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Applying the Ecoacoustic Event Detection and Identification (EEDI) Model to the Analysis of Acoustic Complexity

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Abstract

Ecoacoustic events are functional units of the acoustic environment. Their classification offers a substantial contribution to interpreting ecological complexity. A procedure for their detection and identification, Ecoacoustic Event Detection and Identification (EEDI), is proposed and discussed. Dedicated software (SoundscapeMeter 2.0) is illustrated in a detailed manual. EEDI operates according to two steps: in a first step, a numerical analysis based on the ACI metrics, ACIft and its evenness ACIfte, detects potential events inside an event space. In a second step, the detected events are identified using the acoustic signature (ACItf) of events previously empirically identified.
The EEDI procedure can be extensively used in basic and applied research. In particular, EEDI can be used in long-term monitoring programs to assess the effect of climate change on the dynamics of individual species and on the associated acoustic communities. The EEDI model can also be used to investigate the acoustic intrusion of humans in natural systems and in urban areas.

Introduction

The biophonic complexity of the environment has been recently considered an effective proxy of biodiversity (Sueur et al. 2008, Winner et al. 2014). However, this represents only a part of the contribution to the description of the ecological processes that sound analysis can offer.

In fact, environmental sounds play a role not only as a communication carrier used by animals in their inter-individual relationships (co- and etero-specific), but also as an information context used by animals to improve the knowledge of their subjective world or Umwelt (*sensu* von Uexkull 1982) and to reinforce their capacity to navigate across the individual-based cognitive landscape (*sensu* Farina 2010, p. 19).

Ecoacoustics, which is considered an emergent field aiming to investigate the role of sound in ecological processes (Sueur and Farina 2015), is able to offer a broad spectrum of perspectives and of investigative scales, as well as theoretical and methodological support to explore and interpret the acoustic complexity of the environment.

According to this perspective, Farina et al. (submitted) have recently presented a biosemiotic model, named EEDI (Ecoacoustics Event Detection and Identification), for the analysis of the complex patterns (ecoacoustics events) that emerge from sound data, especially when survey and analysis are conducted on big data like the datasets collected in long-term monitoring schemes.

That said, we aim to present the theoretical basis of EEDI procedures and in particular a new software program (Soundscapemeter 2.0) illustrated in detail in the attched manual (Appendix A). In support of EEDI, some epistemological aspects of sounds and the explanation of the metrics used in the analysis will be presented, as well.

The characters of sound in the landscape context

Sounds are distinct according to their origin in geophonies, biophonies, and technophonies (Pijanowski et al. 2011a,b) and their blend creates soundscapes that are as heterogeneous as the landscapes in space and in time (Farina 2014). Between these, biophonies are the most variable sounds in space and time because they are produced by mobile animals that have seasonal acoustic performances connected to reproductive cycles. Such variability in space and time is largely due to the distribution of resources that oblige individuals to move around across their home range.

Geophonies are more spatially conservative because usually the sources are stationary like a water fall or waves along marine coasts, more predictable like seasonal winds (e.g., tradewinds), or spatially homogenous like rain. However, some geophonies like thunders may occur randomly across a territory and along seasons.

Technophonies are largely stationary in urban areas, near airports, or along highways and, like church bells, may occur at regular intervals. Urban sounds are strictly connected with human daily dynamics and commuter movements.

The Soundscape and its functional components

Soundscapes are the result of the blend of geophonic, biophonic, and technophonic sources, with characters that depend on the percentages of these sonic sources. Soundscape is perceived as an entity that is species-specific. It has spatial and temporal dimensions and its organization largely depends on the characteristics and dynamics of the landscape from which it is originated. The soundscape maintains an inherent heterogeneity at different scales and can be considered a container of other ecological agents like sonotopes, sonotones, soundtopes, acoustic communities, and ecoacoustic events.

Sonotopes

Every soundscape is composed of homogeneous sonic patches or sonotopes characterized by a different percentage of geo-, bio-, and technopnonies (Farina 2014, p. 16–17). Definitively, every sonotope has distinct and specific characteristics or acoustic signatures. A fine-grained mosaic of sonotopes participate to constitute the complexity of the landscape.

Sonotones

At the edge of each sonotope exists an area of transition between two or more sonotopes. This area is depicted as a sonic ecotone or sonotone where the information from different sonotopes overlaps. A sonotone can be considered a region of great sonic uncertainty with expected consequences on the behavior of animals (Farina 2014, p.19).

Soundtopes

If the sonotopes are analyzed at a finer resolution, a new heterogeneity appears. This is not a novelty in ecology, as many objects have fractal-like structure responding to the resolution at which they are observed (Wiens 1994). The sonotope heterogeneity largely depends on the biophonies that change in time and in space. We call soundtopes the sub-division of a sonotope originated by a different distribution of such biophonies (Farina 2014, p.19).

Acoustic community

Farina and James (submitted) have defined an acoustic community as "an aggregation of species that produce sound by using internal or extra-body sound-producing tools, with such communities occurring in both aquatic and terrestrial environments". In summary, an acoustic community is realized by individuals and species that exchange acoustic information. An acoustic community may also be defined as a soundtope without geophonic or technophonic information and has a distinctive acoustic signature. The acoustic signature can be considered as the fingerprint that emerges from the distribution of frequency categories emitted by the species belonging to an acoustic community.

The ecoacoustics event: the biosemiotic interpretation of complexity of the soundscapes

The ecological meaning associated with a soundscape surpasses the distinction of sonotopes, soundtopes, sonotones, and of the acoustic community. The meaning that sounds have for a specific organism depends on the perceptual and cognitive capacity of this organism, on its functions, and on the physiological status.

According to this perspective, an ecoacoustic event is a carrier of meaningful information that is used to accomplish the needs required by the organism to stay alive in the best conditions.

We have introduced the adjective "ecoacoustic" to better specify the typology of such agent. For instance, the word "event" may be defined in several ways, from the philosophical to the political realms. With the adjective "acoustic", we recognize an event like a symphony, a note, etc. With the adjective "ecoacoustic", we consider an event that has a specific ecological role and a contemporary phenomenon studied by the field of ecoacoustics.

An event is a recognizable functional unit of the acoustic environment in which every organism is embedded and represents a biosemiotic agent used by an organism to exercise a necessary control on the environment. Ecoacoustics events are not simply a distinguishable phenomenon but contemporarily are a biosemiotic acoustic eco-field, a carrier of meaning to intercept specific resources (Farina and Belgrano 2004, 2006).

Inside the different typologies of soundscapes, events represent distinguishable categories that have a meaning for the organism that perceive them. We lack precise ideas if an ecoacoustics event for humans may have the same meaning for an animal, but it is reasonable to believe that every organism perceives the sounds from the surroundings not as a sum of many sounds but as a unique and distinct ecoacoustic event, a carrier of meaning.

For instance, the song of a bell is probably also perceived by a horse but with a different meaning. In the same way, fireworks produce excitement in humans but fear in the majority of animals, and a bird chorus may have a completely different meaning for birds and only a typology of natural symphony for people.

Although we lack the capacity to know if the events distinguished by people correspond to the events distinguished by individual species, the categorization of the events is a new way to classify soundscapes and their different status. This is a new field of research that requires confirmation with empirical evidence.

According the theory of the eco-field, every location may have distinct events for an organism, and at the same time other events for other organisms.

There are thought to be at least criteria to detect and to identify an event: aural, visual by examining a spectrum, or cultural. However, the biosemiotic model utilized is common to all, where for every event we recognize a role and a function. Many natural phenomena produce sounds, and such sounds may represent events. Rain, wind, and human voice, when they happen at high intensity, may represent distinguishable events. Moreover, alarm calls, social calls, and their combination are behavioral events. The acoustic activity of a colony of sea birds during breeding time produce important events that have very minimal significance for people but are rich with individual messages for such birds.

How to measure events? This is an important question because an event conveys information and it results a nominable and not a quantifiable entity (Barbieri 2016). A bell of a church that announces a marriage has a different acoustic structure than a bell singing to announce the death of a person, and this difference can be measured. However, this difference must be associated with a coding process to decide the meaning of the two bells.

Definitively, to categorize an event, two distinct steps are required. The first step is the "*detection*": I say "α" bell is different from "β" bell, and this can be demonstrated using a numerical analysis of the acoustic spectrum.To attribute a meaning to these two songs, we have to nominate α=marriage bell and β= death knell; this last process is a process of "*identification*" and is based on a cultural coding (Barbieri 2015). The cultural coding process can be done automatically if we have in advance a collection of bell songs identified that can be compared using an automatic procedure with the acoustic structure of the events that we wish to identify. This is the same procedure used by crime investigation or by national security to identify people using their fingerprints. When the fingerprints are geometrically coincident, then the name of people can be associated and the unidentified fingerprints definitively named (fingerprint authentication). Of course, we always require an identified fingerprint! (Fig. 1)

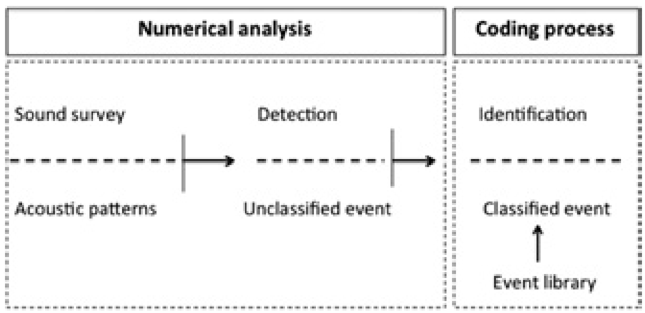

Fig. 1 – Process to detect and identify events using the Ecoacoustic Event Detection and Identification procedure (EEDI).

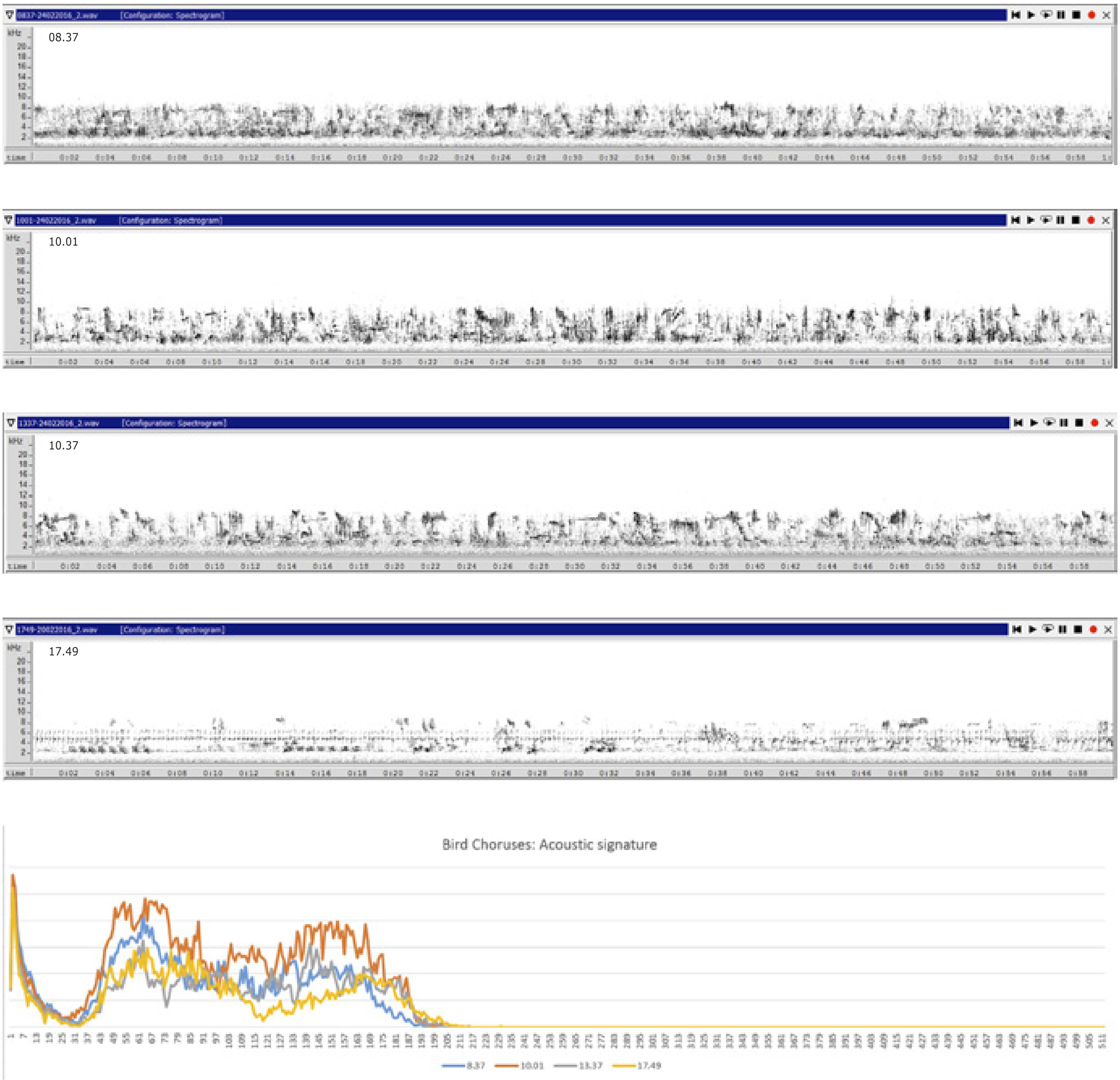

Fig. 2 – An example of four ecoacoustics events created by bird chorus at 08.37, 10.01, 13.37, and 17.49 and their acoustic signature (ACItf) in a Mediterranean shrubland (Madonna dei Colli, Northern Tuscany) detected by the EEDI procedure. These choruses are the results of a combination of different species. In particular, the 10.01 chorus is the result of the song of the Song Thrush (*Turdus philomelos*), a migrant and overwinter species in the Mediterranean. The acoustic signatures show substantial differences due to the different composition of the choruses. The identification of each chorus requires different categories of classified reference signatures.

