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The soundscape methodology for long-term bird monitoring: A Mediterranean Europe case-study

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ABSTRACT

The soundscape represents the acoustic footprint of a landscape, and may well be a source of a vast amount of information that could be used efficiently in, for example, long-term bird aggregation monitoring schemes. To depict such soundscape footprint, specific indexes are requested. In particular, the aim of this paper was to extensively describe the Acoustic Complexity Index (ACI) and to successively apply it to process the sound files recorded in an ecologically fragile area in a Mediterranean maqui (Eastern Liguria, Italy). Daily acoustic animal activity was sampled in 90 one-minute files between the end of May and the end of July, 2010, using a pre-programmed recording procedure (Songmeter, Wildlife Acoustic). The WaveSurfer software, powered by the Soundscape Metric plug-in, was then utilized to quickly process these data.

This approach allows the identification of the compositional changes and acoustic fluctuations activity of a local community (in the proposed case prevalently composed by birds and cicadas). In particular, two distinct patterns emerged during the investigation. From 20 May to 4 July, the soundscape was dominated by birds but, after that period, the onset of the cicadas' songs completely changed the sound dynamics. The proposed methodology has been demonstrated to be a powerful tool to identify the complex patterns of the soundscape across different temporal scales (hours, days and intraseason). This approach could also be adopted in long-term studies to monitor animal dynamics under different environmental scenarios.

1. Introduction

Over recent decades, the growing human intrusion into the Earth's ecosystems has led to the massive destruction and fragmentation of natural habitats (Vitousek et al., 1997). This change, along with an alteration of climatic dynamics, has accelerated the extinction of several species (Chapin et al., 2000) and caused the endangerment of many ecological processes (Fearn and Redford, 2008; Wilcove et al., 1998).

The complexity and increasing fragility of the linked human and natural system require new types of investigation if we are to be able to face the challenge of environmental surprises and take into account legacy effects (Liu et al., 2007).

Despite a tremendous effort to investigate the causes and effects of this unprecedented impact, especially when it comes to maintaining the well-being of man (MEA, 2005 a, b) and associated ecosystem services (Mooney et al., 2009), some processes, like the disruption of the communication systems between organisms (Carson, 1962; Harris-Jones, 2009), or chronic anthropogenic noise exposure (Barber et al., 2009), continue to be poorly understood.

For this reason, given the global threats that we face today, the flux of information in the communication network should be the primary component of environmental complexity to be investigated and monitored.

Of the ecological disciplines in existence, one of the more recent approaches to deal with this challenge seems to be Acoustic Ecology (Pijanowski et al., 2011). The focus of this recent area of research is the study of the soundscape, which is defined as the product of the relationships between the sounds of the environment and the listener (Schafer, 1977). The soundscape is thus an important epistemological tool, because it reflects both the physical and informative properties of environmental acoustic cues and the communication mechanisms of organisms and different species (Krause, 1987, 2002; Kull, 2010; Schafer, 1977, 1994).

Such studies are now possible thanks to technological advances in the quality and efficiency of recording devices and the availability of new metrics and computation tools which can be applied to sound analysis (Pieretti et al., 2011; Pijanowski et al., in press; Qi et al., 2008; Sueur et al., 2008; Villanueva-Rivera et al., in press).

At the present time, the application of soundscape analysis could enable us to efficiently investigate the dynamics of animal behavior, particularly when habitats are modified, fragmented, or destroyed. Birds are good bioindicators of such changes (f.i. Furness et al., 1993; Hill, 1995), and many studies have indeed focused on the monitoring of bird species' richness and distribution in an attempt to highlight

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differences in environmental health (Andren, 1994; MacArthur et al., 1962). The reason for this is the intrinsic characteristics of birds: they are distributed over a wide range of landscapes; their presence is an indicator of the state of the structural complexity of the vegetation (Bradbury et al., 2005; MacArthur and MacArthur, 1961); and, finally, they are easy to detect in comparison to other animal groups (Furness et al., 1993). In addition, we have acquired a good knowledge of the biology of most bird species over the years, meaning that the results obtained from monitoring them are both meaningful and able to be more easily interpreted (Bardeli et al., 2010).

The aim of this contribution is to further illustrate a recently developed metric, the Acoustic Complexity Index (ACI), (Pieretti et al., 2011), in order to investigate the avian soundscape as an indicator of the informative and communication properties of a bird community. This is possible because this new tool may quickly highlight changes in behavior and the composition of a community, both in time and space.

The effective suitability of this new form of soundscape analysis for avian monitoring, a detailed explanation of the different, potential approaches, and the possibility of its applicability to a long-term avian monitoring scheme in fragile areas are all extensively discussed in this paper.

2. Materials and methods

2.1. Study area

The study area, which is located on a westerly exposed gentle slope at 250 masl along the coastal range of the Eastern Liguria Region (Italy) (44°13′30″ N, 9°30′23″ E), is now covered by a dense, luxuriant Mediterranean maqui. Until a complete abandonment in the 1950s, it was previously intensively cultivated, as demonstrated by the remnants of terraces that are still visible in some parts.

There are no paved roads in the site, and urban development seems to be a very remote prospect, but the risk of fire is significant, and such a disturbance may well reset the ecological succession at any time. Indeed, partially burned trunks and scar remnants inside the actual vegetation prove that the entire area has been ravaged by fire several times since the abandonment of cultivation.

The perennial vegetation (randomly sampled in a 30 m radius around the recording station) is composed of Mediterranean scrub, in which *Erica arborea* (mean height 1.90 ± 1.00 m, N = 40), *Quercus ilex* (2.79 ± 1.02 m, N = 17) and *Arbutus unedo* (2.71 ± 1.20 m, N = 13) dominate the shrub layer. Other less abundant species present are *Pinus pinaster*, *Phillirea latifolia*, *Cistus* spp., *Daphne cnidium*, *Calicotome spinosa*, *Mirtus communis*, and *Calluna vulgaris*.

The canopy cover was estimated by way of hemispherical photography using a Nikon Coolpix 950 digital camera with a Nikon FC-E8 0.21x fisheye converter, sampling the vegetation in 57 places located in a 30 m radius from the recording station. The images obtained were processed using the Gap Light Analyzer (GLA) (Frazer et al., 1999). The mean canopy openness results of 22.40% (min 7.87, max 51.99), SD 7.55, CV 33.72.

