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The Sound of Drystones: A Novel Hot-Spot of Ecoacoustics Research

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Abstract: Drystone terraces offer a series of ecosystem services including both biological and cultural benefits. The aesthetic contribution towards the landscape and the increase in biodiversity levels, constitute drystone terraces and other similar constructions, as important biocultural assets. The low maintenance and the eventual abandonment of drystone terraces cause a series of drawbacks regarding the sustainability of agricultural environments. The main goal of this research was to assess the effect of drystone terrace maintenance level on biodiversity. For that reason, two closely distant agricultural areas of Lesbos Island (North Aegean, Greece) in which olive grove drystone terraces dominate were compared. The non-intrusive method of ecoacoustics was selected, and the levels of the acoustic complexity and acoustic diversity were statistically analyzed for areas that included highly maintained and poorly maintained olive grove drystone terraces. The results indicated an increase in acoustic biodiversity levels in the poorly maintained drystone terraces area. At this early stage, the results highlighted the fact that the increased resources in the poorly maintained drystone terraces, in terms of nesting and feeding opportunities, increased the biodiversity levels. Nevertheless, the spatiotemporal expansion of this research is undeniably important.

Keywords: drystone; terrace; biocultural; ecoacoustics; acoustic environment

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Citation: Minioti, M.; Tsaligopoulos, A.; Matsinos, Y.G.; Pavlogeorgatos, G. The Sound of Drystones: A Novel Hot-Spot of Ecoacoustics Research. *Earth* **2022**, *3*, 939–950. https://doi.org/10.3390/earth3030055

Academic Editors: Charles Jones, Daniela Baldantoni and Laura Bulgariu

Received: 14 June 2022
Accepted: 22 August 2022
Published: 26 August 2022

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1. Introduction

Drystone masonry is a form of construction with the application of stones without the use of mortar [1]. Drystone constructions, also known as xerolithic [2] constructions (coming from the Greek words xero/dry and lithic/stone) involve a worldwide spread technique [3]. The expertise of skilled masons [4] that are able to wisely employ raw local materials [5], in order to achieve a construction with the use of interlocking stones is required. The types of drystone constructions range from field boundary stone walls [6,7] and agricultural drystone terraces that are built in order to increase cultivation land in otherwise difficult-to-crop areas [3]. Other constructions include linear structures similar to drystone walls, water channels and paths, individual buildings similar to drystone wall shelters, and individual structures similar to drystone sheepfolds, ovens, and masonry ponds [8–10].

The rystonee construction technique required experience and knowledge and was passed on from one generation to another. The specific construction system can be associated with the notion of ecological wisdom as it is developed through reflective ecological practice [11,12]. The construction methods vary and require tools, patience, and time. The aesthetical contribution towards the landscape shaped the cultural identity of the region [1]. At the same time, the use of material acquired from local quarries or directly from the construction site gave drystone structures a sustainable character [6,13] offering a series of co-benefits [14] and ecosystem services [15].

Drystone constructions and drystone terraces pose a significant role in averting landslides, floods, and avalanches while reducing the risk of erosion and the desertification of

the land [16]. Furthermore, they enhance biodiversity and create adequate microclimatic conditions for agriculture [17]. Furthermore, rainwater conservation and the increase in soil moisture boost land productivity and improve habitat conditions [16]. Other ecosystem services regard erosion control, runoff reduction, biomass accumulation, soil water recharge, nutrient enhancement, the enhancement of plant seedlings' survival rates, ecosystem restoration promotion, and crop yield increase [14] (Arnaez).

Drystone constructions are the interface between culture and nature [18]. Apart from their aesthetic and historical value, drystone terraces enhance habitat heterogeneity by providing nesting cavities and feeding opportunities, hence increasing biodiversity levels [19]. Drystone walls and terraces can increase the number of micro-habitats [20], increasing the species richness of various types and scales [21].