The ecological meaning of ecoacoustic events

When a collection of sound files is inspected with the audio switch off and only the FFT spectrum is utilized as a guide, different visual patterns alternating inside the collection can be easily detected. These patterns are potential ecoacoustics events with which probably specific ecological factors may be associated.

According to the acoustic source, events may be of geophonic, biophonic, or technophonic origin. According to the number of acoustic agents, contemporarily active events may be considered as "simple" when generated only by a single source (e.g. the alarm call of a bird), or as "complex" when two or more acoustic agents overlap or interact each other (e.g., birds singing during rain, or during the transit of a car). Choruses that are one of a more distinct phenomenon in nature, common to birds, frogs, insects, snapping shrimp, sea urchins, and fish are examples of complex events, and the object of several ecological interpretations (Farina et al. 2015) (Figs. 2 and 3).

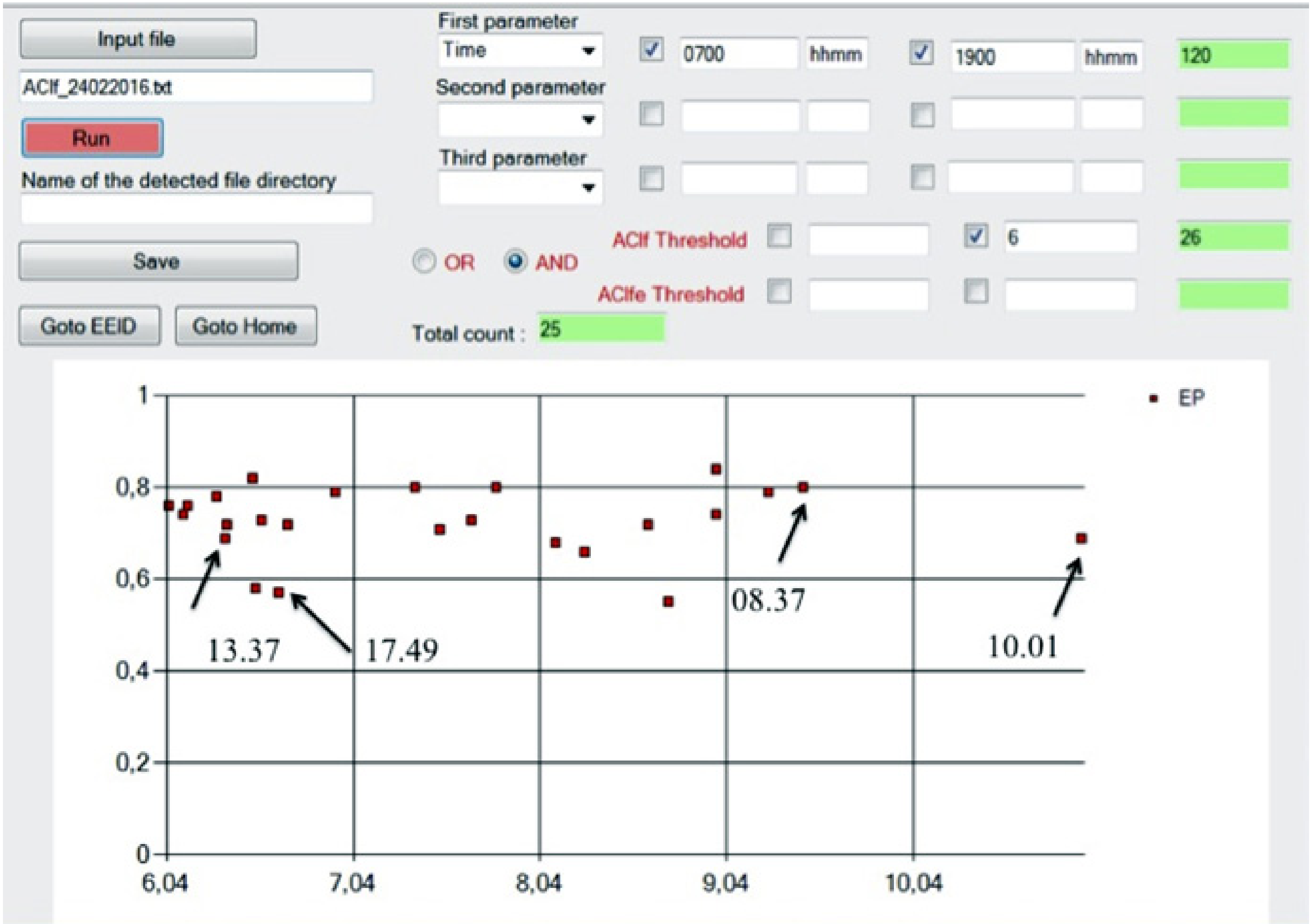

Fig. 3- Distribution in the Ecoacoustic Event Space EES space of the events characterized by ACIft >7and ACIft evenness > 0.4 between (range 0 to 1), time set between 0700 and 1900 on 24.02.2016 in the location Madonna dei Colli (Northern Tuscany). Figure from EEDET (SoundscapeMeter 2.0).

The intrusion of technophonies in the natural environment produces spectral patterns easy to be recognized. Such events may have important consequences on the behavior of vocal animals. A noisy environment may mask the acoustic signal of animals with consequences on their behaviour.

Heavy rains or strong winds have acoustic patterns that can be easily identified. Their appearance, if persistent for days, may have important consequences during the breeding period, interfering with territory disputes and mating selection, when the song activity of birds is a primary tool to assess male primacy.

In conclusion, several patterns that can be observed by browsing an acoustic spectrum have a role in the ecological functioning and dynamics of natural and human-modified systems. However, not all of the distinguished patterns can be associated with an ecological function, and this may represent a part of the unpredictability in the event detection and identification procedure to be carefully considered.

The Ecoacoustic Event Detection and Identification (EEDI) procedure

Searching in a collection of sound files for choruses, weather phenomena like strong rain or wind, or intrusions of technophonies, is an extremely time-consuming task that discourages regular survey in long-term monitoring schemes. An automated procedure is suggested by applying the EEDI process. This the numerical analysis requires complex but automated procedures that are possible by the application of dedicated metrics of information evaluation (Fig. 4). In particular, for the numerical analysis, among the options to select ecoacoustics indices (Sueur et al. 2014) is proposed the use of the Acoustic Complexity Indices (ACI) (Morri 2008; Farina and Morri 2008, Pieretti et al. 2011).

Numerical analysis

The numerical analysis of sound files requires a specific setting of the recording machines that capture the acoustic signals. The entire analysis, here presented, is based on the data produced by the Soundscape Explorer [Terrestrial] SET™, a digital recorder originally designed by A. Farina at the Department of Basic Sciences and Foundations (Urbino University, Urbino, Italy), and subsequently modified, improved, and realized by Lunilettronik (hardware designed by Paolo Salutari, on-board software written by Enrico Tognari) (Fivizzano, Italy), powered by a dedicated software program (SoundscapeMeter 2.0) designed by Almo Farina and written by Paolo Salutari (see the Manual in the Appendix). Sound data stored in wave format are submitted to a Fast Fourier Transform (FFT) and then the ACI metrics are applied.

The ACI metrics (Farina and Morri 2008, Pieretti et al. 2011) measure the variation of the amplitude between:

a) a couple of pulses along a specific frequency bin ($ACIt_f$);

b) a couple of pulses across frequencies along the same temporal interval ($ACIf_t$) (Fig. 4).

Both measures in the EEDI procedure are computed simultaneously along a temporal interval of 1 minute alternated with 5 minutes of stand-by. One minute is empirically considered a reasonable interval of time in which the majority of the ecoacoustics events can be detected, at least in terrestrial environments.

To be applied in a more appropriate way (e.g., searching for patterns), $ACIt_f$ requires an aggregation of data (clumping) (see Farina et al. [submitted], for more detail on clumping function). The complete (explicit) equation for $ACIt_f$ for each frequency bin f, where the clumping option is considered, can be represented as follows:

$$ACIt_f = \sum_{k=1}^{c}\left(\frac{\sum_{i=1}^{\frac{t}{c}}\left|a_{i,j}-a_{i+1,j}\right|}{\sum_{i=1}^{\frac{t}{c}}a_{i,j}}\right)$$

where $a_{i,j}$ is the FFT numerical output, t is the number of temporal steps in which a file is subdivided after FFT, f is the frequency bin, c is the number of clumps in the recording, and t/c is the number of elements composing a clump.

The complete (explicit) equation for $ACIf_t$ can be represented as follows:

$$ACIft = \sum_{i=1}^{t}\ \sum_{j=1}^{f-1}\frac{\left|a_{i,j}-a_{i,j+1}\right|}{\left(a_{i,j}+a_{i,j+1}\right)}$$

where $a_{i,j}$ is the amplitude of each pulse, t is the number of temporal intervals, and f is the frequency bin. The $ACIf_t$ varies according to the temporal steps. The length of the temporal interval may be fixed equal to the clumping dimension of $ACIt_f$; however, this option is not mandatory.

In the EEDI approach, ACI_{ft} is plotted with its evenness ($ACIf_{te}$) calculated by using the Levins evenness B algorithms (Levins 1968, Hurlbert 1978):

$$B = 1/\sum_{i=1}^{t} p_i^2$$

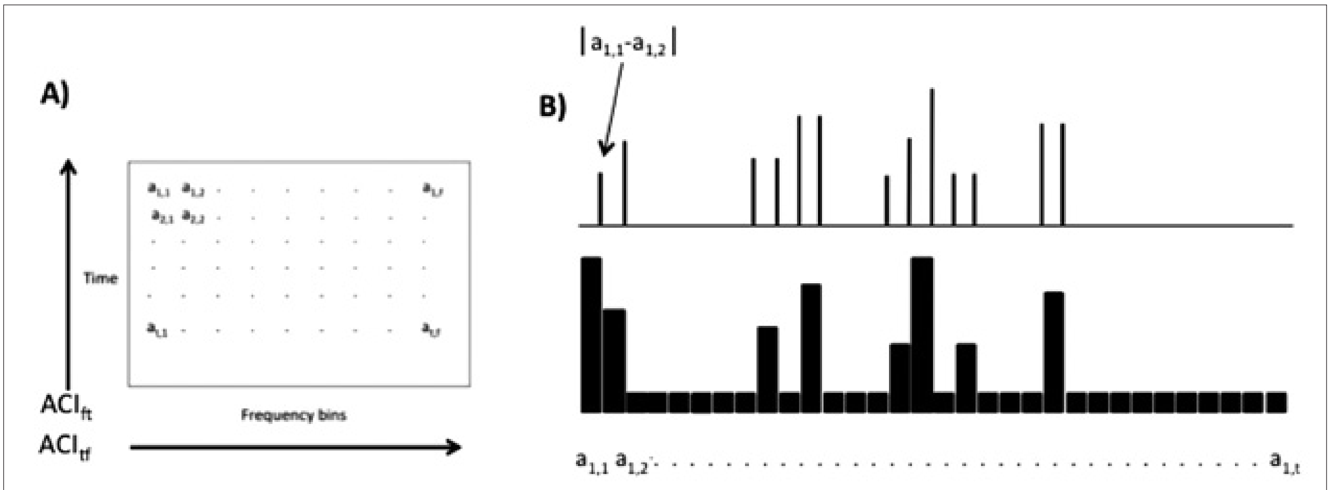

Fig. 4 – Schematic representation how the Acoustic Complexity Indices (ACIft and ACItf) calculate the acoustic information inside a spectrum.

where p_i is the importance of ACI in each frequency bin f ($ACIt_f$) or in each temporal step t ($ACIf_t$). The standardized measure is

$$ACIf_{te} = \frac{B-1}{t-1}$$

The $ACIf_{te}$ is low when only a few acoustic signals are present along the temporal step considered (i.e., 1 minute).

The Event Detection

We have to consider that the EEDI model is applied on a daily collection of 240 individual $ACIf_t$ files (each 1 minute long), and resulting from the recording of 1 minute after 5.

In the EEDI procedure, the first step is represented by the event detection. This procedure is obtained by plotting $ACIf_t$ versus its evenness ($ACIf_{te}$), and this creates an ecoacoustic event space (EES) that may be divided into four nominal quadrants or regions and indicated according to a geographical nomenclature: first quadrant (NW), second quadrant (NE), third quadrant (SE), and fourth quadrant (SW).

The first quadrant (NW) is characterized by low $ACIf_t$ and high $ACIf_{te}$ (e.g., biophonies at low amplitude but at high evenness). The second quadrant (NE) is characterized by high $ACIf_t$ and high $ACIf_{te}$ (e.g., geophonies, such as strong wind and heavy rain that are distributed regularly along the time axis). The third quadrant (SE) is characterized by high $ACIf_t$ and low $ACIf_{te}$ (e.g., short technophonies at high amplitude, such as a jet at low altitude, or a geophony, such as thunder). The fourth quadrant (SW) is characterized by low $ACIf_t$ and low $ACIf_{te}$ (e.g., biophonies, such as isolated alarm calls).

The EES allows the detection of the majority of the potential events present in a single day of recording. The event detection can be sped up by selecting the range of environmental parameters (time, temperature, pressure, humidity, light) that SETs collect contemporarily to sounds, in which to apply the EEDI procedure.

The event identification

The event identification is the final part of EEDI in which a coding procedure is applied that consists in measuring the rate of affinity between a classified event, prepared in advance on an empirical basis, and the detected events selected from the EES.

The first part of the identification consists in the comparison between all the detected events and a classified event of which we know the ecological significance (e.g., a morning chorus).

This comparison is made using the acoustic signature of every detected event that is represented by the distribution of ACItf along frequencies during one minute of recording.

