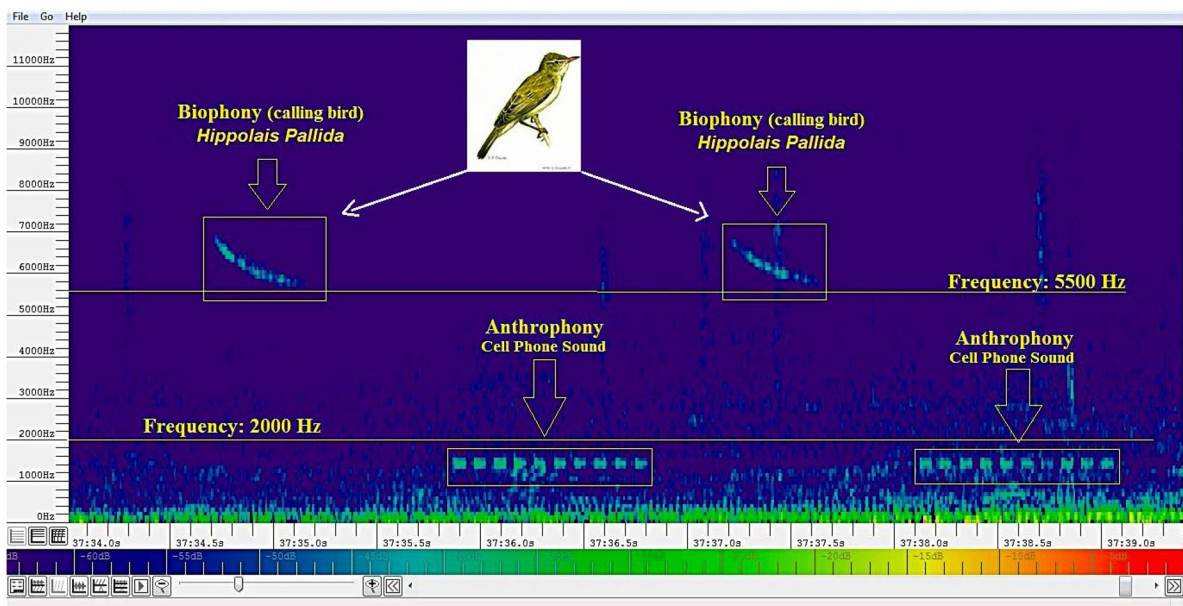
Fig. 3 The frequency range of biophony and anthrophony in the spectrogram page; the bird's sound is in the range of 5500 Hz and higher and the cell phone is in the range of 2000 Hz

Table 2 Descriptions of the six acoustics indices used in the study

Name	Acronym	Range	Description	References
Acoustic Complexity Index	ACI		ACI index is designed to analyze the soundscape and sounds of birds, which focuses on changes in signal intensity and calculates the absolute intensity	(Pieretti et al., 2011)
Acoustic Evenness Index	AEI	$0 < AEI < 1$	The AEI index has measured the ratios of the signal at each frequency fluctuation rate and created spectrums in total acoustic frequency	(Pijanowski et al., 2011a, b)
Acoustic Diversity Index	ADI	$0 < ADI$	ADI is calculated by dividing the spectrometer by sampled frequency (default 1 kHz steps) and calculating signal energy in each part of the signal	(Villanueva-Rivera et al., 2011)
Bioacoustics Index	BI		Used to compare frequency amplitude frequency-amplitude spectra to detect or infer differences in avian bird community composition among between sites	(Frommolt & Tauchert, 2014)
Normalized Difference Soundscape Index	NDSI	$-1 < NDSI < +1$	This index is calculated in specific spectral zones at a normal spectral signal density	(Kasten et al., 2012)
Acoustic Entropy Index	H	$0 < H < 1$	The spectral entropy (SE) is calculated by the average spectral frequency of time frames in signals. This equation considers the total entropy of a time wave	(Sueur et al., 2008)

distinguishing between groups. Therefore, the Tukey test was proposed to compare the difference between group means. It was applied to the set of all pairwise comparisons simultaneously that identifies any difference between two means is greater than the expected standard error (Tukey, 1949).

Feature extraction and selection

In machine learning, feature extraction begins from the initial set of measured data and yields attributes that are informative and non-redundant, driving an increase in the accuracy of the models (Prathusha & Jyothi, 2017). For feature extraction, 8 acoustic indices calculated from audio samples were used. In this regard, the sampled data were first examined to eliminate missing data or outliers caused by calculation errors. In this study, we used the simple form of multiplication and division by two sides (such as a/b and b/a) to develop new features from the eight variables measured. To avoid overfitting, the parameters with a high correlation (more than 0.7) were removed

(Liu et al., 2017), and finally, 10 independent parameters were used to predict the calculated biodiversity indices.