For the purpose of the meteorological characterization of the study area, we refer to the 2010 data bank provided by the meteorological station in the town of Deiva Marina, which is located at sea level; (http://www.ilmeteo.it/portale/archivio-meteo/Deiva+Marina/2010). The mean temperatures over the course of the intra-seasonal intervals in 2010 have respectively been: 20–31 May: 21.25 ± 1.48; 1–11 June: 23.25 ± 2.12; 12–13 June: 21.25 ± 1.35; 24 June–4 July: 26.14 ± 2.54; 5–15 July: 28.11 ± 1.16; and 16–26 July: 28.00 ± 1.78.

2.2. Recording techniques

The soundscape of a selected location was recorded for 56 days, between May 20 and July 26, 2010, from 4.00 a.m. to 10.00 p.m. CET, using a SongMeter Digital Field Recorder (SM1) (Wildlife Acoustics, Inc., Massachusetts) programmed to record 1 min every 11 min. Accordingly, 90 audio-files were collected each day, amounting to 5040 files in total, guaranteeing the max acoustic sampling along the daily interval provided by the SM1 device. The sampling was set at a frequency of 44,100 Hz, 16 bits, and with a 30% microphone gain.

The Wavesurfer software (Sjölander and Beskow, 2000), powered by the SoundscapeMeter plug-in (Farina and Piccioli, in prep), was then utilized to analyze the sound files. A Fast Fourier Transform (FFT) of 512 points was used to obtain a matrix of intensity from each audio-file for 256 frequency classes (86.13 Hz each) along 5167 temporal intervals of 0.012 s. This matrix was the starting point of the ACI analysis.

We decided to only process the spectrogram between 1500 Hz and 15,000 Hz, which amounted to 157 frequency classes. The 15,000 Hz upper threshold was adopted in order to exclude crepuscular insects. In order to exclude background noise, we set an *a priori* filter which was appositely verified for the type of recording used. With the aim of obtaining an immediate picture of the composition of the bird community, a non-standardized survey was conducted by one of us (AF) at a distance of 100 m from the recording point, amounting to a total of 17 h of direct counting over 13 different days (from May to June), at a distance of a week, between approximately 6 a.m. and 8 a.m. The complete list of the identified species is contained in Table 2. A further aural identification of natural- and anthropogenic-born sounds was performed for selected files, with the aim to couple the ACI values with individual species acoustic performances or anthropogenic noise events.

The Surfer v9® was utilized to elaborate on the tri-dimensional models applying the kriging method of interpolation to ACI distribution across the day hours and seasons.

3. Acoustic Complexity Index (ACI) metrics

The Acoustic Complexity Index (ACI) (Farina and Morri, 2008; Pieretti et al., 2011) has been designed to measure the complexity of sound spectrograms obtained from a linear scale of sound intensity and, specifically, to analyze the bird soundscape.

The ACI measures the absolute difference between two adjacent values of intensity, $I_k - I_{k+1}$, where k is the k_{th} position in the intensity values recorded along a single frequency bin (i) and in a single temporal subset (j) on the original matrix extracted from the spectrogram. Subsequently, the ratio between this summation and the total of the sound intensity in j is calculated:

$$\mathrm{ACI}_{ij} = \frac{\sum_{k=1}^{n} I_k - I_{k+1}}{\sum\limits_{k=1}^{n} I_k} \tag{1}$$

Table 1
List of variables used in the ACI metrics.

ACI metrics	Values adopted in this study
k temporal interval	0.001162
$n = Sk$	86
i category of frequency	
$l = Si$	157
j = temporal subset	
$m = Sj$	60
d = day over the course of the season	
$p = Sd$	56
h = sound session over the course of the day	
$q = Sh$	90
b = macro-session	10
c = intra-seasonal interval	10
v = number of days in each intra-seasonal interval	

Table 2
List of birds identified during the recording sessions and ranked according to amount of song activity.

List of birds	
Common Blackbird	*Turdus merula*
European Robin	*Erithacus rubecula*
Red-billed Leiothrix	*Leiothrix lutea*
Sardinian Warbler	*Sylvia melanocephala*
Dartford Warbler	*Sylvia undata*
Subalpine Warbler	*Sylvia cantillans*
Common Firecrest	*Regulus ignicapillus*
Eurasian Jay	*Garrulus glandarius*
Common Chiffchaff	*Phylloscopus collybita*
Blue Tit	*Parus caeruleus*
Long-tailed Tit	*Aegithalos caudatus*
Eurasian Serin	*Serinus serinus*

where n is the number of intensity values (I_k) in temporal interval j (Fig. 1).

The ACI formula is based on the assumption that biotic sounds, such as bird or cicada song, have a great variability in intensity modulation, even in small fractions of time and in a single frequency bin. Antrophonies (human generated noise) and geophonies (wind, water flow), however, have more constant intensity values, resulting in smaller differences between time t and $t+1$. In this way, the ACI extracts the majority of biophonies while reducing or eliminating (when of low intensity) the non-biotic sounds and the effects of distance of sound from the microphone. In particular, it has been stressed that the ACI could be suitable for evaluating bird soundtopes which are defined by Farina (2011) as an intentional, coordinated association of different singing birds.

To reduce confusion in the terminology, we define the following (the values of this case-study are reported in brackets):

a. Sound session (ACI_{ij}), each programmed recording session over the course of the day, also reported as a "sound file" or simply a session (1 min);
b. Temporal interval (k), the interval at which the ACI metric is applied (0.012 s);
c. Temporal sub-set (j), the interval of time into which we divide a sound session (1 s);
d. Daily session, every session a day (totaling 90 sessions);
e. Macro-session, every group of two or more sessions (here 10 sessions);
f. Intra-seasonal intervals, every group of days over the course of the breeding season (11 days);
g. Frequency macro-classes, every group of two or more frequency classes (1350 Hz).

The ACI_{ij} results can be managed in different ways, producing a variety of types of interesting information which characterizes the local soundscape. Accordingly, it is possible to carry investigations out along a temporal and a frequency domain.

3.1. The temporal domain

3.1.1. ACI(session)

This index calculates the grand total of the ACI for each sound session:

$$ACI(session) = \sum_{i=1}^{l} \sum_{j=1}^{m} ACI_{ij} \tag{2}$$

where l is the number of frequency bins and m is the total number of temporal subsets.

Two vectors can be obtained:

$$a)\quad ACI(session)_j = \sum_{i=1}^{l} ACI_{ij} \tag{3}$$

which is the sum of the ACI_{ij} values along the temporal subsets.

The $ACI(session)_j$ can be used to investigate the evolution of the soundscape over time intervals of the same session when this interval is consistent, f.i.1 h.

$$b)\quad ACI(session)_i = \sum_{j=1}^{m} ACI_{ij} \tag{4}$$

is the sum of the ACI_{ij} values along the frequency classes.