To determine the value of correlation, we propose the Pearson coefficient of correlation (Legendre and Legendre 1998), Whittaker's index of association (Whittaker 1952), and Chord distance (Orloci 1967), which is used to attribute statistically the detected events to the classified event.

Concluding comments

The EEDI procedure is based on the research and discrimination of ecoacoustics events inside a collection of environmental sounds.

The environment is rich in under-exploited sources of acoustic information (Ma et al. 2006), and EEDI offers a novel opportunity to extract the acoustic information conveyed in numbers by $ACIt_f$, ACIft and its evenness, in association with environmental parameters (e.g., light intensity, temperature, humidity, atmospheric pressure, and hour of the day) and a coding procedure of ecoacoustic identification.

EEDI, for its user-friendly approach and flexibility, represents a significant resource with which to find practical solutions to move ecoacoustics from the theoretical foundations into the core of an applied ecological discipline, devoted to facing emergent environmental problems like climatic change (Krause and Farina 2015) or anthropogenic noise intrusion in natural systems, and to find necessary and urgently required solutions to such environmental emergences. EEDI offers new possibilities of the utilization of sound data by land managers, landscape architects, conservation biologists, and stakeholders. EEDI is also considered a potential tool that can be used by citizen scientists to contribute to the knowledge base of ecological dynamics.

The EEDI model, which is based on the analysis of the collection of acoustic data on a daily scale, with a temporal resolution of 1 minute, is particularly efficient in the analysis of big data, and its flexibility allows its application to a great variety of acoustic conditions. In fact, it is possible to operate at a level of soundscape scale or at a finer scale of acoustic community or of individual species.

EEDI analysis can be carried out at the soundscape level or at the level of acoustic communities or individual species. At the soundscape level, it is possible to detect and identify geophonies, biophonies, technophonies, or their combinations. It is possible to detect and identify the different sonotopes that emerge within the period of a day or a longer period of time.

When EEDI operates at a level of acoustic community, it is possible to assess the consistency of dawn, mid-day, and dusk choruses, and their seasonal occurrence and length.

At the level of single species, it is possible to investigate the occurrence of calls, songs, and alarm calls across days and seasons.

A particularly important result is the application of EEDI to technophonic sources in urban areas to investigating the level of human impact on the soundscape and its consequences on environment functioning.

Finally, EEDI can be used in long-term monitoring to assess the effect of climate change on vocal animals. The versatility of the EEDI procedure and the potentialities are extensively illustrated in the manual of the SoundscapeMeter 2.0, included in the appendix.

References

Barbieri, M. 2015. Biological codes: Springer, Dordrecht.

Baynes, E.M., Habib, L., Boutin, S. 2008. Impact of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. Conserv. Biol. 22(5): 1186-1193.

Berg, K.S., Brumfield, R.T., Apanius, V. 2006. Phylogenetic and ecological determinants of the neotrpical dawn chorus. Proceedings Royal Society B. 273: 999-1005.

Bibby, C.J., Burgess, N.D., Hill, D.A. 1992. Bird census techniques. Academic Press, London.

Brandes, T.S. 2008. Automated sound recording ad analysis techniques or bird surveys and conservation. Bird Conservation International 18: S163-S173.

Brumm, H. 2004. The impact of environmental noise on song amplitude in a territorial bird. Journal of Animal Ecology 73: 434-440.

Burt, W. H. 1943. Territoriality and home range concepts as applied to mammals". Journal of Mammalogy **24** (3): 346–352.

Cottenie, K. 2005. Integrating environmental and spatial processes in ecological community dynamics. Ecology Letters 8: 1175-1182.

Depraetere, M., Pavoine, S., Jiguet, F., Gasc, A., Duvail, S., Sueur, J. 2012. Monitoring animal diversity using acoustic indices: Implementation in a temperate woodland. Ecological Indicators 13: 46–54.

Farina, A. 2014. Soundscape Ecology. Springer, Dordrecht, NL.

Farina, A., Belgrano, A. 2004. The eco-field: A new paradigm for landscape ecology. Ecological Research 19:107-110.

Farina, A., Belgrano, A. 2006. The eco-field hypothesis: Toward a cognitive landscape. Landscape Ecology 21: 5-17.

Farina, A., Pieretti, N. 2014. Acoustic codes in action in a soundscape context. Biosemiotics 7 (2):321-328.

Farina, A., Pieretti, N., Morganti, N. 2013. Acoustic patterns of an invasive species: the Red-billed Leiothrix (*Leiothrix lutea* Scopoli 1786) in a Mediterranean shrubland. Bioacoutsics 22: 175-194.

Farina, A., Pieretti, N. 2014. Sonic environment and vegetation structure: A methodological approach for a soundscape analysis of a Mediterranean maqui. Ecol. Inf. 21: 120-132.

Farina, A., James, P., Bobryk, C., Pieretti, N., Lattanzi, E., McWilliam, J. 2014. Low cost (audio) recording (LCR) for advancing soundscape ecology towards the conservation of sonic complexity and biodiversity in natural and urban landscapes. Urban Ecology 17(4): 923-944.

Farina, A., Ceraulo, M., Bobryk, C., Pieretti, N., Quinci, E., Lattanzi, E. 2015. Spatial and temporal variation of bird dawn chorus and successive acoustic morning activity in a Mediterranean landscape. Bioacoustics DOI: 10.1080/09524622.2015.1070282

Forman, R.T.T., Godron, M. 1981. Patches and Structural Components for a Landscape BioScience, Vol. 31 (10): 733-740.

Forman, R.T.T., Godron, M. 1986. Landscape ecology. Wiley, New York.

Francis, C.D., Ortega, C.P., Cruz, A. 2009. Noise pollution changes avian communities and species interactions. 19(16): 1415–1419.

Francis, C.D., Paritsis, J., Ortega, C.P., Cruz, A. 2011. Landscape patterns of avian habitat use and nest success are affected by chronic gas well compressor noise. Landscape Ecology 26 (9): 1269-1280.

Griffin, D., Galambos, R. 1941. The Sensory Basis of Obstacle Avoidance by Flying Bats. The Journal of Experimental Zoology **86** (3): 481-505

Hansen, A.J., di Castri, F., Naiman, R.J. 1988. Ecotones: what and why? In: di Castri, F., Hansen, A.J., Holland, M.M. (ed.), A new look at ecotones. Biology International, special issue 17: 9-46.

Hunter, M.L. Jr 1989. Himalayan birds face uphill while singing. Auk 106: 728-729.

Hutchinson, G.E. 1957. Concluding remarks. Cold Spring Harbor Symp. Quant. Biol. **22**, 415–427.

Krause, B. 1993 The niche hypothesis. Soundscape Newsletter 6: 6 – 10.

Luther, D. 2009. The influence of the acoustic community on songs of birds in a neotropical rain forest. Behav Ecol 20:864–871.

MacArthur, R.,H., Wilson, E.O. 1967. The Theory of island biogeography. Princeton University Press, Princeton, New Jersey, US.

Malavasi, R., Farina, A. 2013. Neighbours' talk: interspecific choruses among songbirds. Bioacoustics 22(1): 33-48.

Malavasi, R., Kull, K., Farina, A. 2014. The acoustic codes: How animal sign processes create sound-topes and consortia via conflict avoidance. Biosemiotics 7(1): 89-95.

Merchant, N.D., Fristrup, K.M., Johnson, M.P., Tyack, P.L., Witt, M.J., Blondel, P., Parks, S.E. 2015. Measuring acoustic habitats. Methods in Ecology and Evolution 6: 257-265.

Morton, E.S. 1975. Ecological sources of selection on avian sounds. Am. Nat. 109, 17-34.

Naguib, M. 1996. Auditory distance assessment of singing conspecifics in Carolina wrens: the role of reverberation and frequency-dependent attenuation. Anim Behav 50: 1297-1307.

Patten, M.A., Rotemberry, J.T., Zuk, M. 2004. Habitat selection, acoustic adaptation, and the evolution of reproductive isolation. Evolution 58(10): 2144-2155.

Pieretti, N., Farina, A., Morri, D. 2011. A new methodology to infer the singing activity of an avian community: The Acoustic Complexity Index (ACI). Ecological Indicators 11: 868–873

Pieretti, N., Duarte, M.H.L., Sousa-Lima, R.S., Rodrigues, M., Young, R.J., Farina, A. 2015. Determining temporal sampling schemes for passive acoustic studies in different tropical ecosystems. Tropical Conservation Science 8(1): 215-234.

Pijanowski, B.C., Villanueva-Rivera, L.J., Dumyahn, S.L., Farin, A., Krause, B.L., Napoletano, B.M., Gage, S.H., Pieretti, N. 2011. Soundscape ecology: the science of sound in the landscape. Bioscience 61, 203 – 216.

Plaqué, R., Slabbekoorn, H. 2008. Spectral overlap in songs and temporal avoidance in a Peruvian bird assemblage. Ethology 114: 262-271.

Price , P.W. 1984 . Insect Ecology , 2nd edn . Wiley Interscience , New York.

Schafer, R.M. 1977. The soundscape. Destiny Books, Rochester, Vermont, US.

Sinsch, U., Lumkemann, K., Rosar, K. 2012. Acoustic niche partitioning in an anuran community inhabiting and Afromontane wetland (Butare, Rwanda). Afr. Zool. 47(1): 60-73.

Staicer, C.A., D.A., Spector, and A.G. Horn. 1996. The dawn chorus and other diel patterns in acoustic signaling. In: Ecology and evolution of acoustic communication in birds, edited by D.E., Kroodsma and E.H. Miller EH, Ithaca, NY : Cornell University Press.

Sueur, J. 2002. Cicada acoustic communication: potential sound partitioning in a multispecies community from Mexico (Hemiptera: Cicadomorpha: Cicadidae). Biol. J. Linn. Soc. 75: 379-394.

Sueur, J., Pavine, S., Hamerlynck, O., Duvail, S. 2008. Rapid acoustic survey for biodiversity appraisal. PlosOne 3:12 e4065.

Sueur, J., Aubin, T., Simonis, C. 2008. Seewave: a free modular tool for sound analysis and synthesis. Bioacoustics 18: 213–226.

Tobias, J.A., Planqué, R., Cram, D.L., Seddon, N. 2014 Species interactions and the structure of complex communication networks. Proc. Natl. Acad. Sci. 111:1020 – 1025.

Towsey, M., Parsons, S., Sueur, J. 2014. Ecology and ecoustic at large. Ecol. Inform. 21: 1-3.

Towsey, M., Wimmer, J., Williamson, I., Roe, P. 2014. The use of acoustic indices to determine avian species richness in audio-recording of the environment. Ecological Informatics 21: 110-119.

Truax, B. 1984. Acoustic communication. Ablex Publishing Corporation, Norwood, New Jersey, US.

Ward, P., Zahavi, A. 1973. The importance of certain assemblages of birds as "information-centres". Ibis 115(4): 517-534.

Whittaker, R. H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecological Monographs, 30, 279–338.

Wimmer, J., Towsey, M., Roe, P., Williamson, I. 2013. Sampling environmental acoustic recording to determine bird species richness. Ecological Applications 22(6): 1419-1428.

Appendix A

SoundscapeMeter

Ecoacoustics software: version 2.0

USER MANUAL

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SoundscapeMeter 2.0 software was developed by **Paolo Salutari** based on the models and algorithms designed by **Almo Farina**

SoundscapeMeter 2.0 manual was written by **Almo Farina** and **Paolo Salutari**

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CONTENTS

1. Introduction

1.1 About the SoundscapeMeter 2.0

The SoundscapeMeter 2.0 was developed by Paolo Salutari from the models and algorithms designed by Almo Farina.

The **SoundscapeMeter 2.0** is used to analyze sounds following the model of Ecoacoustics Event Detection and Identification (EEEDI) (Farina et al. 2016) applied to the data output of the Soundscape Explorer (Terrestrial) (SET) ™ Lunilettronik (Fivizzano, Italy) (Fig. 1).

SoundscapeMeter 2.0 is the evolution of the **SoundscapeMeter 1.0** (Farina et al. 2012). **SoundscapeMeter 1.0** was a plug-in of the **WaveSurfer© 1.8.5** (Sjölander and Beskow 2000). The **SoundscapeMeter 1.0** extracts from sound files information like intensity and structural complexity belonging to a frequency's category. The plug-in uses the following indices: Acoustic Complexity (ACIt, ACIf, and their Evenness), Shannon Entropy, and Levenshtein Distance.

SoundscapeMeter 1.0 can be downloaded from the website: www.iinsteco.org.

ACIt and ACIf are now automatically calculated by the **Soundscape Explorer [Terrestrial] SET** and stored in the SD memory.

Fig. 1 – A Soundscape Explorer [Terrestrial] SET tied to a pole for vineyards. The small size (12x20x6 cm) allows to easily place this device in the wild (credit: Almo Farina, IInstEco).

1.2 The SoundscapeMeter 2.0 at a glance

The **SoundscapeMeter 2.0** operates only on the data output of SET recording systems.

It operates under Windows OS.

It processes numerical files that are the result of the transformation of sound files stored in the SET memory after the application, on board the Acoustic Complexity Index (ACIt and ACIf) (Farina and Morri 2008, Pieretti et al. 2011).

ACI metrics are written in this manual in the simplified form: ACIt and ACIf compared with the formal acronyms (ACItf and ACIft).

The **SoundscapeMeter 2.0** has been designed to extract from ACI files information about the ecoacoustics events selected according to the biosemiotic model EEDI (Farina et al. 2016).

It accepts data from SET when recording sessions are scheduled, using the **RecordSetup 1.0** utility, according to the following parameters:
- Recording length: 1 minute
- Pause: 5 minutes
- Start of recording: 0001
- End of recording: 2355
- Threshold noise filter: 8
- Clumping: 1
- Sampling rate: 48 kHz
- Output gain: 30 dB

Three categories of output data are produced by SET during each recording minute:
- sound files (in wave format),
- environmental files (in txt format),
- ACI (ACIt and Acif) files (in txt format).