Other ecological values that have been attributed to drystone constructions include the support of the endemic flora and fauna, their use as seed reserves, the provision of shelter for scrub and other adjacent habitats, the provision of nesting and roosting locations in exposed areas, and the provision of niche opportunities in open and exposed landscapes low in vegetative cover [22]. Furthermore, they act as ecological corridors, promoting ecological and structural connectivity [23–25]. The fact that the specific constructions have the potential to be ecologically engineered encourages even greater diversity and range of species [22]. Drystone constructions can be described as biocultural heritage assets shaping both the biological and material characteristics of the landscape [26–29]. The term biocultural heritage can be defined as "*the understanding of cultural landscapes as the result of long-term biological and social relationships, shaping the biological and material features of the landscape and also memory, experience and knowledge*" [30,31]. Previous research regarding the characteristics of biocultural heritage highlighted the fact that cultural landscapes can be biologically rich [27,30]. Therefore, conservation efforts regarding the biocultural characteristics of drystone constructions would be beneficial. Several social and economic changes over time, the economic collapse of agricultural activities, population changes, and the migration of residents, are the main socio-economic factors of drystone decline [13]. The abandonment of drystone terraces and of agricultural lands in general due to the aforementioned economic and social changes are followed by significant impacts on the environment including soil erosion [32] and possible landsliding [3,14,33,34].

The abandonment of terraced agricultural systems has a negative impact on the landscape [35], while eventually, a more open landscape with less local character is produced [36]. Nevertheless, it has been documented that in Mediterranean areas, the drystone agricultural land abandonment is followed by a natural vegetation regeneration, resulting in soil erosion decreasing [13,32,37–39]. The maintenance of drystone terraces is of vital importance for both the natural and the cultural aspects of the agricultural environment. Furthermore, the biocultural importance of drystone terraces is undeniable, and a monitoring system is tested [40–43], involving non-invasive techniques [44] similar to the ecoacoustic method [45] that is used in order to monitor ecosystems.

The variety of ways that sounds are generated, spread, and received is fundamentally interconnected to the landscape structure [46,47]. The sounds produced by vocalizing animals differ amongst temporal and spatial scales [48,49] and can be quantified, thus providing valuable biodiversity-oriented information [46,50,51]. Consequently, an acoustic community, which can be described as a group of organisms interacting acoustically with each other in a specific habitat [52,53], can be used as a proxy for biodiversity richness.

Any change in the environment has a direct impact on the acoustic behavior of organisms. Therefore, sound stands as a proxy for biodiversity alterations and environmental health [54]. For example, an important aspect of the acoustic communication of avian species can be expressed through the intensity and complexity of their songs, which is also associated with ecosystem health [55]. The newly founded scientific field of ecoacoustics [45], although closely related to bioacoustics, differs as it recognizes sound as an indicator of ecological processes at population and community levels, whereas bioacous-

tics is a field of species behavior research studying sound as a signal that carries information between individuals [45].

The ecoacoustics method stands as a rapid [56], non-invasive [57], and low-cost biodiversity assessment approach regarding the vocalizing species [58] and can be used in a variety of habitats [59]. The main assessment tool of the ecoacoustics approach is the detection and analysis of ecoacoustics events, which can be described as the emergent sonic patterns that result from the individual or combinatory transmission of sound of biological, geophysical, and anthropogenic origin [60]. An ecoacoustic event with major ecological significance that can be used as a proxy of biodiversity richness and a habitat health descriptor is the chorus vocalization of animals which occurs at dawn and dusk [61,62].

Choruses have been used by ecologists and ecoacousticians in order to assess the abundance of populations and refer to the simultaneous complex vocalizations of several species in terrestrial, freshwater, and marine habitats [63]. The specific synchronized vocal display is strongly correlated with sunrise and sunset [64] and is more easily detectible in songbirds [65] and other territorial animals [66]. The major hypotheses that attempt to explain the factors contributing to this ecoacoustic event are the intrinsic factors tied to the circadian testosterone cycles, the environmental factors regarding the intensity of light, atmospheric conditions, habitat structure, and finally, the social factors referring to mate attraction and territory defense [67]. Farina et al. (2015) highlighted the temporal variations of bird dawn choruses and divide the acoustic activity into three periods of equal length regarding the pre-dawn and post-dawn chorus periods [68], comprising the dawn chorus phenomenon.

The assessment of biodiversity through acoustic monitoring can be achieved with the use of acoustic biodiversity indicators. An acoustic biodiversity indicator can be described as a statistical quantity that summarizes some aspects of acoustic energy distribution and other information in a sound recording [51]. Several indicators similar to the Shannon diversity index [69] have been adopted in order to assess acoustic diversity [70]. Furthermore, ecological concepts similar to ecological complexity have also been adopted [47,71] and successfully used [72–74]. As mentioned in Eldridge et al. (2018), using the computational R packages seewave [75] and soundecology [71], the acoustic indicators can be extracted. They are designed to capture the distribution of acoustic energy across time and/or frequency in a digital audio file of fixed length [76] and reflect bird species richness [77].