Regression analysis models

In this section, 3 methods including support vector machine (SVM), random forest (RF), and elastic net regularization (GLMNET) were used to estimate biodiversity indicators (abundance, evenness, richness, shannon, simpson and songbird) from acoustic indices. In this regard, the independent variables are ACI, H, Max, ACI*Max, ACI*Min, ADI*AEI, AEI*BI, AEI*H, Max/Min, and NDSI/BI. In general, there is no special assumption for the 3 methods used, however, scaling and centering of data in different sources has been suggested to improve accuracy, which has also been used in this study. The purpose of modeling is to properly identify the parameters of each model in order to reduce the uncertainty in the prediction while also the classifier can accurately predict unknown data (i.e., testing data). More information about these methods can be found below.

Support vector machine (SVM)

The support vector machine model as a supervised machine learning algorithm was proposed by Vapnik et al. (Vapnik et al., 1997). The functional structure was extended within a system by this algorithm. SVM methods are established based on an inductive principle named Structural Risk Minimization (SRM) which attempts to maximize the marginal area (gap) between the hyperplane and the nearest data points related to each class which is an advantage (D. Li & Simske, 2010). This model is applied to solve the very complex training dataset with proposed many curved margins (Kalantar et al., 2018). In the SVM model, the coherence between input and output variables (In this study, it includes 10 independent acoustic parameters and each of the biodiversity indicators respectively) is identified by the structural risk minimization (SRM) norm parameter (Das & Choudhury, 2020). In this study, the SVM method with radial basis function (RBF) kernel was used in the R e1071 package for modeling purposes.

Random forest (RF)

The random forest performs the regression technique using a set of random data and independent decision trees (Breiman, 2001). This method works based on the bootstrapping, in which approximately two/third of the data is applied to create the decision trees, and the remaining data (about 1/3rd) is then used to evaluate the model performance or, to calculate the error named "out of bag error" (Breiman, 2001). The random forest technique is known as one of the top-performing methods(Ranaie et al., 2018; Toosi et al., 2019; Valavi et al., 2022). The advantages of this method include high statistical accuracy and a replication decision tree for adequate analysis,(Yu et al., 2011). The random forest model in the R randomForest package has approximately 10 model parameters. The most important of these parameters is the number of decision trees. In this context, 500 decision trees were used for modeling.

Elastic net regularization (GLMNET)

GLMNET is a generalized linear model based on regression via penalized maximum likelihood (Xing et al., 2014). This method is fast and can operate with a wide range of datasets from low to high. The GLMNET algorithms reduce cyclical coordinates and improve functions by cycles repeatedly (Hastie et al., 2016). This method has been applied in different fields (Friedman et al., 2010; Jurka et al., 2004; Xing et al., 2014; Yuan & Lin, 2012), but its application in ecology has been less studied (Torabian et al., 2021; Tredennick et al., 2021). The most important parameters of this model are alpha and lambda, which in this study were set to 1 and 100, respectively. The R Caret package was used to run this model.

Optimization modeling

In this study, the optimization model was applied to reduce the independent variables that can predict the best results of the acoustics indices modeling (Mamo & Dennis, 2020). First, all combinations of 2 to 10 predictive variables were produced (For example, for binary combinations, variables 1 and 2, variables 1 and 3, variables 1 and 4… variables 9 and 10) then the modeling process was performed for each of them. Generally, more than 18,000 samples were modeled for the dependent variables. Take into account that achieving high training accuracy may not be beneficial (i.e., a classifier that accurately predicts training data whose class labels are indeed known). As was mentioned above, separating the data set into two parts, one of which is considered unknown, is a common strategy in addition to better managing data with few observations. The predictive accuracy of unknown sets closely reflects the performance of classifying an independent data set. An improved version of this procedure is known as cross-validation. Using cross-validation three validation statistics (R square, adjusted R square, and MSE) were used to evaluate the accuracy of the modeling (Legates & McCabe, 1999; Veerasamy et al., 2011).

Results

In the present study, the recording site took about 30 min. The number of bird species observed was listed to evaluate the biodiversity indices (Appendix A). Acoustic indices and biodiversity indices were calculated to find the relationship between biodiversity and eco-acoustic indices.