According to this setting, 240 one-minute wave files, 240 ACIt files, 240 ACIF files, and one file of environmental data are obtained for every day of recording.

		1	2	3	------------	511	512
1	00:01	11.02	47.29	31.86	------------	26.71	19.45
2	00:07	10.45	45.69	28.77	------------	22.60	16.55
3	00:13	10.85	45.38	30.09	------------	23.65	17.16
4	00:19	10.42	45.02	30.17	------------	22.57	15.79
5	00:25	10.93	46.83	32.73	------------	26.08	18.73
6	00:31	12.25	48.22	32.64	------------	26.70	17.77
-----	------------	------------	------------	------------	------------	-----------	-----------
239	23:49	8.80	45.10	31.00	------------	24.00	16.19
240	23:55	8.76	42.40	32.64	------------	26.24	18.88

Fig. 2 – Structure of the ACIt files. The first column indicates the time of day (from 0001 to 2355; every 5 minutes of stand-by= 240 rows). The other columns (1 to 512) are the frequency bins (operating at a sampling rate of 48 kHz; every frequency bin represents a band of 46.875 Hz.

ACIt files produced by SET are composed of 240 lines (minutes) x 512 columns (frequency bins) (Fig. 2).

ACIf files produced by SET are composed of 2,812 lines (0.02133713") x 240 columns (minutes) (Fig. 3).

	1	2	3	4			238	239	240
	00:01	00:07	00:13	00:19	------------	------------	23:43	23:49	23:55
1	2.029583	1.37038	1.365773	2.482778	------------	------------	1.100328	0.318644	0.463768
2	1.925814	0.978158	2.027932	1.523598	------------	------------	0.993457	1.519842	1.162213
3	1.730925	2.563813	1.212582	2.748709	------------	------------	2.920587	1.804038	2.74087
4	1.472859	2.292434	1.598681	0.976249	------------	------------	1.953749	2.291661	2.487692
	------------	------------	------------	------------	------------	------------	------------	------------	------------
	------------	------------	------------	------------	------------	------------	------------	------------	------------
2810	1.879681	1.602698	1.966982	1.675548	------------	------------	1.261061	1.742983	2.383891
2811	2.351979	1.500031	1.33347	2.225874	------------	------------	1.185842	1.372422	3.050005
2812	2.393628	2.268267	2.009762	2.254421	------------	------------	0.551781	2.41257	1.961276

Fig. 3 - Structure of the ACIf files. The first row indicates the time of day (from 0001 to 2355; every 5 minutes of stand-by= 240 columns). The other rows (1 to 2,812) are the time intervals at which the ACIf is calculated during one minute of recording (2,812 intervals of 0.02133 seconds).

Environmental data (light, temperature, humidity, pressure) are collected by on-board SET sensors every second and the mean value, calculated during every minute of recording, is stored in the active SD card (one or two SDs used by SET, 32 Gb each).

The SET files must be moved from the SD into a hard disk before launching the **SoundscapeMeter 2.0**.

2. SoundscapeMeter 2.0 routines

The **SoundscapeMeter 2.0** is composed of five routines (Fig. 4):

INIT: creates separate folders for every day from a multiday session of SET, and copies into them the ACIt and ACIf files produced by the SET. In each " day" folder of the day, the environment data file is also moved, and, finally, the ACIt and ACIf files of the day are computed (and stored in the same folder).

ASD: determines the minutes (i.e. the rows) of an ACIt file (composed by 240 minutes and 512 frequency bins) whose data match the selection parameters inserted by the operator. Selection can be made on time, light, temperature, humidity, atmospheric pressure, and frequency.

MACIf: calculates the mean value of ACIf and its standard deviation, where AXIf is selected according to a threshold applied to environmental parameters (time, light, temperature, humidity, pressure, frequency).

EEDET: extracts a range of homogeneous events by plotting ACIf and its evenness (ACIfe) according to a multiple choice of environmental parameters and ACIf / ACIfe values.

EEID: identifies, among the data produced by **EEDET,** the events that are in accordance with the selected acoustic signature of a classified event.

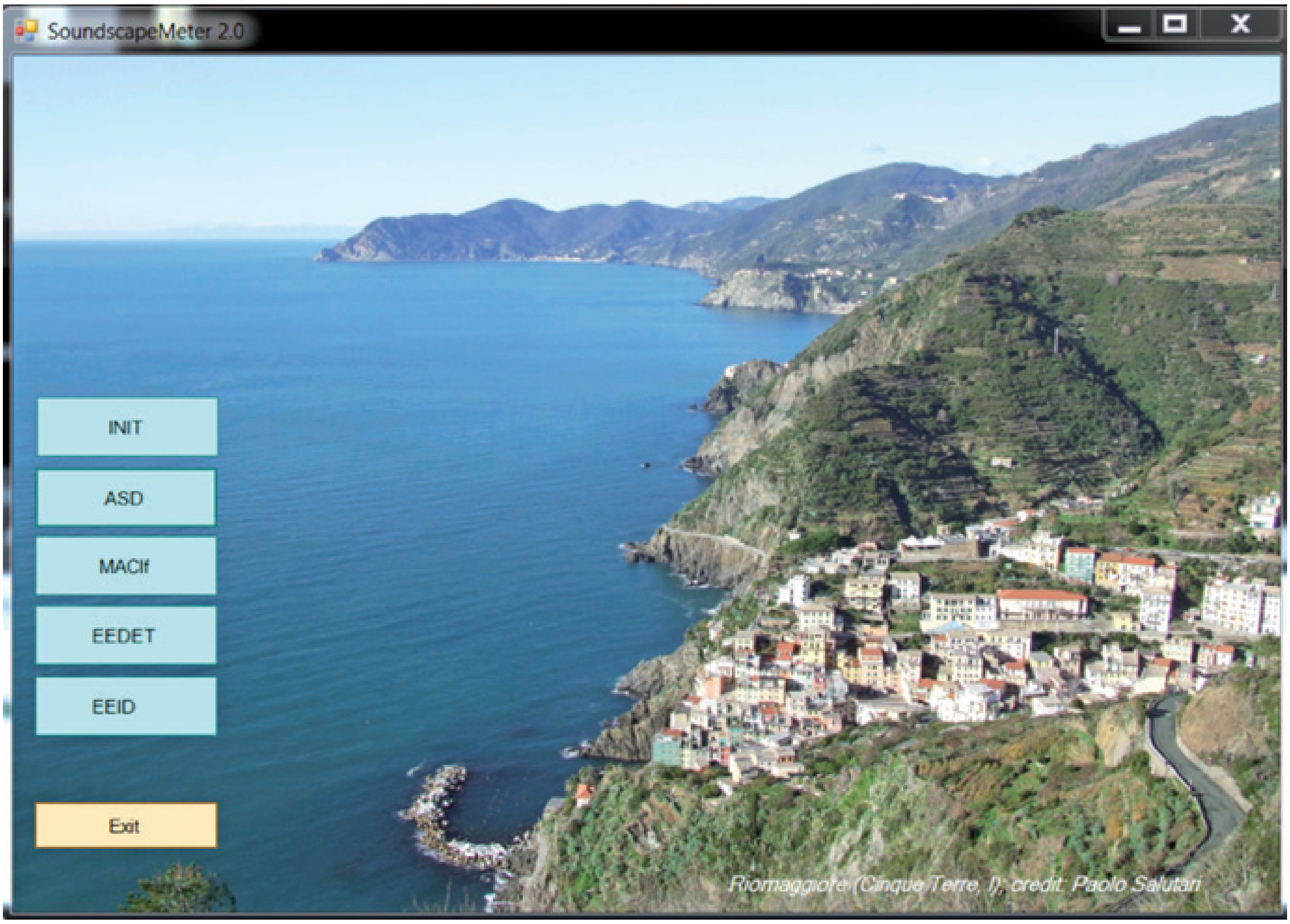

Fig. 4 – SoundscapeMeter 2.0 home page. Each button launches a routine, and it is possible to move from one routine to another without exiting from the program.

2.1 INIT

INIT: creates separate folders for each day from a multiday session of SET, and adds the environmental variables in each daily file (ACIt and ACIf) (Fig. 5).

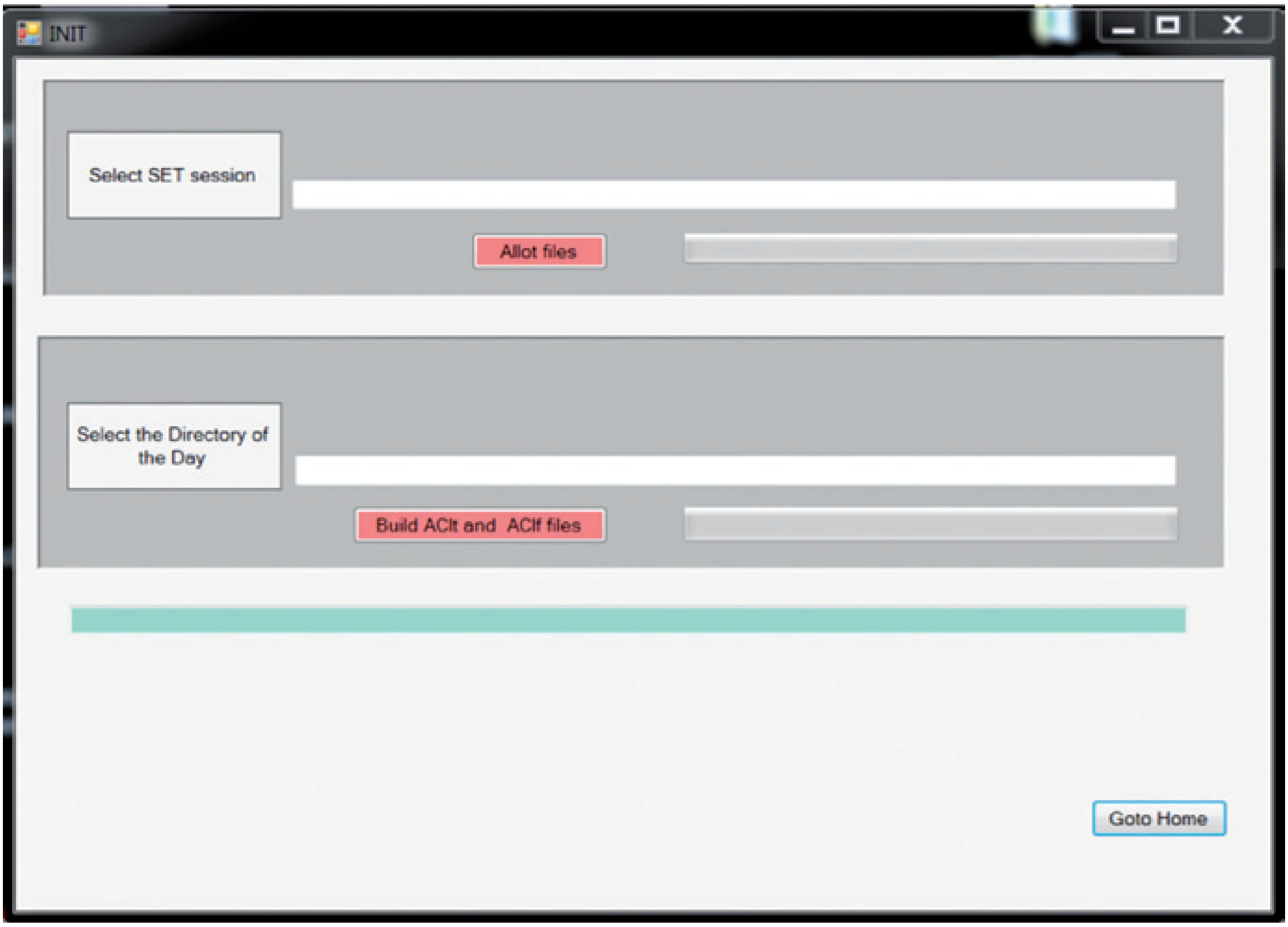

Fig. 5 - The INIT form with two functions: **Allot files** and **Build ACIt and ACIf files**.

Sound files are stored in the SD card of the SET with a .wav (wave) format in a folder named “**wave**”. ACIt and ACIf filesare stored in the SD card of the SET in a folder named “**aci”** (Fig. 6).

This routine operates on the ACIt and ACIf 1-minutefiles stored in the SD according to a criterion of daily hours.

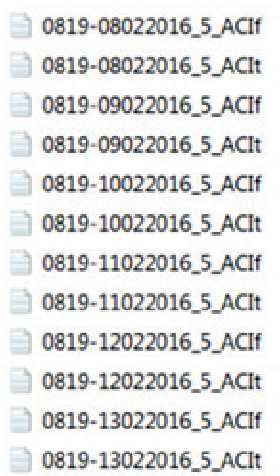

Fig. 6 – Partial list of files stored in the “**aci”** folder of the SD card programmed by the SET. Every file refers to a specific minute, and files are sorted according the minute and hours of the day:

0819-13022016_5_ACIt :minute, hour

0819-**13022016**_5_ACIt :day, month, year

0819-13022016_**5**_ACIt :SET identifier

0819-13022016_5_**ACIt** :ACI typology (ACIt or ACIf)

This routine is divided in two sub-routines. The first routine separates ACIt and ACIf files from the common **aci** folder and allots ACIt and ACIf files of each day in a specific folder. According to the required schedule programmed on the SET (see above), every new folder (their number depends on the number of days during which a SET has recorded) contains 240 ACIt and ACIf 1-minute files, sorted according to the hour of the day (from 0001 to 2355).