The $ACI(session)_i$ is the basis for further analyses, especially when comparisons between different files are requested or when we intend to evaluate the trend of the ACI over the course of the day or season for each frequency class (Fig. 2).

3.1.2. ACI(loc)

The ACI(loc) is the sum of all of the elements of the matrix ACI $(session)_{hd}$. This index can be used to compare the acoustic

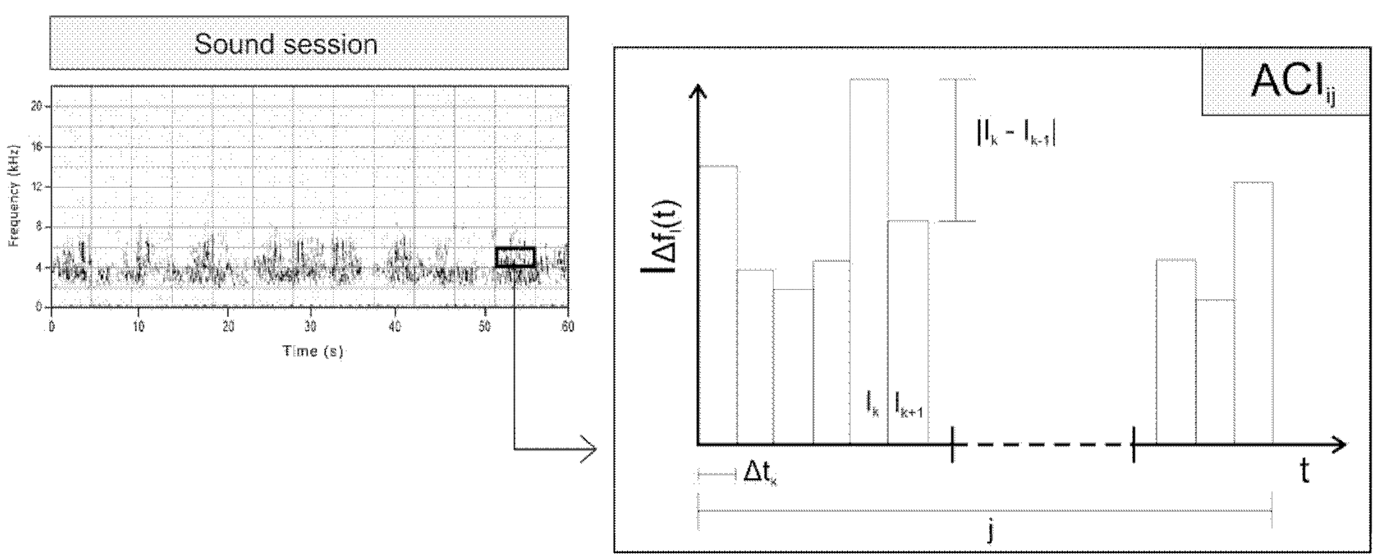

Fig. 1. Schematic representation of the way in which the Acoustic Complexity Index is calculated, starting from the spectrogram of a recording session of one minute long. I = sound intensity and dk = a temporal interval of 0.00162 s. This algorithm is applied 86 times per second.

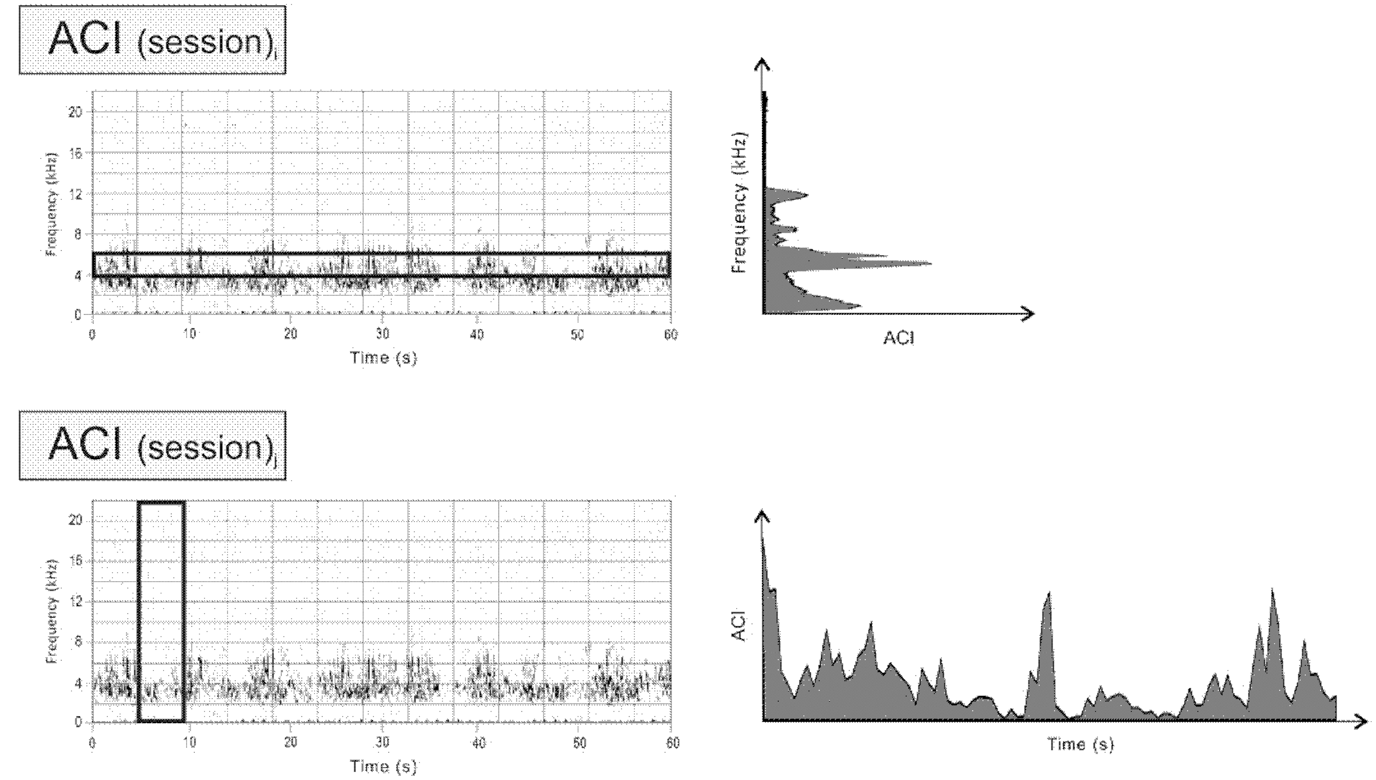

Fig. 2. ACI(session)$_i$ and ACI(session)$_j$ are respectively the vectorial transformation of the matrix A_{ij} according to the frequency (f) and the temporal (t) axes. In our case, the A_{ij} is composed of 157 classes of frequency and 60 temporal subsets.

complexity either between localities or for the same locality in different periods.

$$ACI(loc) = \left(\sum_{d=1}^{p} \sum_{h=1}^{q} ACI(session)_{hd} \right) / p \quad (5)$$

where d is the day over the course of the season, h is the session over the course of the day, p is the total number of days and q the total number of sessions per day.

