12. The sonic heritage of ecosystems
Towards a formulation

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This paper discusses the importance of the 'paleo-soundscapes' of remote natural habitats as unique footprints of the systemic behaviour of healthy ecosystems and proposes considering them as intangible heritage to be urgently recorded and preserved. The interdisciplinary project Fragments of Extinction has worked towards preserving that ecological heritage through multidimensional sound recording fieldwork in primary equatorial rainforests since 2002. The soundscapes of these unique, untouched and undisturbed places – increasingly threatened by human pressure and climate change – represent an object of patrimonialization that can offer insights to a range of fields. The project seeks to merge science (ecoacoustics), technology (3D sound recording and reproduction) and art (environmental sound art) to contribute to the preservation of examples of the ordered and fragile equilibrium of biodiversity, and to encourage ecological awareness among audiences.

For 15 years, I have been working on a long-term multidisciplinary project about the Sixth Mass Extinction.[1] The project, Fragments of Extinction, has involved recording fieldwork in the Amazon, Africa and Borneo. This fieldwork has enabled me to document, archive and disseminate (through dedicated immersive installation art, such as the immersive ecoacoustic concert performed for the opening of the 2015 SOIMA conference in Brussels) the sonic aspects of primary rainforest biodiversity (Fig. 1–2).[2] Fragments of Extinction relates to the empirical work and theoretical concepts of sound and visual heritage in three important ways:

1. It considers soundscapes, in particular those in equatorial rain forests, to be a unique repository of ecological processes of primary ecosystems and – consequently – worthy to be safeguarded as intangible heritage and a target of patrimonialization.
2. It utilizes advanced recording technology to allow access to primary soundscapes and warrants, respectively, the archiving, the analysis and the sensorial (aesthetic and cognitive) experience of the sound of most distant, untouched and – yet – vanishing habitats of the planet.
3. It insists that art, as cultural interpretation, can virtually interplay with nature, engaging in dialogues with scientific exploration even as it communicates and disseminates broad public initiatives on issues of conservation and supporting ecological awareness overall.

Soundscape as intangible heritage

Soundscape – the combination of sounds that arise from an environment – represents an underestimated imprint of the dynamics of natural ecosystems (Shafer, 1977). While there exists a growing discourse within ecology on the

1 According to the Millennium Ecosystem Assessment (2005), the current global extinction rate is between 100 and 1 000 times higher than it would naturally be. As a result of the direct human pressure on ecosystems (mostly deforestation and overexploitation) and the effects of human impacts on the biosphere (triggering invasive species and pollution), an exponentially growing number of the planet's recently estimated 8.7 million living species are going extinct. In 1993, Harvard biologist E.O. Wilson predicted that the extinction rate would reach 30 000 species per year, and most current studies have judged Wilson's estimate to be correct. That equals three species going extinct every hour. Current estimates do not factor in the effects of climate change. Of all known species, one in four mammals, one in eight birds and 41 percent of amphibians now appear on the International Union for Conservation of Nature's Red List of threatened species.

2 For a project overview and sound excerpts of ecosystems, see www.fragmentsofextinction.org.

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FIGURE 1. Preparation for 3D recording, Yasunì, Ecuador. Photo by Alex d'Emilia

FIGURE 2. Opening ecoacoustic concert by David Monacchi at the SOIMA 2015 conference in Brussels. Photo by Alex d'Emilia

consequences of the Sixth Mass Extinction (Kolbert, 2014; Leakey and Lewin, 1996; Wilson, 2010), less attention has been dedicated to the loss of the acoustic aspects of biodiversity, which is vital for the ecological equilibrium of many species sharing the same habitat. Although the sound of natural phenomena has been the object of investigation by fields such as acoustic ecology (within the humanities), bioacoustics (within the life sciences) and ecomusicology (within music and anthropology), the acoustic consequences of ecosystems degradation (such as ecoacoustic depletion) have been long neglected. It is only recently that scholars have invoked a perspective which could take into account soundscape and soundscape analysis as markers of the ecological processes of habitats and, as such, reliable evidences of habitats' degradation. One iteration of this perspective can be found in the newly established field of ecoacoustics (Farina and Gage, 2017; Sueur and Farina, 2015).[3]