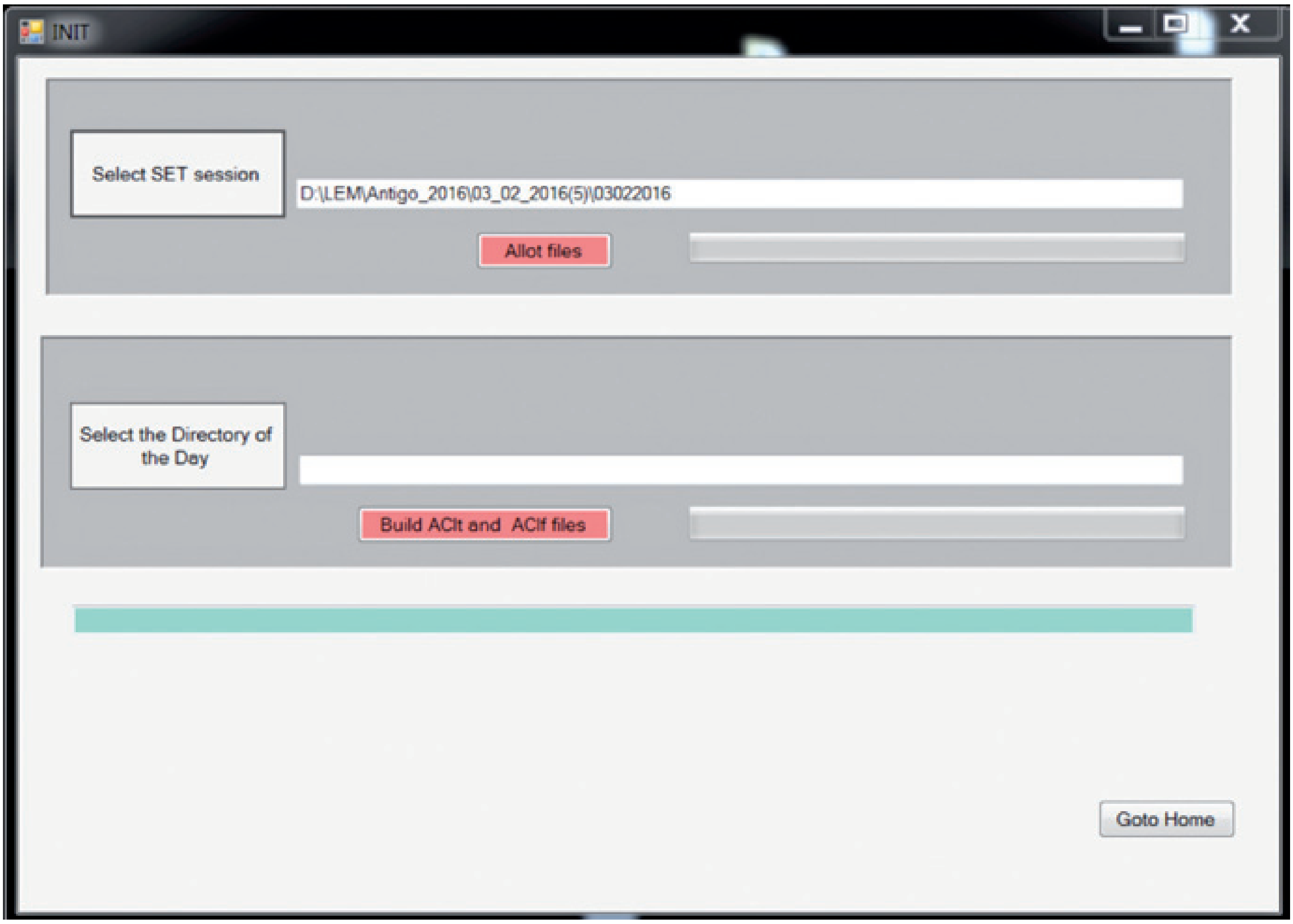

Fig. 7 - To activate the sorting of ACIt and ACIf files, first the folder in which the data acquired by SET are stored must be selected, after having pressed the **Select SET session** pushbutton.

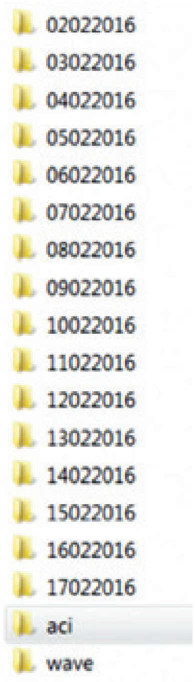

Fig.8 - Example of the contents of the directory of a SET session (with **aci** and **wave** subdirectories) after the launch of the **Select SET session** routine, and after to have pushed the command **Allot files** that creates daily folders, each containing, in turn, 240 ACIt and 240 ACIf and the environmental data file of that day.

After having selected the directory in which the files downloaded from SET have been stored (e.g., D:\LEM\Antigo_2016\03_02_2016(5) with the command **Select SET session**, where LEM stands for Lunigiana Ecoacoustics Monitoring, Antigo_2016 is the locality. 03-02-2016 is day, month and year, and (5) is the identifying number of the SET), the command **Select the Directory of the Day** creates in the same directory separate folders for each day of recording (Figs. 7, 8).

The second routine, by selecting a specific day (day subdirectory) with the **Select the directory of the day** pushbutton and launching the **Build ACit and ACIf file** command, creates unique ACIt and ACIf files for a selected day. An ACIt file is composed of 240 one-minute ACIt files, and the same is true for the ACIf file (Fig. 9). The environmental information associated with every minute is included in each file.

This process must be repeated for every day of the SET session. SET operates, on average, for 26 days with two battery packs, with the setting of 1 minute recording and 5 minutes of standby. This number (26 days) is dependent upon battery capacity.

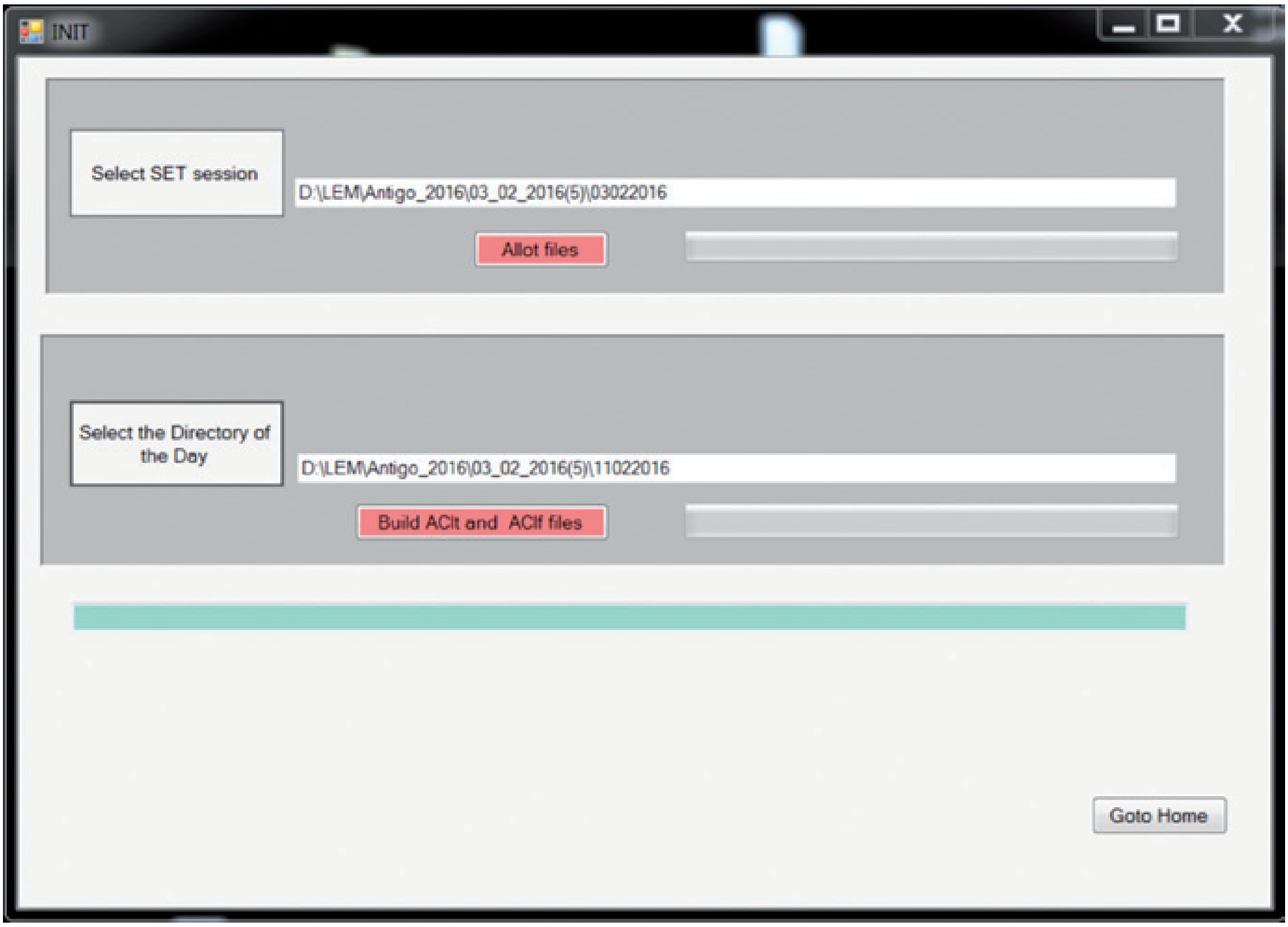

Fig. 9 - To create a unique ACIt and ACIf from 240 one-minute files ACIt and ACIf, the **Build ACIt and ACIf** files command must be pushed after having chosen a specific day folder. With this routine the weather data are associated to the ACIt and to ACIf files.

2.2 ASD

This routine allows the user to select from the ACIt files only the minutes (rows) that meet the multi-choice preferences set by the operator and saves the resulting data. In the **Primary parameter** combo-box there is a list of parameters (time, light, humidity, pressure, and frequency) that can be chosen for operating the selection.

For the chosen parameter, it is possible to set the lower threshold, the upper threshold, or both.
In order to make a threshold active, the corresponding check-box at its left must be checked.

Three cases are possible:

- Lower threshold set and its relevant checkbox checked: The minute of the ACIt file is considered only if the selected parameter is lower than the lower threshold.
- Upper threshold set and its relevant checkbox checked: The minute of the ACIt file is considered only if the selected parameter is greater than the upper threshold.
- Lower and upper threshold set and both checkboxes checked: The minute of the ACIt file is considered only if the selected parameter is greater than the lower threshold and lower than the upper threshold.

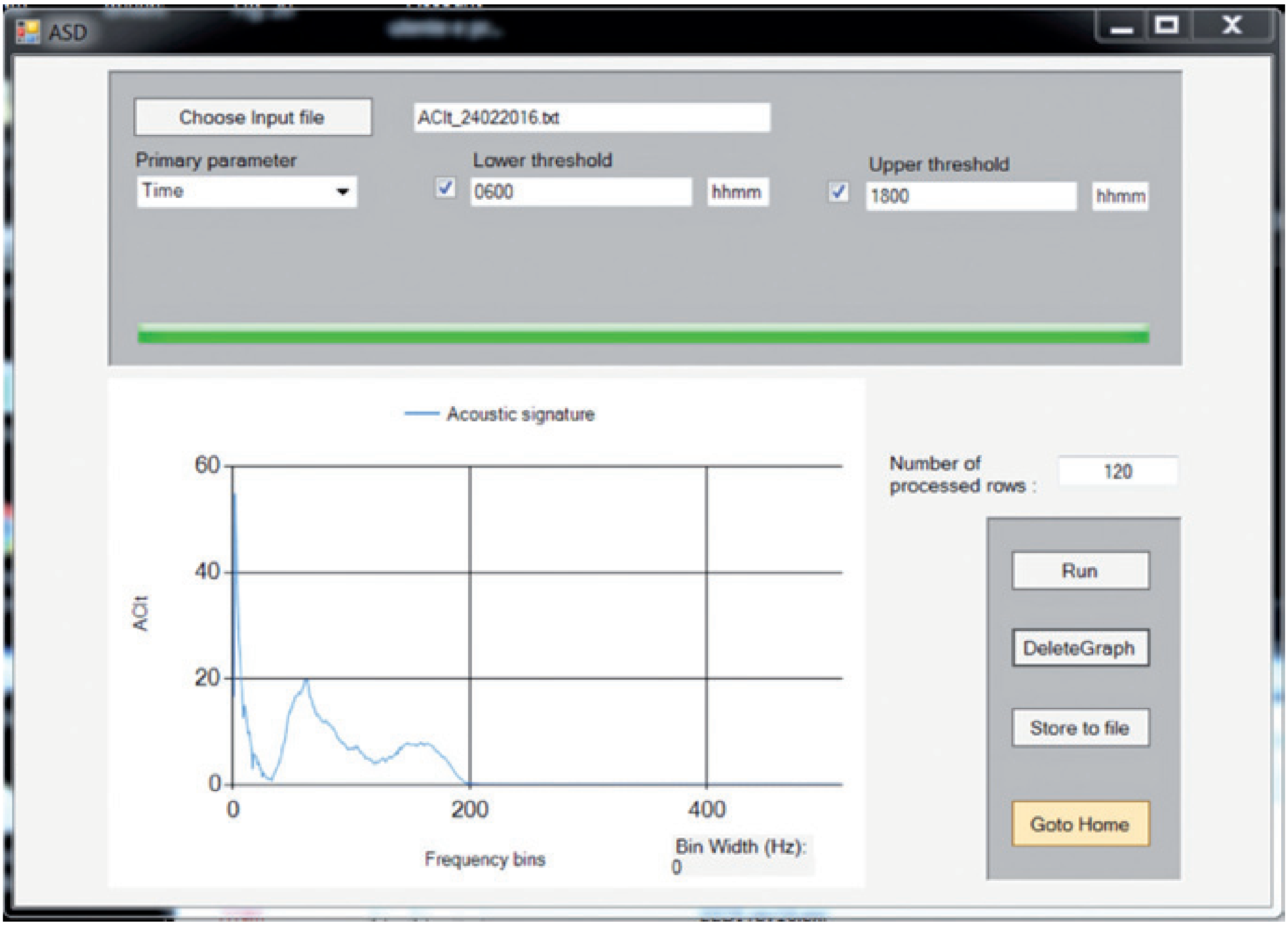

Fig. 10 – The ASD routine requires the input of an ACIt file and a combination of weather parameters. In the example, only minutes between 0600 and 1800 are considered.