From this matrix we obtain two vectors:

$$a)\ ACI_{(loc)_h} = \sum_{d=1}^{p} ACI(session)_{hd} \quad (6)$$

which is the distribution of the ACI over the course of a daily session when all days are considered together.

$$b)\ ACI_{(loc)_h} = \sum_{d=1}^{p} ACI(session)_{hd} \quad (7)$$

which is the distribution of the ACI over the course of the days when all daily sessions are considered together (Fig. 3).

3.1.3. ACI(season)$_{bc}$

In order to interpret the daily trend better, we have grouped the ACI(session)$_{hd}$ into nine macro-sessions (b). These are comprised of 10 sessions each (covering 2 h) and are in six intra-seasonal intervals (c) of 11–12 days each (20–31 May, 1–11 June, 12–23 June, 24 June–4 July, 5–15 July, and 16–26 July). Due to the lack of some elements in some groups, the ACI(season)$_{bc}$ is expressed as an average value.

3.2. Frequency domain

This analysis takes into consideration the distribution of the ACI$_{ij}$ along the different frequency bins. The purpose is to obtain a soundscape signature which highlights the importance of each frequency category for the different temporal frames (hours, days and intra-seasonal intervals). We indicate that an ACI(session)$_{ihd}$ is a matrix composed of ACI values which are distinct for frequency classes (i), session (h), and day (d).

$$a)\ ACI(sign\_season)_{ih} = \sum_{d=1}^{p} ACI(session)_{ihd} \quad (8)$$

represents the distribution matrix of the ACI along the frequency classes and sessions.

$$b)\ ACI(sign\_season)_{id} = \sum_{h=1}^{q} ACI(session)_{ihd} \quad (9)$$

represents the distribution matrix of the ACI along the frequency classes and days (Fig. 4).

3.2.1. ACI(sign_season)$_{ic}$

$$ACI(sign\_season)_{ic} = \left(\sum_{v=1}^{r} ACI(sign\_season)_{iv} \right) / r \quad (10)$$

represents the distribution matrix of the ACI along the frequency classes and intra-seasonal intervals, where both v and r equate to the number of days in each intra-seasonal interval c.

On some days the recordings failed due to technical problems or unfavorable weather conditions. As a consequence, the ACI(sign_season) has been calculated as a mean value on the basis of the number (r) of recording days in each intra-seasonal interval.

The frequency classes have been further merged into 10 frequency macro-classes of 1350 Hz, while the different daily macro-sessions were grouped into nine intervals of 10 sessions.

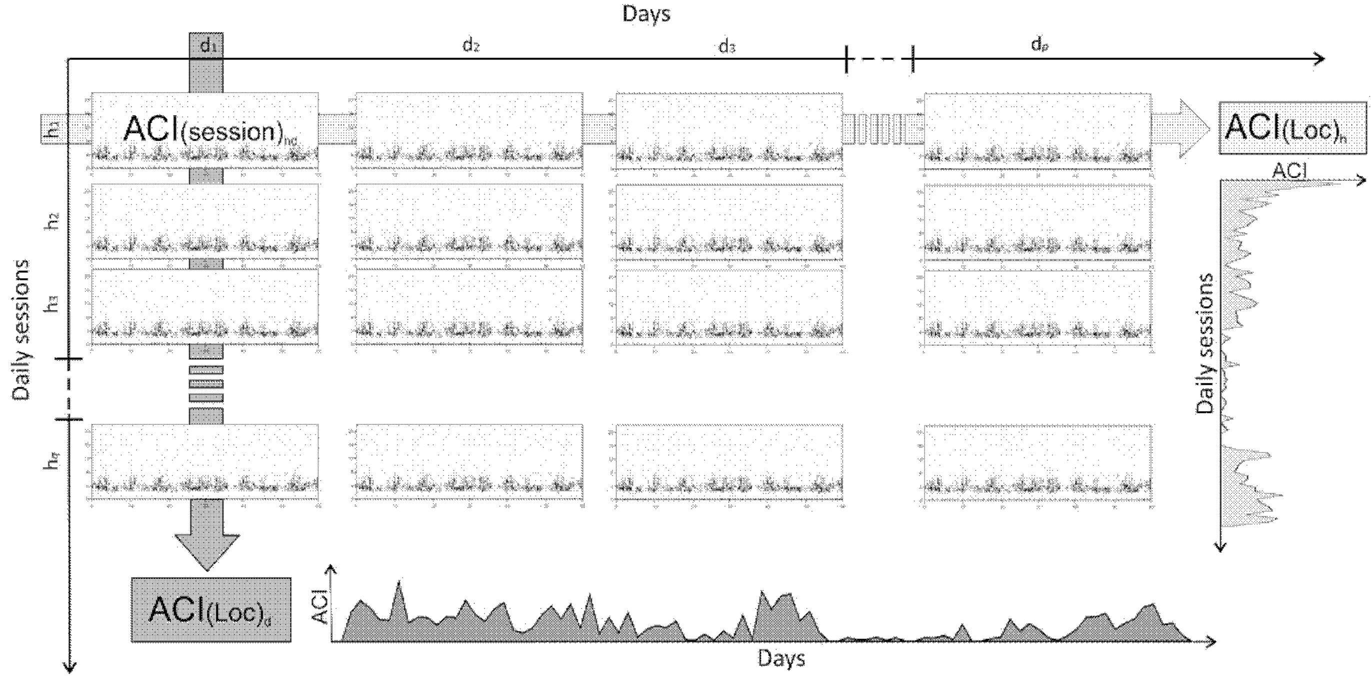

Fig. 3. The ACI(loc)$_h$ and ACI(loc)$_d$ are, respectively, the vector extracted from the ACI(session)$_{hd}$ matrix, where h is the number of daily sessions (90) and d the number of days (56).

Table 1 sets out all of the variables utilized in the ACI metrics along with the values used in this case-study.