In 2002, I first travelled the Brazilian Amazon to collect recordings of soundscapes in primary forest areas: these seminal data constituted the initial archive of the Fragments of Extinction project. The Amazon recordings immediately revealed the systemic order and equilibrium of the sonic behaviour of species vocalizing in an ecosystem, which at the time were only theoretically conceptualized by the acoustic niche hypothesis (ANH; see Krause, 1993). According to this hypothesis, species vocalizing in a healthy habitat tend to produce their calls along principles of niche segregation,

3 The first ecoacoustics conference, held in Paris in June 2015, led to the foundation of the International Society of Ecoacoustics; see https://sites.google.com/site/ecoacousticssociety/about.

FIGURE 3. A 24-hour recording session, Yasunì, Ecuador. Photo by Alex d'Emilia

both in *frequency* and *time*. This means that (1) many species avoid sound competition with other species by using narrow and separate frequency bandwidths, and (2) certain species take advantage of moments in time, where a crowded frequency range is empty of other organisms' sound to avoid overlaps. From the point of view of the acoustic adaptation hypothesis (AAH; see Morton, 1975), the rich diversity of vocalizing animals showed that an organizing criterion regulated systemic sonic behaviour in the adaptation of animals' calls to the acoustic environment and its morphology. By relying on these principles, interspecific and intraspecific vocalizations would be arranged very efficiently in the collective aural space, as happens for other ecological phenomena. In equatorial areas, where daily cycles are most stationary (due to the equal duration of day and night throughout the whole year), species are evolutionarily tuned to this circadian uniformity, which results in more regular and predictable acoustic niches.

Additional collections of circadian recordings (in the Dzanga-Sangha Reserve, in central Africa, 2008; Ulu Temburong National Park, on Borneo, 2012; and Yasunì in the Amazon, 2016) – done with increasingly more sophisticated technology (Monacchi, 2016) – have verified these impressions. The recordings confirmed the value of soundscape processes as evidence of (and a vehicle for) a functional and aesthetically relevant organization of biodiversity within one habitat (Fig. 3).[4]

On my 2016 trip to Yasunì, Ecuador, it was apparent how dramatic seasonal changes or disturbing anthropogenic sounds disrupt niche organization.[5] This occurs when sounds such as distant noises from oil-drilling platforms mask some bandwidths and make them inaccessible to species, which vocalize in those frequencies.

Human impingements on formerly untouched and undisturbed places are inevitably corrupting soundscapes of primary habitats. Unfortunately, changes to the imprints of a primordial ecological order and complexity have already taken place. There is an urgent need to preserve what is left of these soundscapes; otherwise, there will be no chance for future generations to access this heritage.

3D technology as tool for soundscape preservation

The Fragments of Extinction recording fieldwork uses high-definition recording for the discovery and preservation of not simply singular and discrete species but of the intrinsic systematics and aesthetics of an entire ecosystem. Given the loss and ongoing degradation of intact soundscapes in most of the primary (equatorial) areas, cutting-edge 3D recording technologies can play a critical role in archiving 'traces' of the primordial acoustic organization and converting this intangible natural heritage into a 'tangible' memory of the systemic behaviour and beauty of the disappearing *sonic intelligence* of nature.

Fragments of Extinction recordings used 'space-inclusive' and 'space-preservative' standards and experimental microphone techniques (Monacchi, 2011). By storing the entire spherical information of a sound field, these methodologies allow the preservation of the spatial information of the acoustic environment and maintain the complexity of its organization (through 3D direction, acoustic perspective, dimension of the sound sources) to make it available in public venues using every possible format of multichannel reproduction. Research technologies developed for high-definition indoor approaches, such as first-order ambisonics (FOA) and high-order ambisonics (HOA), have been thus refined and modified to work in challenging climatic conditions (high humidity, rain, wind and animal hazards) and brought to remote environments (Africa and Borneo) for the first time. For an idea of the complexity of these field recordings, the month-long session in the Amazon in 2016 collected 1.45 TB of soundscape recordings in simultaneous binaural, 4-channel and 32-channel formats.