A quick way to quantify bird vocalizations is the processing of the intensities recorded in an audio file, leading to the extraction of the Acoustic Complexity Index (ACI) [72,78]. The specific acoustic indicator is linked with the ecological complexity concept [79] and is based on the observation that biological sounds present an intrinsic variability of intensities, in contradiction with human-generated noise that presents constant intensity values [72]. Another commonly used acoustic indicator is the Acoustic Diversity Index [47,71] (ADI), which uses a similar analogy between species distribution and the distribution of sound energy [75,80–83]. With the use of acoustic indicators, the ecological role of sound, including the dawn chorus phenomenon, can be quantified and compared.

The biocultural aspects of specific drystone constructions similar to drystone terraces, the unique landscape formation created, and as an extension, the unique acoustic environment shaped, and in several cases, the rich historical, cultural, and natural background of specific areas, constitute xerolithic sites as hot spots of ecoacoustic research [84].

Considering the above, the purpose of this research was:

- To contribute with knowledge regarding the xerolithic heritage of Lesbos Island, focusing on drystone olive grove terraces;
- To better understand the impact of drystone terraces on biodiversity levels using a small-scale and non-invasive ecoacoustics approach;
- To compare the effect of drystone terrace maintenance level on acoustic complexity and diversity;

- To highlight a novel and rich sound recording site for ecoacousticians, aiming towards the long-term preservation of drystone constructions.

2. Materials and Methods

On the island of Lesbos, Greece, 80% of the agricultural land is covered by olive groves, and more than 11 million olive trees have been counted [32,39]. The rural landscape of Lesvos mainly involves pastures and olive groves which are dominated by drystone terraces. Until the mid-1960s, cultivation terraces were the main form of cultivation, livestock raising and beekeeping practice, and also were the most significant human intervention in the Aegean Islands, similar to Lesbos Island [85].

For this research, agricultural areas that included highly maintained and poorly maintained olive grove drystone terraces in two different but close proximity regions of Lesbos were used as passive acoustic monitoring checkpoints. Both areas are located in the northeastern part of Lesbos Island and have a distance of about 3 km from each other. The highly maintained drystone terraces located in the Thermi area (39.168299, 26.499782) and the poorly maintained drystone terraces located in the Pamfila area (39.155401, 26.517737) were randomly selected. At this point, the authors of this research wish to declare that the degree of the maintenance of the checkpoints selected does not reflect the overall quality of the drystone terraces in both areas. In Figure 1 the highly maintained drystone terraces, located in the Thermi area and the poorly maintained terraces in the Pamfila area, are presented.



Figure 1. On the left (**a**) the highly maintained drystone terrace sound recording spot in the Thermi area, and on the right (**b**) the poorly maintained drystone terrace sound recording spot in the Pamfila area.

Data Acquisition and Analysis

For each type of drystone terrace, stereo sound recordings were conducted using two TASCAM DR-05x digital sound recorders. The recorders were placed near trees at the height of 1.5 m and programmed to record at 44.1 kHz sampling rate using the built-in omni-directional microphones in order to collect 24-bit uncompressed WAVE audio files. For ten consecutive days, sound recordings were carried out simultaneously in a paired manner in order to compare the highly and poorly maintained drystone terraces, respectively. Each recording lasted one hour and was carried out during the dawn chorus period (more specifically the post-dawn chorus periods, [68] 7.30 am–8.30 am) from 10 April to 20 April 2019. The one-hour audio files were analyzed using one-minute sections and later were averaged. In total, ten hours of uncompressed WAVE audio files were collected, which were processed in order to obtain information related to the acoustic biodiversity levels of the area. The weather conditions during the ten-day sound recording period were

moderate (temperature 16–18 °C), with low wind speed and no rain. Due to the fact that the sound recordings were conducted simultaneously in close distance (approximately 3 km apart) and in similarly shaped olive grove terraces regarding size and shape, we can assume that the recording sessions were carried out at identical conditions, with the only difference being the degree of maintenance.

The R Statistics software [86] was used in order to extract the acoustic biodiversity indicators. In particular, the R computational packages, seewave [45,87] and soundecology [71,88], were used in order to obtain the acoustic biodiversity indicators. For this research the acoustic complexity index (ACI) and the acoustic diversity index (ADI) were extracted, as they are two of the most effective and commonly used indicators [89,90], thus allowing future comparisons.