4. Results

The ACI(loc)$_d$ results revealed that the bird community has two main acoustic peaks, one on about 30 May and a second on 16 June. Thereafter, a general decrease in the ACI values was noted, and after July 9 the cicadas' songs dominated the soundscape (Fig. 5).

In order to distinguish bird song activity from that of the cicadas, we split the ACI(loc)$_h$ into two separate periods (May 20–July 8, July 9–26). The first portrays a typical bird community shape, with the majority of activity being early in the morning (dawn chorus) and a second, less important, chorus taking place at dusk. The onset of the cicadas' songs on 9 July completely changed this pattern; this insect is very active from 9 a.m. to 6.30 p.m. (Fig. 6), with an ACI peak at noon.

These two different patterns can be better distinguished using the ACI(season)$_{bc}$ index, where the ACI values were grouped into nine macro-sessions and six intra-seasonal periods (Fig. 7, Table 1s).

The bird community was more active during the intra-seasonal interval, 20–31 May, with there being a slight decrease in activity in the next three periods and a clear drop in the number of songs performed in July. This pattern can be easily observed by focusing on macro-sessions one, two, three and nine (corresponding to about 4.00–10.00 a.m. and 6.00–8.00 p.m.). After 9 July, the situation suddenly changed, since the bird singing activity was partially masked by the cicadas' song, which dominates the soundscape from the second half of the morning until dusk, during macro-sessions four to eight.

These results are also evident from the 3D representation of the ACI(session), in which the entire set of sound data obtained by plotting the value of the ACI for 56 days × 90 daily sessions (Fig. 8) is represented. In this way, it is possible to observe the dawn and dusk peaks of activity, the introduction of the cicadas' song in July, and the presence of some anomalies (spikes) which could be identified using the original digital sound archives.

For instance, peak #1 was the result of a helicopter flying at low altitude, while peak #2 was produced by a gust of wind.

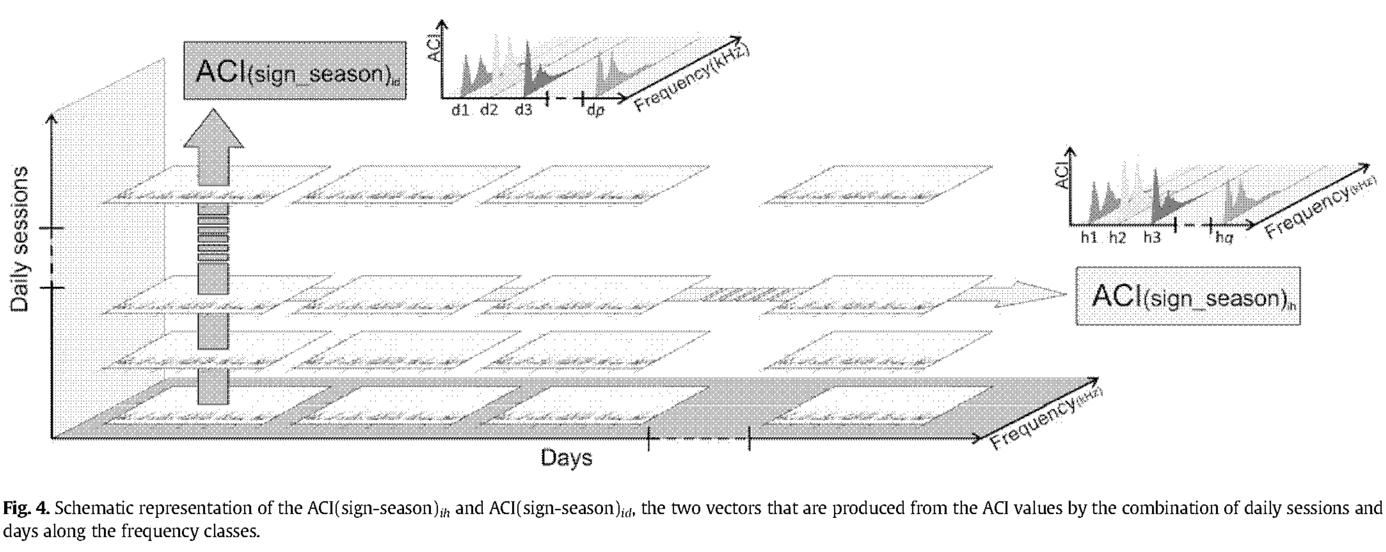

Fig. 4. Schematic representation of the ACI(sign-season)$_{ih}$ and ACI(sign-season)$_{id}$, the two vectors that are produced from the ACI values by the combination of daily sessions and days along the frequency classes.

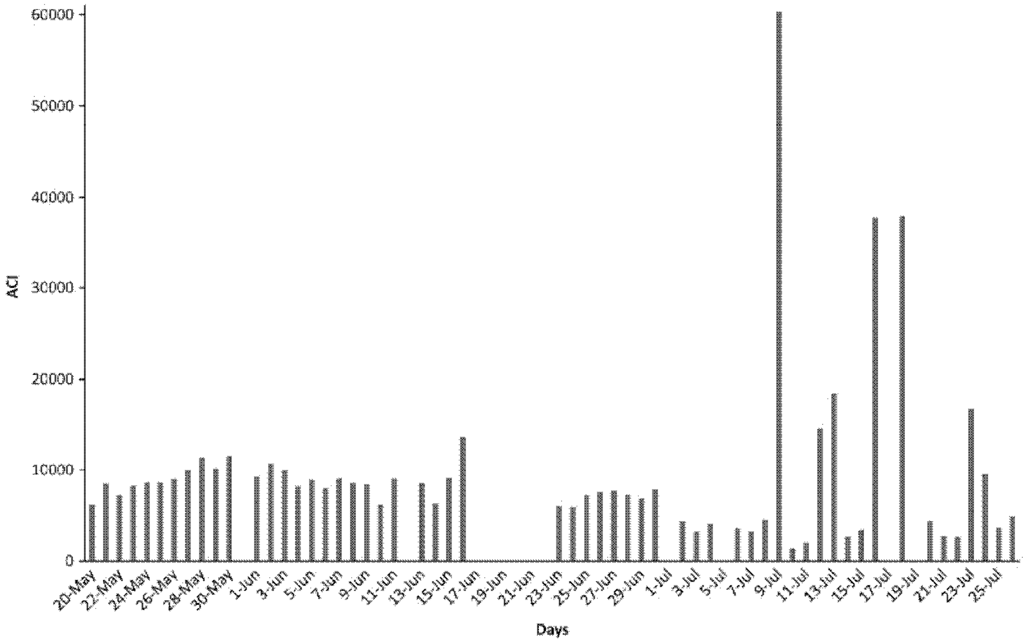

Fig. 5. Distribution of ACI(loc)$_d$ along the season. Gaps are days with unfavorable climatic conditions or technical problems.