The vivid 24-hour 3D-sound portraits of diverse tropical rainforests that have come out of this project have provided data for scientific exploration and heritage material to be shared with audiences (Fig. 4). The space-preservative recording strategies have proved appropriate also for conducting detailed *ex-post* analyses of biodiversity. As research data, the recordings have been submitted to highly sophisticated electroacoustic analyses on both a micro and

4 As an example of functionality, data processing of samples of circadian recordings in Borneo has indicated further organizing criteria operating in mutual avoidance (e.g. between crickets and cicadas), increase in amplitude of certain species (e.g. cicadas), increased repetition rate (barbets) and jamming avoidance (intra- and interspecific).

5 For a detailed report of the Ecuador fieldwork, see www.montura.it/en/talking_about/news/fragments-of-extinction.php.

FIGURE 4. Collecting the autonomous system in the morning after a circadian recording, Dzanga-Sangha Reserve, Central African Republic.

macro level. On the micro level, they have been used to identify basic components, or 'acoustic codes', of a complex primary soundscape (Pieretti, Farina and Morri, 2011). At the macro level, they have been employed to explore the overall behaviour of an old growth forest ecosystem and the acoustic niches' segregation dynamics.

Ambisonics 3D technology introduces the process of patrimonialization of the soundscape insofar as it allows the preservation and transmission of *knowledge* about the evolutionary mechanisms of species' long-term cross-adaptation. Technology, then, is a powerful means to solicit people's awareness about the aesthetics and the 'intelligence' of soundscapes and their analogy to a primordial musical composition. In fact, documenting soundscapes as compositions proved to be relevant for both ecological thinking and artistic engagement.

Where art explains nature

The vision inspiring Fragments of Extinction and the overall conception of a soundscape heritage of primary ecosystems is one in which art and nature merge yet also mirror each other, in order to mutually enhance their aesthetics and their potential to attract people's senses and sensitivities.

As an artist I am captivated by the perfect coordination that the natural ensembles in forest soundscapes exhibit. The challenge comes in determining how to maintain and disseminate these ensembles in as pristine or unaltered a manner as possible while still interplaying with them as artful pieces. How do I present them without letting art interfere with or mask the primordial aesthetic features that I aimed to document and reveal?

The compositional approach I developed as a response to this challenge, termed as 'eco-acoustic composition' (Monacchi, 2008), proved a good vehicle both for conveying the beauty of sound environments' complexity and balance and for complementing it with musical performance to make the outcome accessible to the public. Music, as a form of cultural intervention, integrates the natural configuration of the soundscape, filling temporal or frequency niches that are left empty by existing species, and interacting with them as another, exotic, still resonant and reactive, communication call.

An important role in this work has always been played by visual rendition of soundscapes, mainly conducted by spectrograms (Fig. 5–6).[6] Besides functioning as essential tools in bioacoustics and ecoacoustics for investigating the spectral microcosm of sound and framing the organization of soundscape, real-time spectrogram analyses also serve

6 A spectrogram is a Cartesian diagram displaying the spectral acoustic energy through time. Time is in the horizontal axis, frequency in the vertical axis, and intensity is depicted through colour intensity. In ecoacoustics the spectrogram reveals very clearly the diverse imprints of species' calls which are usually displayed along separate and immediately identifiable frequency lines, bandwidths or complex morphologies. From a systemic perspective it is shown how species avoid mutual overlap and manage to inhabit different frequency layers or temporal sections of the soundscape. This is usually more evident the older and more untouched the ecosystem is.