The acoustic complexity index is based on the observation that biotic sounds such as birdsong are characterized by the variability of intensities, while anthropogenic sounds similar to road traffic noise have constant intensity values. Furthermore, the acoustic diversity index is an adaptation of the species diversity Shannon index considering the proportion of the signals present on the audio file processed.

The resulting acoustic biodiversity indicators were statistically compared in order to detect differences amongst the sites of interest. For the specific small-scale research, we determined the statistical differences of the acoustic indicator levels in two different drystone terrace sites using the SPSS software (IBM SPSS Statistics, Version 28.0.1.0). Descriptive statistics were used in order to illustrate the mean, median, standard deviation, skewness, and kurtosis of the acoustic indicators (Table 1). Furthermore, using the Z-scores of the resulting acoustic indicators, boxplots were created for comparison (Figure 2). Secondly, an appropriate mean difference comparison test was chosen according to the distribution of the data. The null hypothesis H_0 was that there is no significant difference in the acoustic indicator levels at different conditions of drystone terraces during the post-dawn chorus period. In order to estimate the magnitude of difference between the two means of indicators, the effect size for t-tests was estimated [91,92]. More specifically, the effect size according to Cohen's d classification of effect sizes was calculated [93] by dividing the paired samples' mean difference with the pooled estimated standard deviation. According to the Shapiro–Wilk test conducted, the distribution of the data collected was not significantly different from the normal distribution (sig. > 0.05). Therefore, due to the fact that the assumption of normality has been met, a paired samples *t*-test was conducted.

Table 1. Descriptive statistics and Shapiro-Wilk (SW) test of normality results.

Drystone Terrace Condition	Mean	Mdn	SD	Min.	Max.	Skewness	Kurtosis	SW	df	*p*
Acoustic complexity of highly maintained drystone terraces	766.92	697.23	279.57	459.21	1364.61	1.119	1.079	0.905	10	0.248
Acoustic complexity of poorly maintained drystone terraces	1812.42	1784.62	106.57	1680.29	1997.55	0.700	−0.391	0.941	9	0.618
Acoustic diversity of highly maintained drystone terraces	0.0287	0.0250	0.01657	0.01	0.06	0.619	−1.077	0.904	10	0.240
Acoustic diversity of poorly maintained drystone terraces	0.1233	0.1281	0.01035	0.10	0.13	−0.927	−0.633	0.849	10	0.056