The analysis of the ACI data performed in the frequency domain enables the acoustic signature for each intra-seasonal period to be described. The signature produced by the ACI(sign_season)$_{ic}$ (from May to early July) reveals a repeated pattern with two distinct peaks, while thereafter there was a multiwave pattern produced by the cicadas (Fig. 9).

From May to early July, the first peak, around frequency classes one to 12, is higher and narrower than a second peak, which is roughly located between classes 17 to 35. Moreover, from July 5 to July 26, the size of the first peak is much reduced, while the second peak disappears completely.

Table 2s sets out the mean, SD and CV of every macro-class of frequency along the six different intra-seasonal periods. Meanwhile, the final four macro-classes are less represented over the study period.

5. Discussion

5.1. Some comments on the methods

On the basis of the stated aims of this contribution, we applied the ACI metric, showing the potentialities, and the manipulations of the data according to the different temporal frames (hours, days and

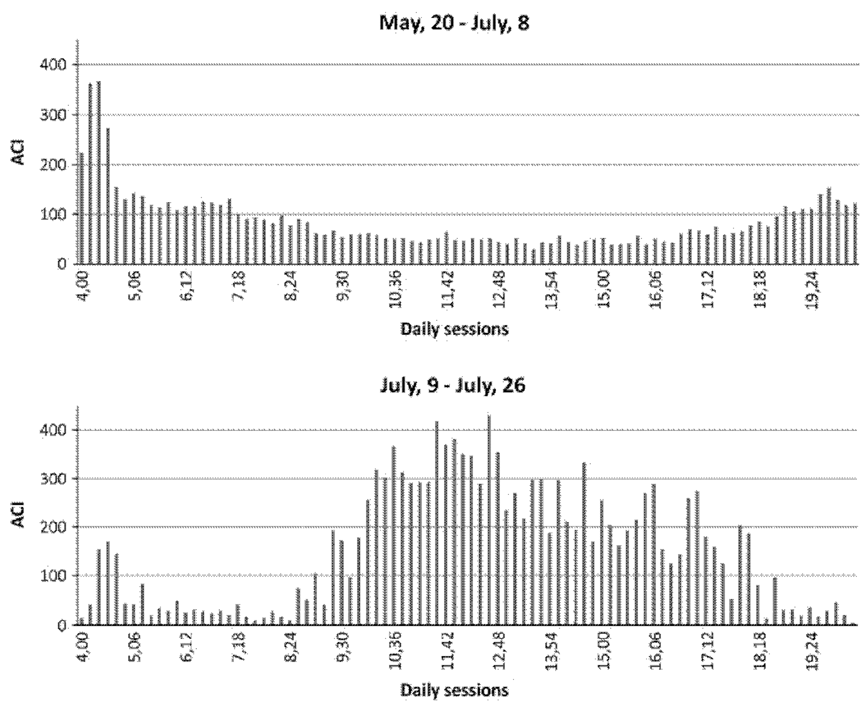

Fig. 6. Daily distribution of ACI(loc)$_h$ during two periods according to cicadas silence (May 20, July 8) and during cicadas song activity (July 9, July 26).

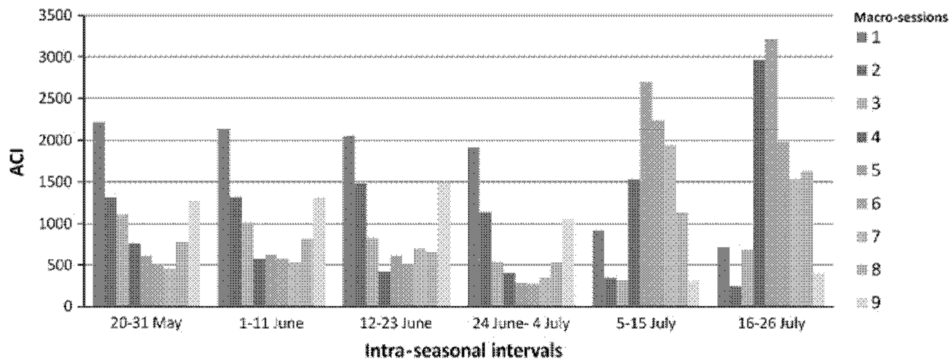

Fig. 7. Distribution of the ACI(sign_season)$_{sc}$ metric along the six intra-season periods (*c*) (20–31 May, 1–11 June, 12–23 June, 24 June–4 July, 5–15 July, 16–26 July) and nine macro-sessions (*s*).

intra-seasons) and the long, different groups of frequency bands. This approach enables us to investigate behavior and community complexity and to obtain answers to some questions relating to the multifaceted way in which birds interact acoustically.

The choice of recording sessions of 1 min every 11 min seems to be a good compromise when it comes to obtaining a reasonable sampling of the daily trend of a soundscape. The evaluation, for the first time, of the SoundscapeMeter-plug-in (Farina and Piccioli, in prep) has demonstrated in the results herein that this software not only works efficiently, but has also enabled us to extract a great deal of information from the data. Moreover, the data processed during each daily session can be easily confronted by listening to the original sound files directly. This procedure allowed us to quickly verify possible anomalies in the data due to events like anthropogenic noise, strong wind, rain and other meteorological occurrences.

The location of the recording station can make a difference (as observed in the same areas covered by other nearby recording stations, Farina in prep), but definitive evidence that birds intentionally creating a soundtope (*sensu* Farina et al., in press) is still lacking.

5.2. Some comments on the results

The study site, herein selected because a typically problematic area along the coastal range of Mediterranean Europe, has been demonstrated to have a Hi-Fi soundscape ("a Hi-Fi environment is one in which sounds may be heard clearly without crowding or masking" Schafer, 1977, p. 272). This is largely due to the morphology that is typical of a hanging-valley and its relative remoteness from anthropogenic, continuous disturbance sources. Due to a secondary succession that is exposed to vegetation rejuvenation after frequent fires, the study site continues to be particularly favorable when it comes to investigating the turnover and dynamics of bird assemblages.