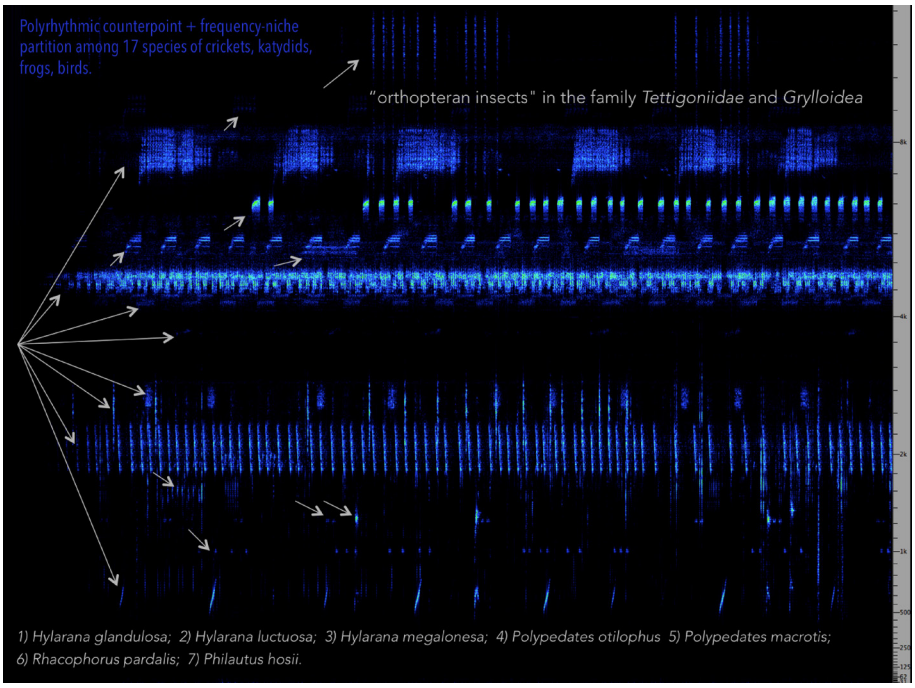

FIGURE 5. Spectrogram of a riverbank forest habitat's recording in Brunei, with species recognition.

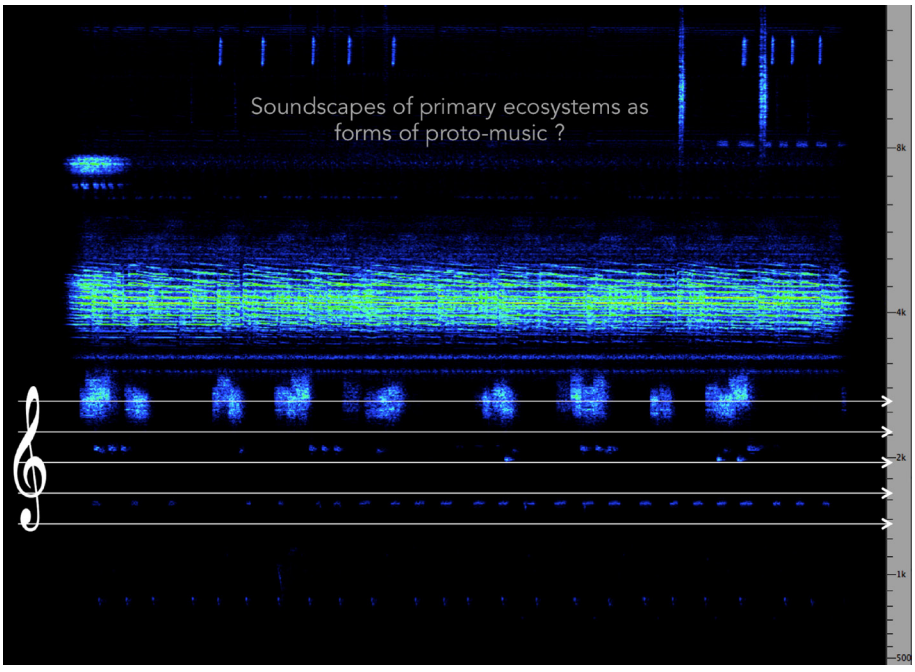

FIGURE 6. Niche partition in frequency among insects in Dipterocarp forest habitat, Brunei.

as powerful and intuitive instruments for audiences' understanding and aesthetical experience. They display at a glance the ordered balance and the elegant interspecific efficiency in the shared acoustic space. The complex species ensembles (insects, amphibians, birds, mammals) vocalizing in the same habitat form the score of an eco-symphony which tends to be immediately perceived and understood through these visuals.