Bird diversity in urban parks

According to the field observation, we identified 50 bird species in the 21 Isfahan parks urban which two species of birds were aquatic. Of all listed species, most observed species (12 ones) were seen in the NS Park, and belong to Muscicapidae and Fringillidae families, of which 7 and 5 species were reported, respectively. The entire species of these two families are known as singing birds. During the field study, the total bird abundance occurrences were estimated at 1532 in spring. Since the purpose of the research was on biophony, we excluded birds that sing at frequencies ranging from 1000 to 2000 Hz from the final analysis. Table 3 shows the abundance of bird species observed and diversity indices for the chosen parks.

Statistical analysis

Analysis of variance

The boxplots in Fig. 4 show the significance level, the maximum and minimum acoustic variability, ACI, AEI, ADI, BI, NDSI, H, Max and Min in all sample points. According to Fig. 4, the boxplot addressing KS Park and ES Park has the highest and the lowest ACI values of 2570 and 1787, respectively. Besides, the highest values for ADI, AEI, BI, NDSI, and H indices belong to GM Park (1.85), SO Park (0.89), SO Park (51), and SO Park (0.99), and SO Park (0.82), respectively. Moreover, the lowest value for the indices is linked to SO Park (0.03), SA Park (0.45), ER Park (13), MA Park (0.41), and BG Park.

As mentioned in the material and methods section, the ANOVA and Tukey tests assessed and compared the parks. A Tukey test was run for ACI, AEI, ADI, NDSI, BI, H, Max and Min and its results are presented in Fig. 4. The test consisted of pairwise comparisons of the means among all sample parks to get the significance level of parameter variations (95% confidence interval). Overall, the obtained results are as follows. The most important difference is between NS and GM parks. Also, considering ADI, there is a significant difference between SA and GO parks. For the BI, the most notable difference occurs in MA with SO Mountain
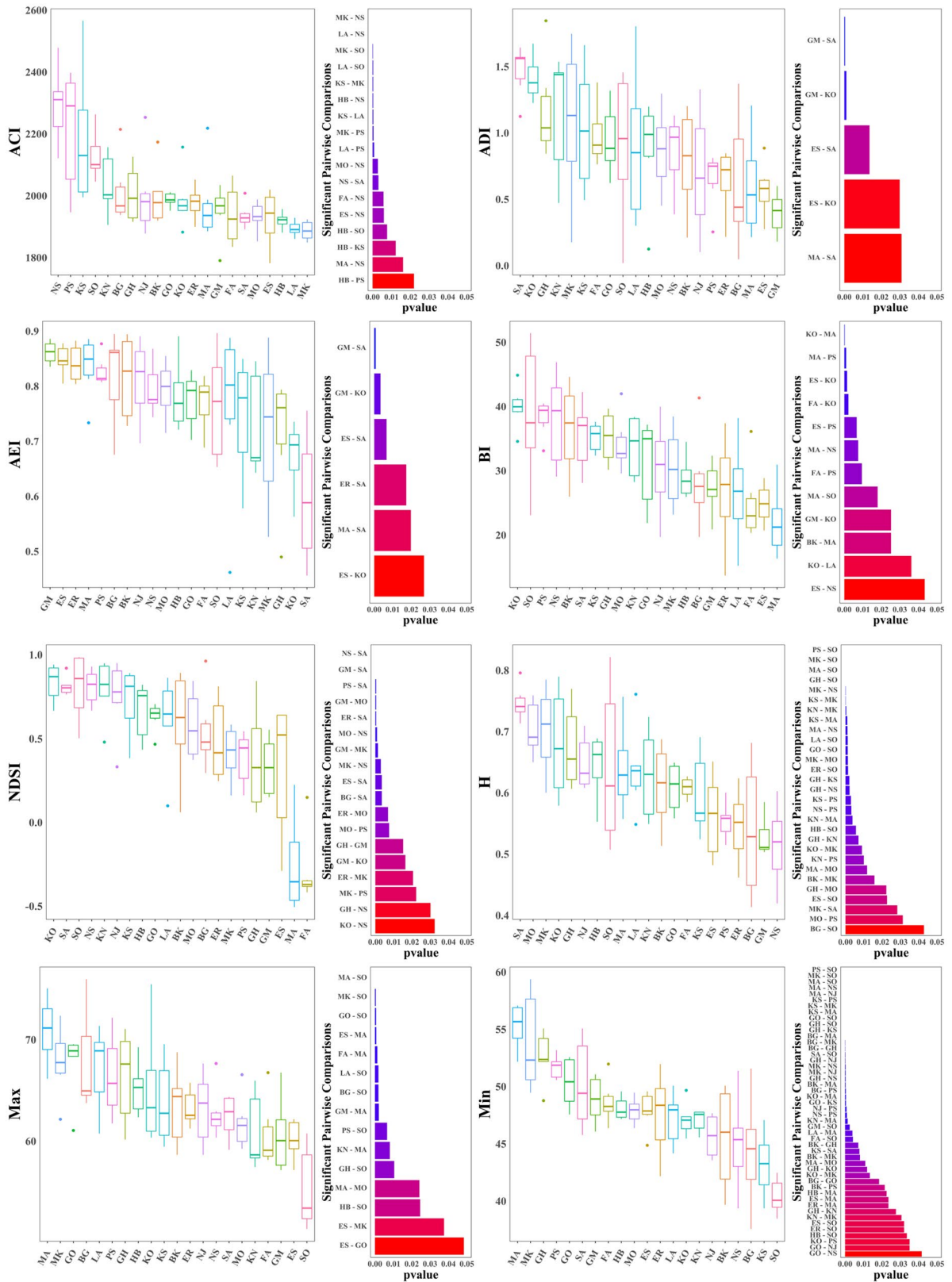
Park and between MA and KO parks. There is a maximum significant difference between FA and GM parks and MA and GM parks on NDSI.