If the selected parameter is frequency, two more boxes appear (Fig. 11).

- A sampling rate box allows the user to select 24, 48, 96 and 192 kHz (i.e. the sampling rate of the input files, default 48 KHz/sec).
- A second box allows the user to select the “secondary” parameter, among time, light, humidity, and pressure options.

Once this secondary parameter is selected, it is possible to set its thresholds, with the same rules detailed above for the primary one.

A graph of the computed selection appears on demand (button **Graph**).

Finally, the selected elements of the ACIt file can be stored in a txt file for further computations (button **Store to file**).

The number of rows found according to the selection is shown, as well (**Number of processed rows**).

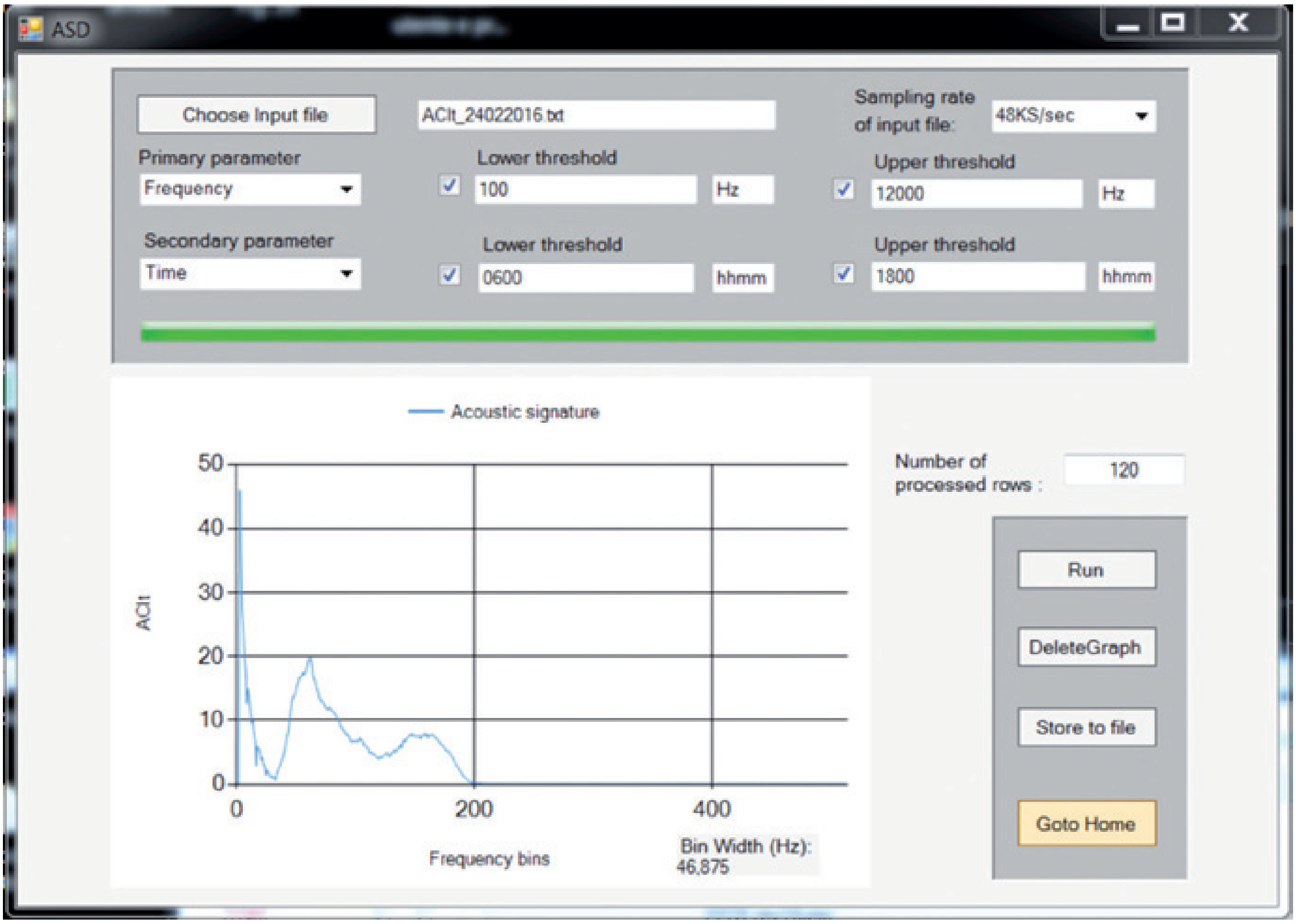

Fig. 11 – When frequency is selected in the form, a second line appears with the weather parameters to set; this is not mandatory. The **Sampling rate of the input file** (24, 48, 96, 192 kHz) also appears. In the example, only frequencies between 100 and 12000 Hz and minutes between 0600 and 1800 are considered. The selection can be stored in a specific filed pushing **Store to file** button.

2.3 MACIf

This routine calculates the mean value of ACIf and its standard deviation according to a threshold applied to environmental parameters (time, light, temperature, humidity, pressure) (Fig. 12).

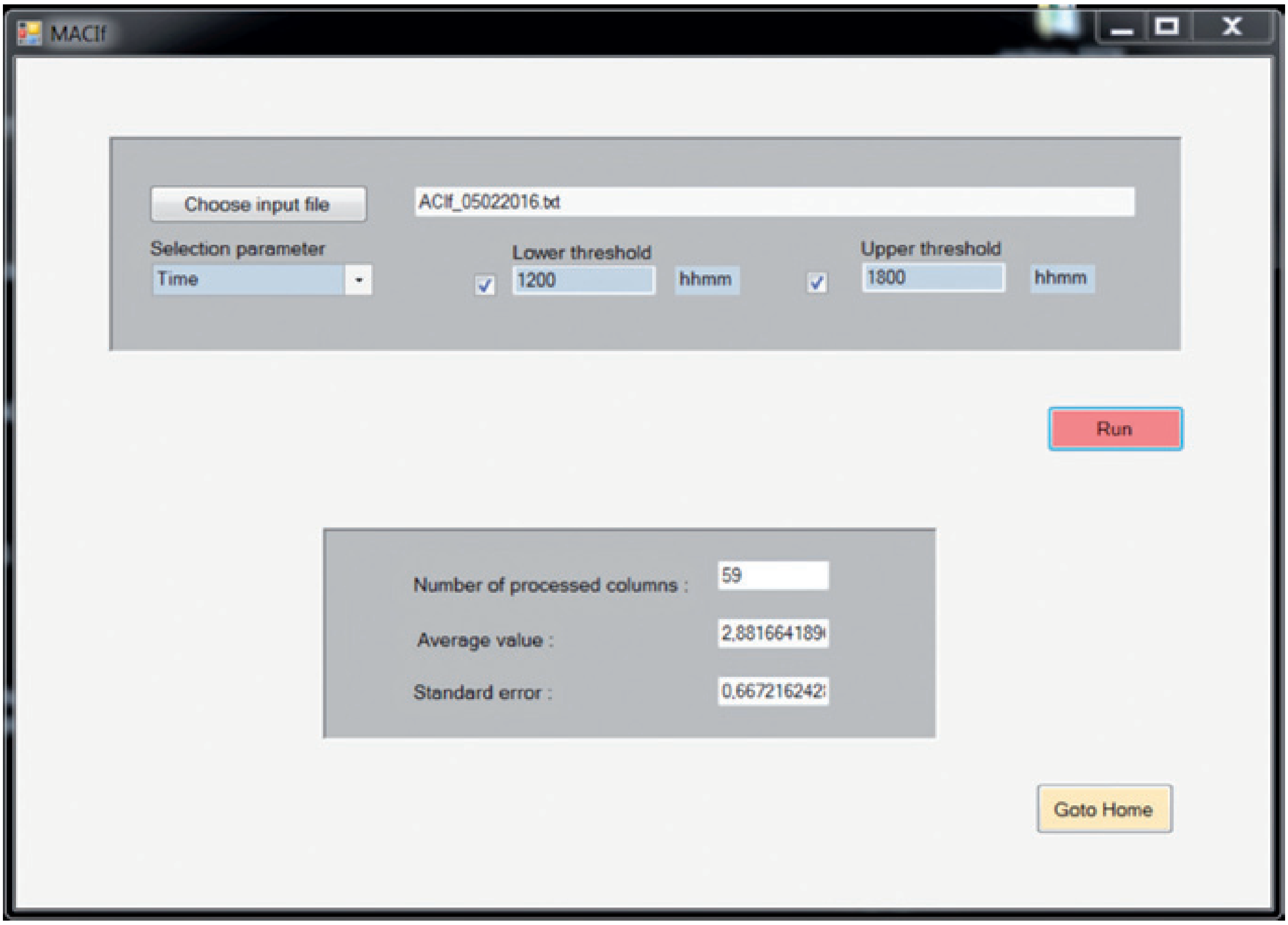

Fig. 12 - MACIf selects from an ACIf file the columns that correspond to the value of weather parameters selected. In the example, only minutes between 1200 and 1800 are considered. Number of processed columns, Acif average value and Standard error are displayed.

In the form are reported the number of processed columns, the average value of ACIf, and its standard error.

A file reporting the result is stored automatically in the same folder of the input file (Fig. 13).

Fig. 13 - Example of files automatically created by MACIf according to the selected threshold of the environmental parameters. Hum:Humidity, Lux:Light, Press:Pressure, Temp:Temperature, Time:daily hours-minutes.

2.4 EEDET

This routine extracts a range of homogeneous events by plotting Acif and its evenness (ACIFe) according to a multiple choice of environmental parameters, and values of ACIf and ACIf evenness.

EEDET is the core of **SoundscapeMeter 2.0**, and this routine offers a broad range of possibilities to analyze data (Fig. 14).

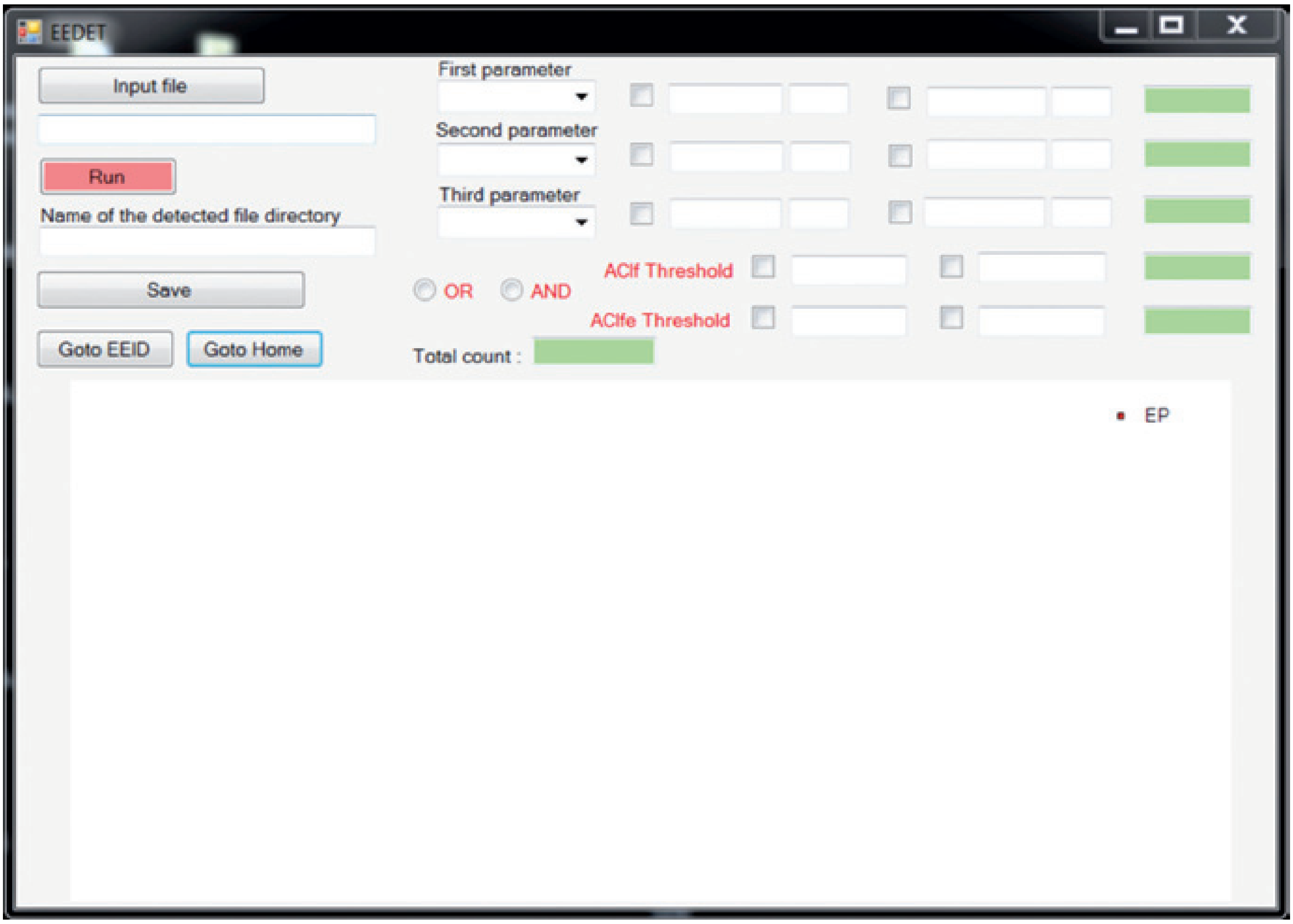

Fig. 14 – Main form of Ecoacoustic Event Detection, **EEDET**. This routine that is the core of **SoundscapeMeter 2.0**, offers a broad range of possibilities to analyze data combining different parameters.