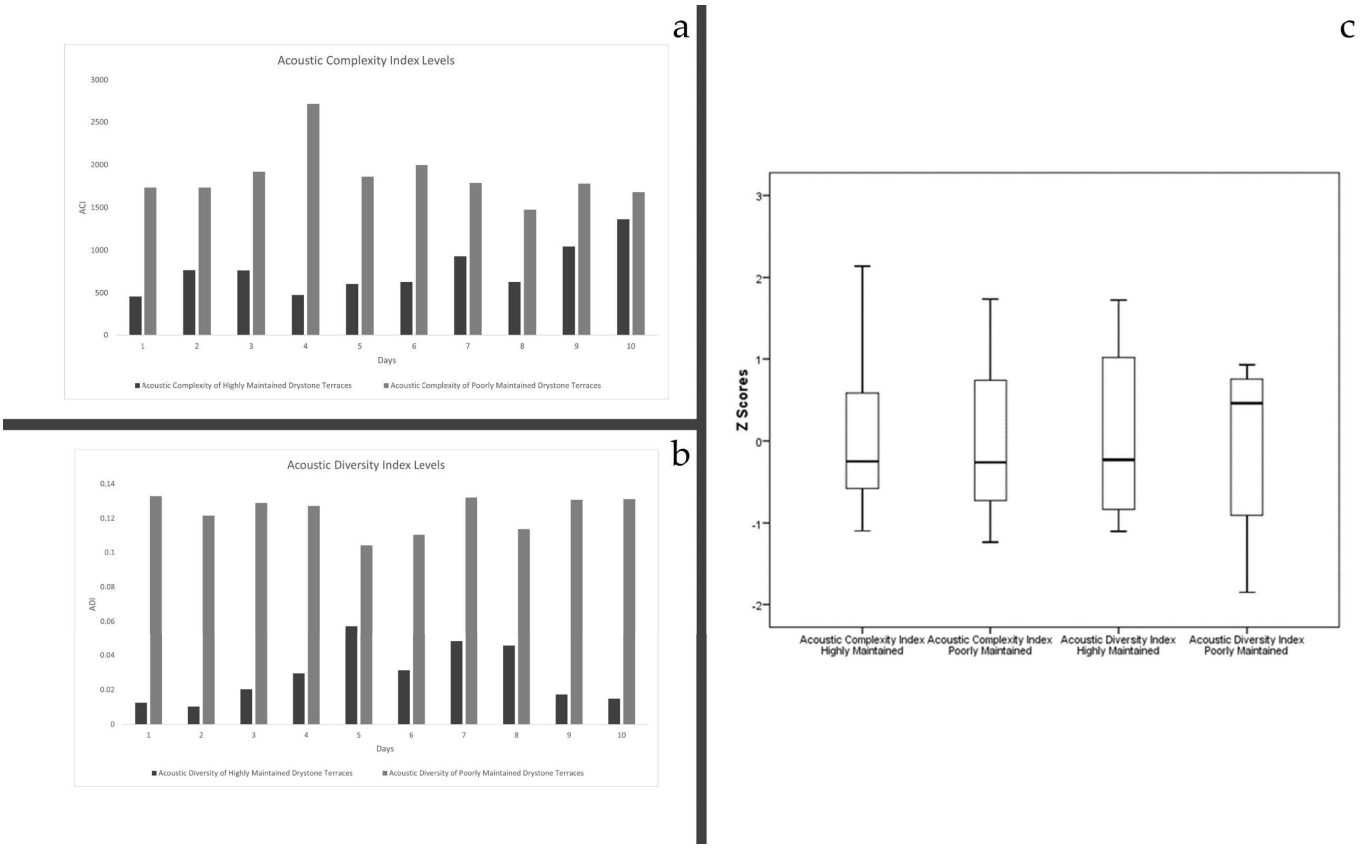


Figure 2. Top left (**a**) The resulting acoustic complexity index levels for each day of measurement for the highly and poorly maintained drystone terraces, bottom left. (**b**) The resulting acoustic diversity index levels for each day of measurement for the highly and poorly maintained drystone terraces, on the right. (**c**) The box plot of the acoustic indicators Z-scores in relation to different conditions of drystone terraces. The boxes represent the upper and lower quartile ranges and the solid line in each box represents the median.

3. Results

The resulting acoustic indicators for both conditions of drystone terraces present fluctuations for every recording day. The dissimilarities regarding the levels of acoustic complexity and diversity can be observed in Figure 2. The poorly maintained drystone terrace site presents, in all cases, higher levels of both acoustic complexity and diversity. On the 4th day of the recording session at the poorly maintained drystone terrace site, the acoustic conditions of the day resulted in a higher level of acoustic complexity. The specific out-of-scope acoustic event was identified as an outlier and regarded as a missing value for the statistical analysis conducted. The decision to exclude this exogenous event highlights the sensitivity of the acoustic indicators and the involved risk, in accordance with the strict time frame available.

The descriptive statistics shown in Table 1 provide information regarding the characteristics and distribution of the resulting values, along with the spread and centers of the data set presented (Figure 2). The resulting skewness and kurtosis levels and the Shapiro–Wilk test of normality results for the acoustic complexity indicator of the highly maintained drystone terraces (M = 766.92, Std. = 279.57) highlight a right-skewed leptokurtic normal distribution. Additionally, the results regarding the poorly maintained drystone terraces (M = 1812.42, Std. = 106.57), present a left-skewed platykurtic normal distribution. Similarly, the acoustic diversity levels of the highly maintained drystone terraces (M = 0.0287, Std. = 0.01657) present a left-skewed leptokurtic normal distribution. Finally, the results of the poorly maintained drystone terraces (M = 0.1233, Std. = 0.0103), present a left-skewed platykurtic normal distribution.

A paired samples *t*-test (Table 2) was carried out in order to identify whether there were significant acoustic complexity and diversity differences amongst olive grove drystone terraces at different conditions. The results for the acoustic complexity levels in the poorly maintained drystone terraces, in relation to the highly maintained ones, differ significantly: t(7) = 8.007, $p = 0.000 < 0.001$, with an effect size of D = 2.83. Similarly, the acoustic diversity levels also indicate mean differences: t(9) = 12.322, $p = 0.000 < 0.001$, with an effect size of D = 3.89, thus rejecting the null hypothesis. Both resulting effect sizes are very large according to Cohen's D classification of effect sizes [94,95].

Table 2. Paired Samples Test results and effect size results.