Regression analysis modeling

The ten variables were extracted for modeling, which in most equations, just two to nine variables carried out the best accuracy in all combinations (Table 4). Table 4 shows the predictor variables to estimate the biodiversity indices. The regression results demonstrated that the highest R square was related to the songbird, evenness, and richness indices in the SVM model with 0.93, 0.92, and 0.90. Also, the Shannon index was the highest R square (0.86) in the RF model. The evenness and songbird indices had the most predictor variables in the SVM model, 10 and 9, respectively.

Table 3 Biodiversity indicators were estimated from the field observed in Isfahan urban parks

Parks name	abundance	richness	Simpson	Shannon	Evenness
KO	56	7	0.61	1.36	0.55
GM	74	3	0.24	0.47	0.53
MO	66	4	0.29	0.63	0.47
HB	104	4	0.52	0.9	0.62
BG	67	6	0.4	0.92	0.41
PS	42	4	0.5	0.93	0.63
SA	102	6	0.35	0.74	0.35
MK	75	6	0.28	0.67	0.32
SO	61	9	0.56	1.31	0.41
KH	87	7	0.4	0.92	0.35
ES	44	4	0.43	0.82	0.56
FA	11	3	0.56	0.91	0.83
BK	106	3	0.47	0.7	0.67
GO	69	3	0.47	0.74	0.7
NS	111	9	0.36	0.89	0.27
LA	131	2	0.08	0.18	0.6
ER	80	3	0.07	0.18	0.4
GH	75	4	0.19	0.45	0.39
MA	29	3	0.34	0.64	0.63
NJ	55	4	0.46	0.92	0.62
KS	78	2	0.14	0.27	0.65

◄**Fig. 4** Boxplot of acoustic indices (ACI, AEI, ADI, BI, NDSI, H, Max, and Min) for the studied parks and paired comparison diagram of parks (Tukey's test) based on indices values

Discussion

Soundscape analysis, by acoustic indices, offers researchers with valuable ecological information to evaluate biodiversity, species behavior, environmental health, and human wellbeing assessment in urban landscapes (Bradfer-Lawrence et al., 2019). Eco-acoustics can be one of the empowering ecological tools which help in-situ field and remote surveys and expands long-term monitoring programs (Farina, 2018; Linke et al., 2018). Here, we calculated six acoustic indices using recorded sounds in urban parks. They are some of the most famous indices successfully used in ecoacoustics (Farina, 2018). Soundscape analysis can be applied to different ecological studies using quantifying it with indicators (McLaren & Degroote, 2012). According to the literature review, and analytical research, this study is the first research project in analytical urban soundscape using acoustic indices in Iran.

The highest rate of biophony based on two indices was related to SO park and The highest abundance and number of species observed were related to SO park and NS park. While in contrast to MA and FA parks, the abundance of species was at the lowest possible level, which demonstrated that the abundance and number of species have greatly affected the bio-sounds (Duarte et al., 2015).