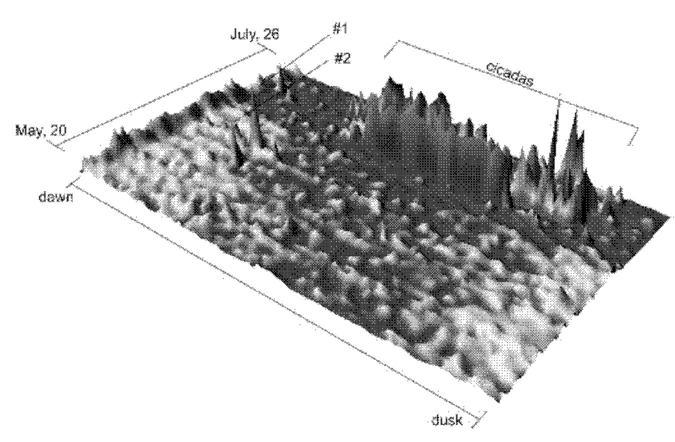

Fig. 8. 3D representation of the soundscape over the course of the season (56 days) (y axis) and daily sessions (90) (x axis). From the image it is possible to note the dawn and dusk chorus, reduced song activity in the middle of the day, and the presence of some spikes (anomalies): 1: This peak is the result of a low altitude helicopter flight. 2: The introduction of the cicadas' song in July when bird activity is much reduced or absent. This picture, obtained using Surfer9®, is of great interest in a monitoring program because of its immediate readability and the ability to verify every anomaly or visible trend.

This region is regarded as a hot spot for biodiversity, like other parts of Mediterranean Europe (Myers et al., 2000), and has long been shaped by human activity, which has increased the complexity of the land mosaic (di Castri, 1981) and, as a consequence, affected its biological diversity (Blondel, 2006; Grove and Rackham, 2001).

Increasing areas of coastal land are today being neglected, and despite the growth in human well-being, ecosystem services are rapidly degrading (*e.g.*Raudsepp-Hearne et al., 2010). In particular, the neglect of resources has led to the loss of the correspondent semiotic interfaces (the eco-fields, *sensu* Farina and Belgrano, 2006) that are necessary for their tracking (Farina, 2011).

Furthermore, the ecological fragility of this area also contributes to its recent colonization by the Red-billed Leiothrix (*Leiothrix lutea*), a medium-sized babbler that is native to southeast Asia, southern China and the Himalayan regions of India and is known to be invasive in Hawaii (Ralph et al., 1998) and Japan (Amano and Eguchi, 2002a,b; Dubois, 2007; Eguchi and Amano, 2004).

Recently introduced to northern Italy (Pautasso and Dinetti, 2009), the Red-billed Leiothrix is now abundant locally (Nardelli, per. com.; Farina et al., in press), and the study of the population dynamic and competition effects on other species of birds is a very appealing topic for further research. Indeed, after a confrontation with aural direct listening of the recorded files, this species (easily to be detected in the spectrograms, song and call produce typical regular figures) contributes to the soundscape, particularly in the late breeding season (Fig. 9, July 5–26, frequency bins 1 to 15) when others, like the Common Blackbird and European Robin, become silent.

What emerges from the results is the fact that the bird community is very active in the early morning, after dawn, and at dusk, with a decrease in song activity over the course of the season. This confirms a well-known pattern that has also been observed in other bird communities (Burt and Vehrencamp, 2005; Dabelsteen and Mathevon, 2002; Kalcenik and Krebs, 1982; Mace, 1987; Staicer et al., 1996). Meanwhile, Fig. 9 highlights greater daily, acoustic regularity at the beginning of the breeding season, which is a clear indicator of the non-casual organization of the soundscape. However, in July, the soundscape changes abruptly due to the increase in the cicadas' song, which produces highly variable ACI values. This variability is probably due to the fact that cicadas produce a broad-band signal with a high degree of frequency and time heterogeneity. When we observe the ACI value early in the morning and at dusk, when the cicadas are silent, there is an expected decreasing trend in terms of bird song activity.

The acoustic signature has at least two distinct patterns: from 20 May to 4 July, the presence of two peaks is the result of the