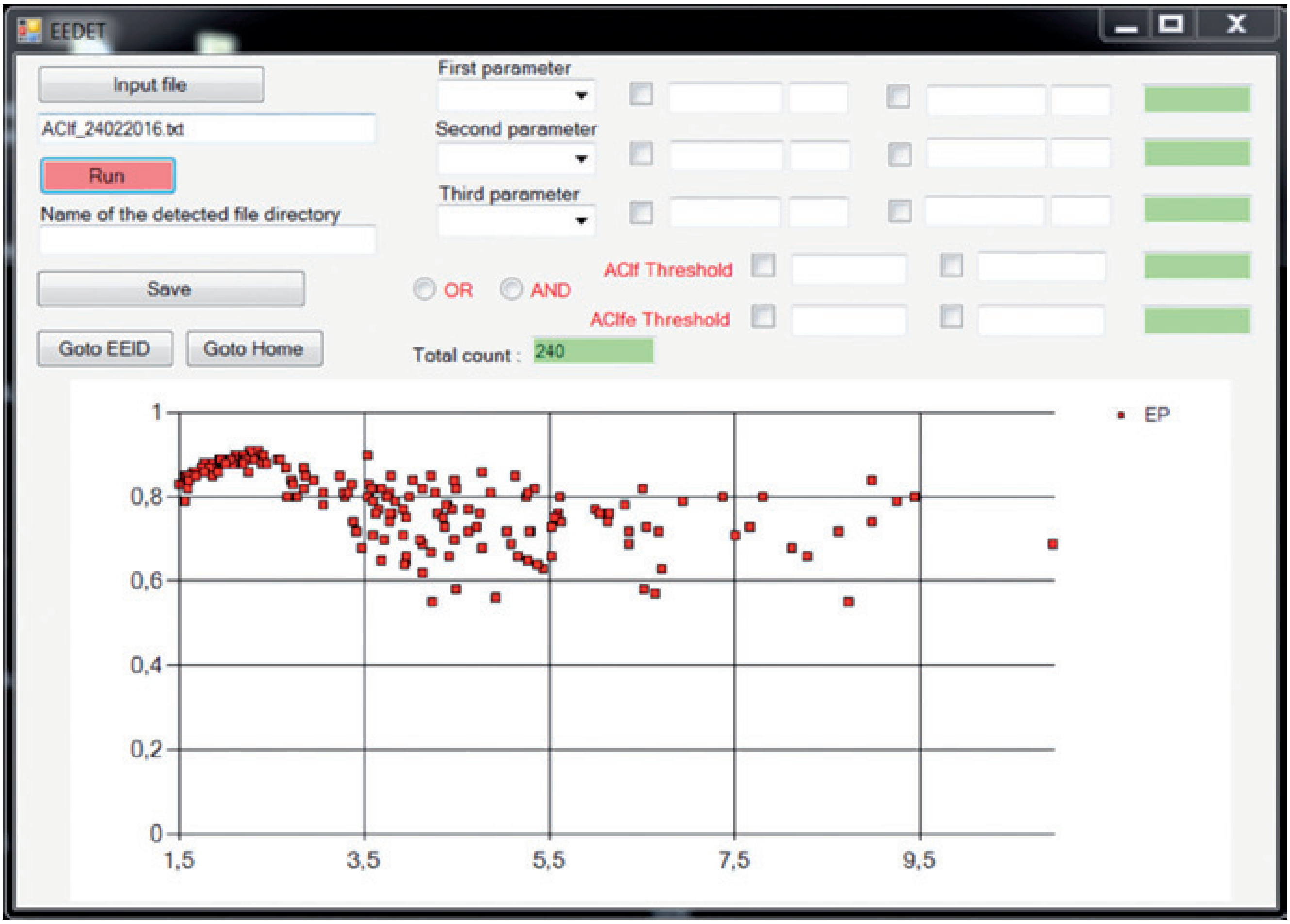

Fig. 15 – In this case, we have selected the file ACIf of 24 February 2016 (at this stage, the number of SET is not reported in the file path) without any environmental or ACIf and ACIfe thresholds. The distribution of every ACIf and ACIfe value is reported in the Ecoacoustic Event Space (EES).

The first step is to select the **Input file**; it must be one of the ACIf files obtained by the subroutine #2 of **INIT**.

We can then execute the routine without selecting any parameter. In this way, it appears as a graphic plot with all the 240 ACIf values. This figure is useful to evaluate the trends of the selected day and the range of ACIf and of its evenness (that may vary from 0 to 1, on the "y" axis of the plot). It is possible to determine at what time of the day each point of the graphic corresponds to, by simply placing the mouse over the point: a label appears, showing the corresponding hour and minute.

From the example of Fig 15, the minutes with low evenness and high values of ACIf are indicators of potential biophonic events, and the successive model will be based on this assumption.

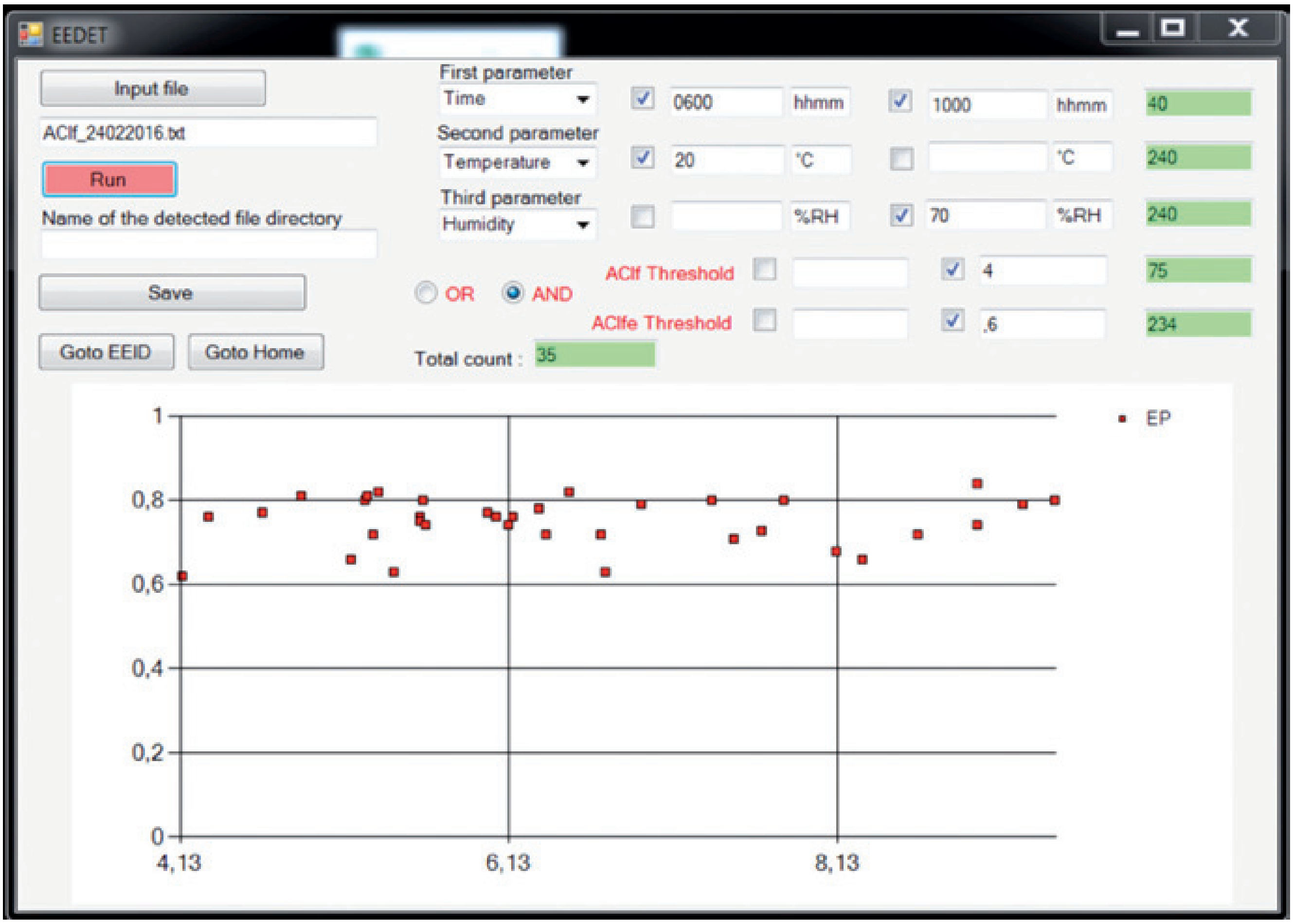

Fig. 16 – After the insertion of time (0600 - 1000), temperature (< 20°C), humidity (>70%) , and ACIf (> 4) and ACIfe (> .6) threshold based on a model of chorus, 35 detected events result that must submitted to identification.

Fig. 16 reports the result of the model to extract morning biophonies, fixing the environmental parameters as follows: Time 0600-1000 am, Temperature <20 °C, Humidity >70%. ACIf was empirically fixed at >4 and its evenness ACIfe > 0.6. In the form, the number of cases for each condition is reported in the green boxes at the right.

The environmental parameters are fixed by default in the **<and** > condition, i.e. a row is considered if all the conditions set on the first, second, and third parameters are met at the same time.

In contrast, selection made on ACIf and ACIfe can be set to **<or>** or **<and** >.

If **<or>** is selected, it is sufficient that a row meets just one of the selection criteria set for ACIf and ACIfe, while if **<and>** is selected, both the conditions on ACIf and ACIfe must be met.

The final number of events that fit the model (considering both the environmental parameters and the ACIf/ACIfe parameters) is reported in the **Total count box** (in green).

The graphic is automatically scaled according to the range of the ACIf values.

	Daily time	ACIf	Acif evenness
1	06:25	4.14	0.62
2	06:31	6.72	0.63
3	06:37	5.59	0.76
4	06:43	5.61	0.8
5	06:49	4.3	0.76
6	06:55	5.17	0.66
7	07:01	5.59	0.75
8	07:07	7.5	0.71
9	07:13	8.28	0.66
10	07:19	5.34	0.82
11	07:25	5.3	0.72
12	07:31	6.31	0.78
13	07:37	5.25	0.8
14	07:43	5.62	0.74
15	07:49	4.87	0.81
16	07:55	6	0.77
17	08:01	6.13	0.74
18	08:07	8.12	0.68
19	08:13	6.5	0.82
20	08:25	7.8	0.8
21	08:31	7.37	0.8
22	08:37	9.45	0.8
23	08:43	8.98	0.84
24	08:49	7.67	0.73
25	08:55	8.62	0.72
26	09:01	6.05	0.76
27	09:07	5.43	0.63
28	09:13	9.26	0.79
29	09:19	8.98	0.74
30	09:25	6.69	0.72
31	09:31	6.36	0.72
32	09:37	4.63	0.77
33	09:43	6.15	0.76
34	09:49	5.27	0.81
35	09:55	6.94	0.79

Fig. 17 – This is an example of selected events using the model "chorus". 35 events have been found and their daily time, ACIf and ACIfe values stored.

At the end of the process, the model is saved, filling the box **Name of detected file directory**.
In this case, the chosen name is: "*Morning_chorus_24_02_2016(2)*.
A directory is created in the same folder of the day, and inside it three files are stored:

- *Modified_ACIt*
- *Modified_ACIf*
- *Morning_chorus_24_02_2016(2)*.

Modified_ACIt and Modified_ACIf are the corresponding ACIt and ACIf values of the day, but they only contain the data of the detected events (all other data – rows and/or columns – are set to zero).

The *Morning_chorus_24_02_2016(2)* file contains daily time, ACIf, and ACIFe of the 35 one-minute events (Fig. 17). This file will be used for the final identification of the detected events.

2.5 EEID

This routine identifies among the data elaborated by **EEDET** the events according to a selected acoustic signature of a known event that is created into a library.