Paired Samples Test										
					95% CI of the Difference					
	Drystone Terrace Condition	**Mean**	**SD**	**Std. Error Mean**	**Lower**	**Upper**	**t**	**df**	**Sig.**	**Cohen's D**
Pair 1	Acoustic complexity of highly maintained drystone terraces Acoustic complexity of poorly maintained drystone terraces	992.05	350.41	123.89	699.09	1285.01	8.007	7	0.000	2.83
Pair 2	Acoustic diversity of highly maintained drystone terraces Acoustic diversity of poorly maintained drystone terraces	0.09454	0.02426	0.00767	0.07718	0.11190	12.322	9	0.000	3.89

4. Discussion

For this research, the effect of olive grove drystone terrace conditions on acoustic biodiversity was studied by means of sound recordings. The sound recording analysis and the acoustic indicator extraction highlighted differences amongst the biodiversity levels of drystone terraces of different maintenance. The small-scale experiment that was conducted, found that, for this case, the poorly maintained drystone terraces positively affect the acoustic biodiversity levels of the surrounding area.

Previous research has shown that abandoned or partially managed fields with drystone wall boundaries can often give rise to spontaneous scrub vegetation. The spontaneous emergence of vegetation due to bird activity may enhance the ecological values of drystone constructions [6].

The argument could involve the notion of agricultural intensification in contrast to a more sustainable approach. As discussed above, drystone terrace landscapes need to be maintained, well managed, and protected in order to avoid the problems that could derive from agricultural land abandonment [13,96]. Nevertheless, it has been discussed that farmland abandonment could result in an opportunity for biodiversity appraisal [97–99].

A more spatiotemporally advanced sound recording protocol is needed in order to avoid possible biases. There are several factors contributing to the increase in the acoustic biodiversity indicators, that are not necessarily of biological origin [100]. The biocultural complexity is highly influential regarding the numerical outcome of these indicators [26]. Additionally, the background noise of any acoustic environment under study could also cause implications for the reliability of the acoustic biodiversity indicators. Nevertheless, these shortcomings mainly affect urban acoustic environments in which anthropogenic noise is omnipresent [25]. Furthermore, the effectiveness of the acoustic biodiversity indicators relies on the presence of vocalized species similar to birds. It is undeniable that birds alone do not reflect the totality of the biodiversity in an area. Nevertheless, it is reasonable to assume that the existence of birds in an area could be directly associated with the abundance of available resources regarding feeding and nesting opportunities.

This could be due to the behavioral plasticity [101] of the species under study and increased nesting opportunities by various organisms taking advantage of the loose rocks and cavities of the drystone construction. Furthermore, the available trees supported by the drystone terraces also present great nesting and feeding opportunities. The increased availability of feeding and nesting chances for insectivorous birds is probably the main reason for biodiversity appraisal that is aurally expressed.

It is a well-proven fact that drystone constructions, and especially the ones in agricultural landscapes, offer several ecosystem services, amongst which is biodiversity appraisal. As discussed in the introduction section, the abandonment of agricultural territories presents gradual landscape alternations that are reflected in the ecology of the area. The issue of poorly maintained drystone terraces could not necessarily suggest a permanent improvement in biodiversity levels. Other forthcoming risks, involving soil erosion and hydrogeological hazards, could eventually cause bigger ecological challenges. The authors of this work believe that the spatiotemporal development of this research is of vital importance. It is considered necessary to conclude whether the increased acoustic biodiversity levels in poorly maintained drystone terraces are a result of good practice in terms of ecological wisdom or the epilogue of a final performance of an otherwise semi-abandoned and destined-to-fail agricultural ecosystem.

5. Conclusions

This research highlighted the usefulness of sound recording as an ecosystem health assessment tool. An acoustic environment can reflect the current state of an ecosystem at various scales, with the use of acoustic biodiversity indicators. Therefore, a long-term acoustic monitoring network is suggested for various land-use scenarios as an early evaluation apparatus regarding exosystemic health and environmental pressure assessment. As mentioned, drystone terraces and walls, along with other drystone constructions, present numerous ecosystem services. The degree of maintenance, keeping a balance between intensiveness and abandonment in terms of sustainability, can be a key factor regarding the overall effectiveness of drystone terraces.

Author Contributions: Conceptualization, M.M. and A.T.; methodology, M.M. and A.T.; software, A.T.; formal analysis, Y.G.M.; investigation, M.M.; data curation, A.T. and Y.G.M.; writing—original draft preparation, M.M. and A.T.; writing—review and editing, A.T., Y.G.M. and G.P.; supervision, Y.G.M. and G.P.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank the reviewers for their valuable comments.

Conflicts of Interest: The authors declare no conflict of interest.

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