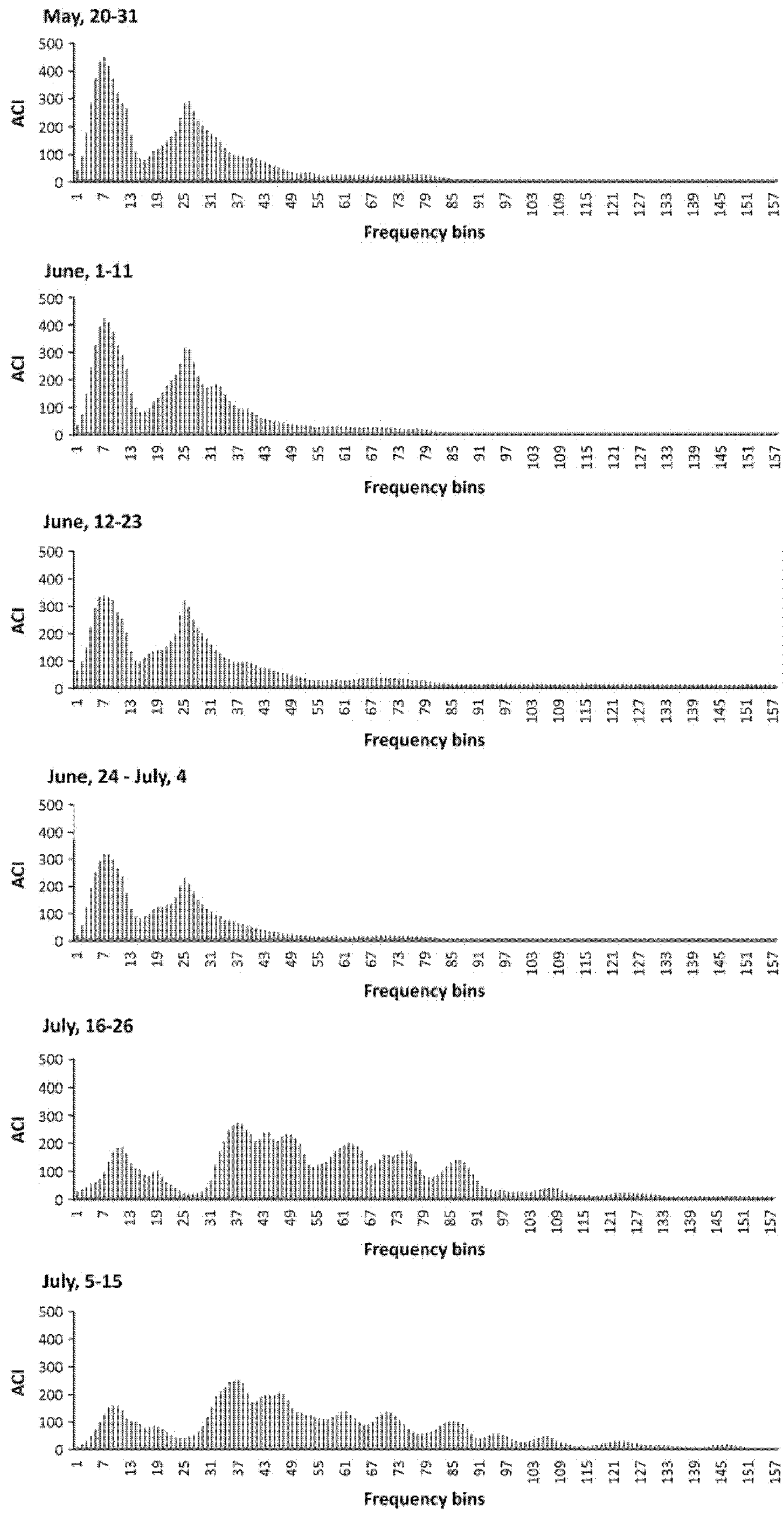

Fig. 9. Soundscape signature for every intra-seasonal period ACI(sign_season) (20–31 May, 1–11 June, 12–23 June, 24 June–4 July, 5–15 July, 16–26 July). In the y axis this is the average value of the ACI, while in the x axis this is the frequency classes.

contemporary song of the Common Blackbird, Red-billed Leiothrix and European Robin. This changes after that period, when the trend is less clear and the contributions of warblers like the Dartford Warbler, Sardinian Warbler and Subalpine Warbler emerge. The acoustic activity of these warblers is more variable and less important when it comes to soundscape characterization.

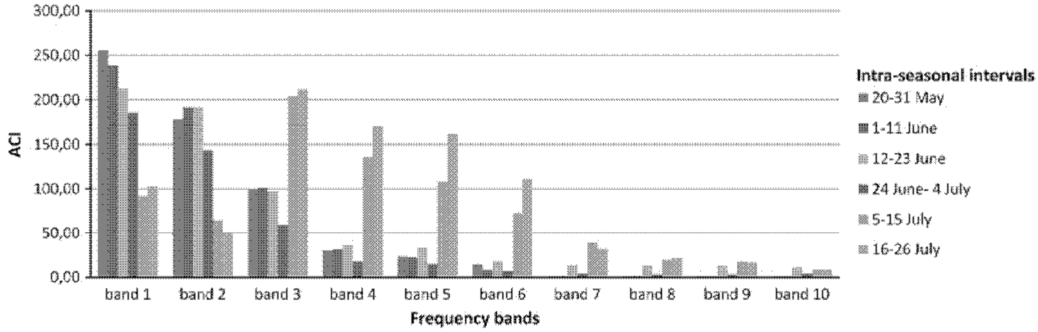

Fig. 10. Distribution of the mean ACI value along the 10 macro-classes of frequency (band 1 = 1500–2850, band 2 = 2851–4200, band 3 = 4201–5550, band 4 = 5551–6900, band 5 = 6901–8250, band 6 = 8251–9600, band 7 = 9601–10,950, band 8 = 10,951–12,300, band 9 = 12,301–13,650, band 10 = 13,651–15,000) and the 10 intra-season periods.

The small peak observed in the first frequencies in July is the result of the acoustic contribution of the Red-billed Leiothrix, which was previously masked by the acoustic activity of the Common Blackbird (Fig. 9).

From the analysis of the frequency bands aggregated into macro-classes (Table 2s, Fig. 10), it is evident that the first two macro-classes, from 1500 to 4200 Hz, demonstrate a clear decrease over the course of the season. Meanwhile, from 4200 to 9600 Hz, the sharp increase in the last intra-seasonal period is almost certainly due to the cicadas' activity.

5.3. Some comments on the soundscape approach

As recently discussed by Krause et al. (in press), characterization of the soundscape can help with the evaluation of the diversity of an animal assemblage. In their research, Gage and Krause chose four locations in the Sequoia National Park (California, US) according to their elevation and vegetation type. They then superimposed the vegetation signature on to the acoustic signature by extrapolating the soundscape of other localities with similar vegetation cover. This method opens the way for an efficient methodology for landscape evaluation, although some caveats cannot be avoided. Indeed, we have to take into consideration the fact that the soundscape is a dynamic "object" and that to collect an acoustic signature in a fine grained mosaic, like the Mediterranean maqui, requires the positioning of more than one recording station to ensure the proper characterization of the soundtope (Pijanowski et al., in press; Krause et al., in press).

Prior to this investigation, information about the soundscape of this area was completely absent and, for this reason, it is not currently possible to conduct a comparative analysis. Nevertheless, this study is a good starting point when it comes to investing in long-term research and monitoring. Indeed, in the future, we expect that the soundscape may be modified by fire events, changes in human impact due to increased tourist activity, climatic shifts, and the unpredictable dynamics of the Red-billed Leiothrix population.

The ecological fragility of the study area suggests that this location is a good candidate for long-term ecological research.

The climatic crisis that the Earth has been experiencing in recent years (Gitay et al., 2002; McArty, 2001) could be a further element to take into account when investigating probable changes in biological rhythms, particularly since birds, like many other organisms, are very sensitive to climatic parameters and their variability (Crick, 2004; Peterson, 2003). Accordingly, this changing context may well affect their acoustic performances in terms of phenology and intensity where the ACI index seems to be able to detect such variations.

6. Conclusions

Until recently, the processing of sound files frequently required a long computation time, discouraging their extensive use in monitoring schemes. Today, however, the SoundscapeMeter plug-in has proved to be a tool that is able to process a large amount of sound data in a very short period of time; for instance, a one minute sound file is processed in 5 s. This development enables data to be processed in real time, immediately after its collection from the field. Accordingly, it is in this direction that our efforts to utilize this plug-in for long-term monitoring activities are oriented.

As a consequence, and as seen in Fig. 8, computation of the ACI enables us to observe the dynamics and changes that occur in a bird community over the course of the hours, days and seasons, as well as also allowing us to verify every anomaly that might occur during an automatic recording, such as due to anthrophonies (helicopters) or geophonies (rain, wind gusts).

Producing a soundscape signature (Fig. 9) also means that it is possible to describe the patterns of sound activity that a local community produces, while ACI metrics have been demonstrated to be a powerful tool with which to analyze the complex patterns of a soundscape. Accordingly, the aim of testing this metric with a view to later applying it to a routine monitoring scheme seems to have been achieved.

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ecoinf.2011.07.004.

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