The ability of acoustic recordings to identify links between bird diversity and components of structural complexity was tested by Shaw et al. (2021). The results showed that automated acoustic recording can be an effective and superior method for monitoring resident forest birds (Shaw et al., 2021). Shamon et al. (2021) investigated relationships between acoustic indices and bird species richness/diversity in a Northern Great Plains grassland system. The result showed that the BI and the ACI had the highest correlation with bird richness in the Northern Great Plains systems (Shamon et al., 2021).

Complex sounds are made when sounds contain more than one frequency, the different frequency components interact and the soundscape is affected by the elements and structural components of the urban (Benocci et al., 2022). Spatial elements and spatial patterns such as land cover, and types of vegetation in parks can impact the biophonic (Benocci et al., 2022). The study conducted by Hao et al. (2022) showed that the BI index in urban forest parks was higher than in other urban areas (Hao et al., 2022). As a result, the variety of bird sounds and biophonic was more in these parks. Other factors that can affect the complexity of landscape sound and acoustic disorders are temporal changes related to seasonal and daily changes (Siddagangaiah et al., 2022). In the study of Mullet et al. (2016), which was conducted on landscape sounds in south-central Alaska, the result displayed that the changes in the season and the hours of the day (morning or night) have potential effects on the sound of landscape due to changes in human activities (traffic), and bird migration time (Mullet et al., 2016).

The results of the BI, the density of bio-sounds, with a visual interpretation of the shape and structures of parks indicate that parks with more margins along the road are less diverse than parks that have fewer margins along the road, such as MA Park (100,106 m^2). In addition, the result of BI shows that the level of human sounds overcame biophony sounds in parks located where in areas with more traffic and daily activities of the population (such as Laleh Park (117,180 m^2) and Isargaran Park (116229m^2), As a result, the BI in these parks it has smaller. Therefore, the BI index is a suitable indicator for investigating noise pollution in this study and can be estimated the noise pollution across the bio-sound. Hao et al. (2016) investigated the masking effect of birdsong on the noise environment of two typical main roads in the UK and the Netherlands. They discovered that increasing the frequency of birdsong over 30 s by 2 to 6 times increased the pleasantness of traffic noise environments by 2.7 to 6.7 (Hao et al., 2016). In addition, Ghadiri khanaposhtani et al. (2019) investigated the effects of road noise pollution on acoustic indices and estimated that the result demonstrated noise pollution has a potential influence on the NDSI and the BI indices (Ghadiri Khanaposhtani et al., 2019). In the future, we want to evaluate the effects of other parameters and their impact on acoustic indices and soundscape using landscape metrics and vegetation index.

Several factors can affect the number of acoustic indices (Liu et al., 2014). Also, a study conducted by Rahimi and Fakheran (2013) showed that as

Table 4 The validation results of predicted biodiversity indicators using three regression analysis models

	Richness	Aboundance	Evenness	Shannon	Simpson	Song bird
SVM	ACI H Max ACI*Max AEI*BI AEI*H Max/Min NDSI/BI	H Max ACI*Max AEI*BI AEI*H Max/Min NDSI/BI	ACI H Max ACI*Max ACI*Min ADI*AEI AEI*BI AEI*H Max/Min NDSI/BI	H Max ACI*Max ACI*Min ADI*AEI AEI*BI AEI*H NDSI/BI	H Max ACI*Max ACI*Min ADI*AEI AEI*BI AEI*H Max/Min NDSI/BI	ACI H Max ACI*Max ADI*AEI AEI*BI AEI*H Max/Min NDSI/BI
Rsq	0.9	0.88	0.92	0.86	0.86	0.93
Adjusted Rsq	0.83	0.82	0.85	0.77	0.74	0.87
MSE	3.36	8.05	0.018	0.14	0.028	0.89
	Richness	**Aboundance**	**Evenness**	**Shannon**	**Simpson**	**Signing bird**
RF	H AEI*H Max/Min	H ACI*Max	ACI ACI*Min	Max ACI*Max ADI*AEI AEI*BI NDSI/BI	ACI H Max ACI*Min AEI*H NDSI/BI	H Max ADI*AEI Max/Min
Rsq	0.83	0.81	0.8	0.86	0.84	0.84
Adjusted Rsq	0.8	0.79	0.77	0.81	0.8	0.8
MSE	4.27	8.86	0.022	0.17	0.041	1.52
	Richness	**Aboundance**	**Evenness**	**Shannon**	**Simpson**	**Signing bird**
GLMNET	ACI H ACI*Max ACI*Min ADI*AEI AEI*BI AEI*H NDSI/BI	ACI Max ACI*Max ADI*AEI AEI*BI AEI*H Max/Min	ACI H ACI*Max ACI*Min ADI*AEI AEI*BI Max/Min NDSI/BI	H ACI*Max ACI*Min NDSI/BI	ACI Max ACI*Max ACI*Min ADI*AEI Max/Min NDSI/BI	ACI H Max ACI*Max ACI*Min ADI*AEI AEI*BI AEI*H NDSI/BI
Rsq	0.84	0.59	0.62	0.46	0.34	0.84
Adjusted Rsq	0.71	0.37	0.37	0.33	0.25	0.71
MSE	0.73	6.83	0.028	0.67	0.02	0.73