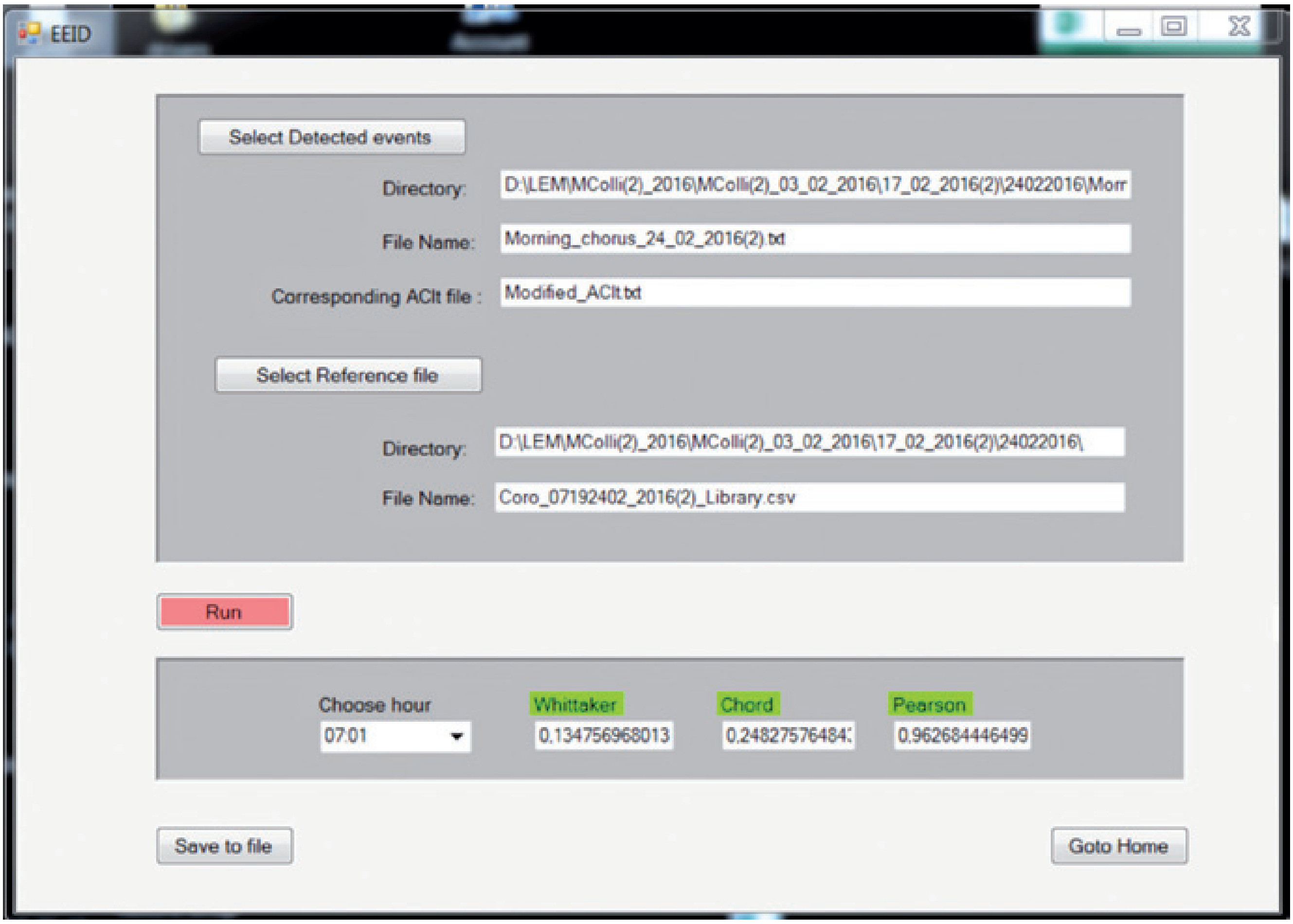

Fig. 18 – With this routine, detected events are identified according to a reference file. In this case, a bird chorus is matched with the detected files. In the example, the correlation (Whittaker, Chord and Pearson metrics) at 0701 in the morning is visualized.

EEID requires a **Detected events file** that is created by the **EEDET** routine; in the case presented in Fig. 18, the file is "*Morning_chorus_24_02_2106(2)*". This file is associated with the Modified_ACIt file that contains the acoustic signature of all the detected events, in this case numbering 35.

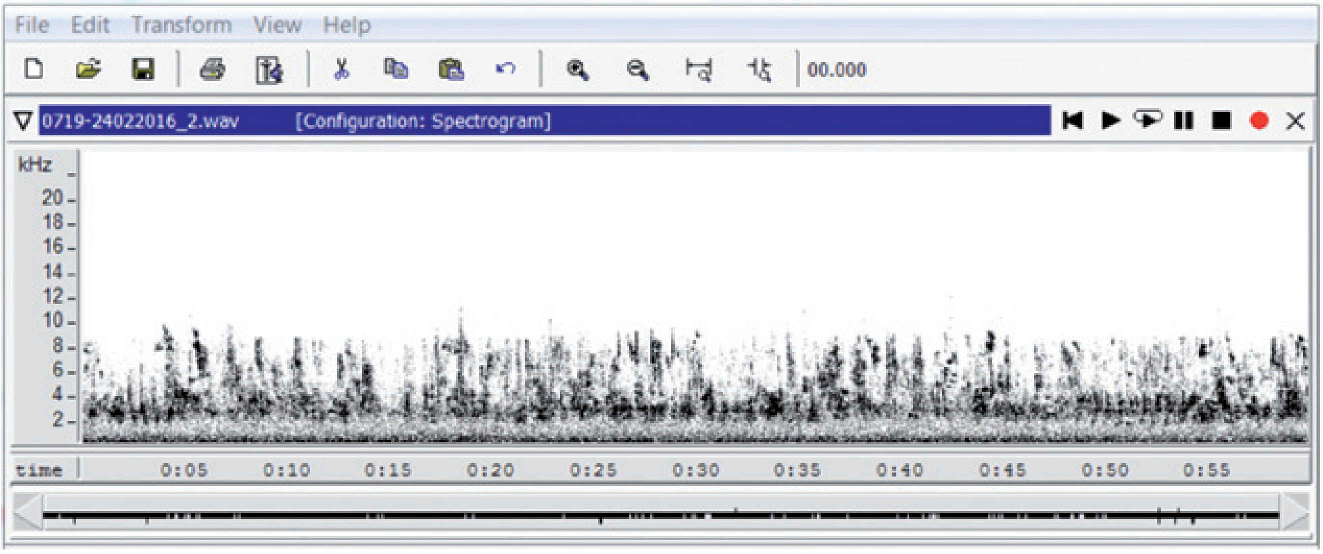

Fig. 19 – Example of the spectrum of a reference file obtained from a morning chorus recorded at 0719 of 24-02-2016 in the location Madonna dei Colli (2).

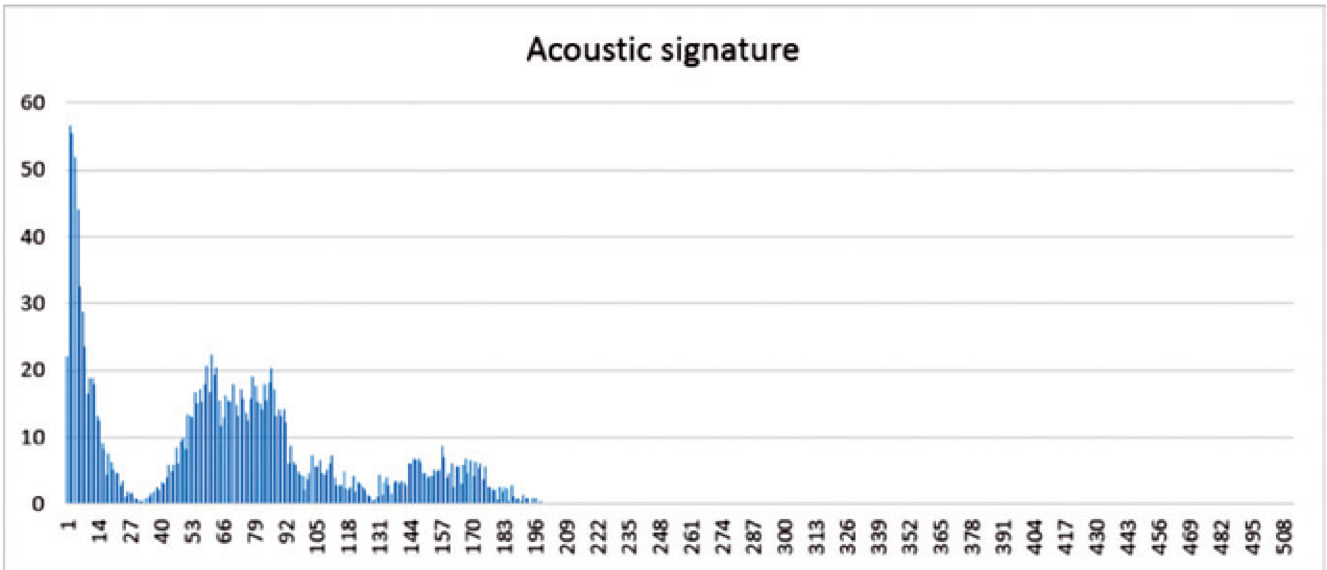

Fig. 20 - The acoustic signature of a reference file obtained from a morning chorus. In the ACIt values are reported on the y axis and the 512 frequency bins of 46.875 Hz each, in the x axis.

To complete this procedure, we introduce the reference file, its spectrum (Fig. 19), and its acoustic signature (ACIt) (Fig. 20). This file is extracted from an ACIt file of the same day or of other days that in our experience represents an ecoacoustic event. In our case, this is a morning chorus of birds. This file is composed by one line of 512 ACIt values. The files must be saved in the cvs format to be recognized by **EEID**.

	Hour	Pearson	Chord	Whittaker	Sorted	Hour	Pearson	Chord	Whittaker
1	06:25	0.8953513	0.41361732	0.21360604		07:19	1	0	0
2	06:31	0.85558343	0.48798948	0.22601309		07:01	0.96268445	0.24827576	0.13475697
3	06:37	0.89770399	0.41136787	0.20020986		07:37	0.96108218	0.25366412	0.13406398
4	06:43	0.90446274	0.39599096	0.18852692		09:37	0.95726222	0.26486992	0.14291286
5	06:49	0.93966819	0.31453337	0.16259551		07:49	0.95364798	0.27582714	0.14153047
6	06:55	0.91037679	0.38410651	0.19874589		06:49	0.93966819	0.31453337	0.16259551
7	07:01	0.96268445	0.24827576	0.13475697		09:49	0.93296748	0.33412676	0.16368335
8	07:07	0.77017052	0.60860012	0.30588518		07:43	0.92750807	0.34457291	0.1703601
9	07:13	0.75160558	0.63143377	0.3004703		07:55	0.9266598	0.34645376	0.15854033
10	07:19	1	0	0		09:31	0.92150643	0.35893614	0.17050356
11	07:25	0.91030259	0.38657089	0.21039015		07:31	0.92020997	0.36933336	0.20034827
12	07:31	0.92020997	0.36933336	0.20034827		08:13	0.91924108	0.36506377	0.17856303
13	07:37	0.96108218	0.25366412	0.13406398		06:55	0.91037679	0.38410651	0.19874589
14	07:43	0.92750807	0.34457291	0.1703601		07:25	0.91030259	0.38657089	0.21039015
15	07:49	0.95364798	0.27582714	0.14153047		09:07	0.90839657	0.39138888	0.20806521
16	07:55	0.9266598	0.34645376	0.15854033		06:43	0.90446274	0.39599096	0.18852692
17	08:01	0.89449425	0.4151462	0.20957676		09:43	0.90298419	0.40037605	0.19420238
18	08:07	0.89190306	0.4258852	0.19931626		06:37	0.89770399	0.41136787	0.20020986
19	08:13	0.91924108	0.36506377	0.17856303		06:25	0.8953513	0.41361732	0.21360604
20	08:25	0.89352689	0.41881886	0.19677775		08:01	0.89449425	0.4151462	0.20957676
21	08:31	0.88579879	0.43220559	0.19629026		09:55	0.89365501	0.41868082	0.19085003
22	08:37	0.814967	0.54848806	0.25276546		08:25	0.89352689	0.41881886	0.19677775
23	08:43	0.82167709	0.53741206	0.24230497		08:07	0.89190306	0.4258852	0.19931626
24	08:49	0.85202256	0.49232331	0.23159914		08:31	0.88579879	0.43220559	0.19629026
25	08:55	0.80166612	0.56693689	0.26470529		09:01	0.88135707	0.44282205	0.21646739
26	09:01	0.88135707	0.44282205	0.21646739		06:31	0.85558343	0.48798948	0.22601309
27	09:07	0.90839657	0.39138888	0.20806521		08:49	0.85202256	0.49232331	0.23159914
28	09:13	0.84942748	0.50029322	0.25533648		09:13	0.84942748	0.50029322	0.25533648
29	09:19	0.79369912	0.57892312	0.26327546		09:25	0.83092594	0.52621957	0.24874634
30	09:25	0.83092594	0.52621957	0.24874634		08:43	0.82167709	0.53741206	0.24230497
31	09:31	0.92150643	0.35893614	0.17050356		08:37	0.814967	0.54848806	0.25276546
32	09:37	0.95726222	0.26486992	0.14291286		08:55	0.80166612	0.56693689	0.26470529
33	09:43	0.90298419	0.40037605	0.19420238		09:19	0.79369912	0.57892312	0.26327546
34	09:49	0.93296748	0.33412676	0.16368335		07:07	0.77017052	0.60860012	0.30588518
35	09:55	0.89365501	0.41868082	0.19085003		07:13	0.75160558	0.63143377	0.3004703

Fig. 21 – The correlation (Pearson, Chord, and Whittaker) between the detected events (35) and the reference file of a morning chorus. In this case, at 07:19 the correlation is perfect because the acoustic signature used for the identification is the same as the detected events. The data sorted according to the highest Pearson value can help to decide the threshold of identification.

After having pressed the run button, it is possible to explore the correlation value by choosing the daily hour and minute. The distance between the reference file and the selection of detected events is based on three types of correlation: Pearson, Chord, and Whittaker. By using experience, it is possible to select the range of correlations inclusive of a morning chorus event (Fig. 21).

References

Farina, A., Morri, D. 2008. Source-sink e eco-field: ipotesi ed evidenze sperimentali. Atti del X congresso nazionale della SIEP-IALE. Ecologia e governance del paesaggio: esperienze e prospettive. Bari, 365–372.

Farina, A., Lattanzi, E., Piccioli, L., Pieretti, N. 2012. The SoundscapeMeter. http://www.disbef.uniurb.it/biomia/soundscapemeter

Farina A., Pieretti N., Salutari P., Tognari E ., Lombardi A. (submitted). The Application of the Acoustic Complexity Indices (ACI) to Ecoacoustic Event Detection and Identification (EEDI) Modeling. Biosemiotics

Pieretti, N., Farina, A., Morri, D., 2011. A new methodology to infer the singing activity of an avian community: the Acoustic Complexity Index (ACI). Ecological Indicators 11, 868–873.

Sjolander, K., and Beskow, J. 2000. WaveSurfer—An open source speech tool. Proceedings of the ICSLP 2000, Vol. 4, pp. 464–467.