we move from the city center to the suburbs, the level of human sounds decreases, and the level of bio-sounds increases (Rahimi & Fakheran, 2013). In this study, SO Park had the highest amount of biophony, which is the same as the results of this study. The highest value of the AEI index is related to MA and ES parks, which was due to the existence of anthrophony and the volume of different sounds.

The feature extraction and the feature selection methods were used to predict 10 final variables to model the relationship between biodiversity indices and acoustic indices. The results of the modeling

revealed that there was a nonlinear relationship between biodiversity indices and predictor variables. In general, the modeled acoustic indices of the SVM method perform better than the other methods (RF and GLMNET). However, the RF method was able to model diversity indicators with the least number of independent variables, and its accuracy was close to the SVM method. The results of the GLMNET method obtained from modeled diversity indicators displayed that just two diversity indicators covered richness, and songbird had performance similar to SVM and RF.

Comparing the independent variables showed that the H variable played the most significant role in the modeling, additional in the AEI*H variable. The ACI variable was one of the most important variables when combined with the Min and Max variables demonstrating a more effective performance. The NDSI/BI variable became one of the important variables used in modeling, particularly Shannon and Simpson prediction modeling, that provided an intensified index of biophony. The results showed that the combination of the BI and the AEI, i.e., (AEI/BI) played a key role in modeling biodiversity indices, particularly in the SVM regression model. In this study, the maximum and minimum sound levels were considered as variables. Based on the results, using them with other variables, especially the maximum sound level, can be useful for increasing the accuracy of predictions. All models (i.e., SVM, RF, and GLMNET) that were used to model biodiversity indicators had good performance for richness and songbird. So, by using the songbird index modeling, it is possible to detect some of the singing species in cities similar to Isfahan.

Conclusion

The urbanization process affects the species' biodiversity in the urban ecosystem and causes habitat changes. The development of urban green spaces provides better conditions for species richness and biodiversity of birds, which will improve urban biophony (La Sorte et al., 2020). Isfahan city is a suitable option for investigating biophony due to having many various parks. Acoustic indices are a powerful tool for rapid assessments of habitat change and monitoring changes in species communities. The acoustic

method is superior to point counts for determining species richness. To our knowledge, this is the first study of its kind using acoustic indices for assessing bird diversity in Isfahan urban parks. The SVM, RF, and GLMNET regression techniques were applied to model the relationship between biodiversity indicators and acoustic indices. Therefore, we used the acoustics indices with the maximum and minimum sound data recorded to generate predictor variables to determine biodiversity indicators. The introduced approach was additionally appropriate because it increased the accuracy of results. The results of acoustics analysis demonstrated that the H, NDSI, BI, and ACI indices were useful because they could serve as proxies for bird richness and activity that reflect differences in habitat quality. The regression results demonstrated that the highest R square was related to the songbird, evenness, and richness indices in the SVM model with 0.93, 0.92, and 0.90. Also, the Shannon index was the highest R square (0.86) in the RF model. The results showed that SO park has the highest diversity of bird species and is in better condition in terms of biophony, which is more important for protection than other parks. This research displayed that noise pollution can negatively affect the value of the bioacoustics index, which is reflected in the modeling. According to the results, parks located in crowded urban places had less value in bio-acoustic recording, and the value of the bioacoustics index in this park was low.

Our findings suggest using acoustics indices as an efficient approach for monitoring bird biodiversity in urban landscapes and suggest a model for studying the environmental quality of urban park areas. Bioacoustics indicators are efficient tools for assessing the ecological situation. These can be used to select bird-watching sites and urban management for better design and planning of urban landscapes and urban green spaces. It is suggested to use landscape metrics and vegetation indicators for investigating how landscape sound changes in the urban landscape in the future.

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Declarations

Ethics approval and consent to participate All authors have read, understood, and have complied as applicable with the statement on "ethical responsibilities of authors" as found in the instructions for authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

Competing interests The authors declare no competing interests.

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