A dedicated space was needed to divulge and perform in powerful ways the memory and potential of the sonic heritage of ancient habitats. The Eco-acoustic Theatre (patented in 2013) has been engineered to reproduce 3D audio and visually render a 360° real-time spectrogram of the soundscape as it unfolds. From an electroacoustic point of view, the 21 or more loudspeakers (equally spaced on rings and all equidistant from the centre) can render a

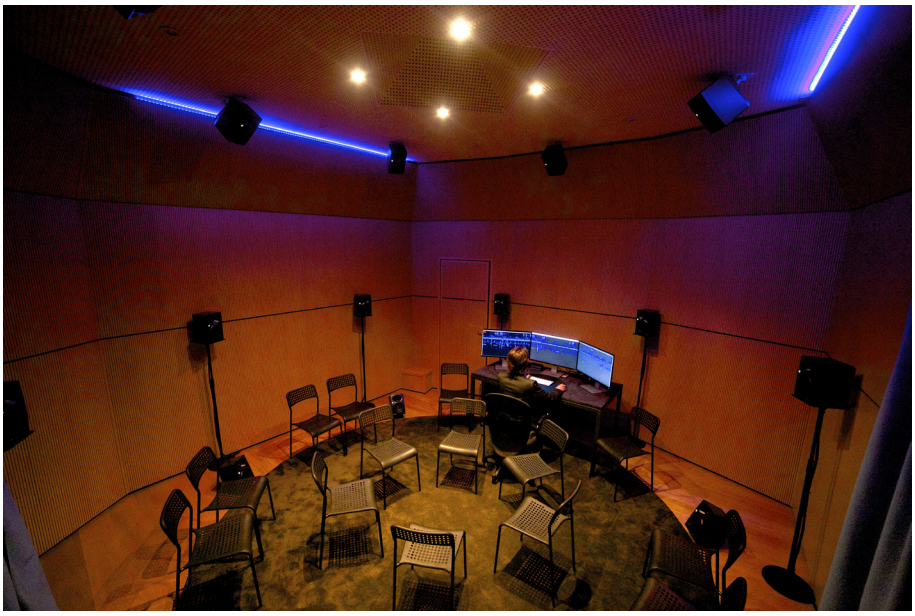

FIGURE 7. The full-periphonic 21-loudspeaker space at the Conservatorio 'G.Rossini' of Pesaro, used for analysis and post-production of 3D soundscapes for the Eco-acoustic Theatre. Photo by Alex d'Emilia

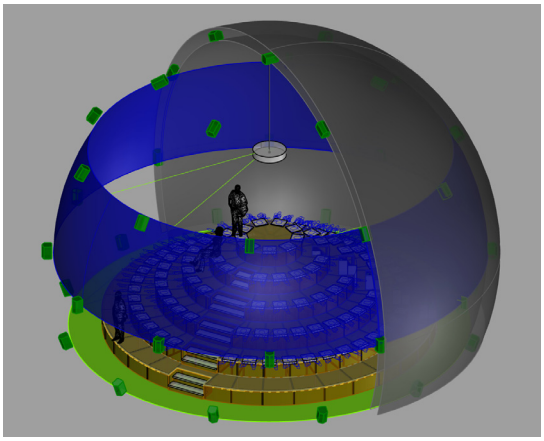

FIGURE 8. A rendering from the patent (2013) for the Eco-acoustic Theatre. 3D rendering by Pippo Marino

high-definition 3D sound field in the middle of the theatre, enabling a nearly perfect soundscape virtualization (Fig. 7–8).[7] The space-preservative ambisonics recordings can be in this way rendered in spherical periphony for large audiences, retaining all sound features important for a correct perception of the density of sound environments (e.g. distance of sound sources, dimension and overall sound perspective).

The Eco-acoustic Theatre is an example of how technology can merge with art in enhancing sensory experience and cognizance of the laws that have shaped these paleo-acoustic environments.

Inside the venue, sounds and images (solely real-time spectrographic analyses) are linked in an innovative combination. The visual analyses (projected and moving on a screen) augment the perception of the soundscapes, showcasing to the audience the habitat's structure and its niches' configurations. An electroacoustic performer can insert ephemeral sensor-driven sound elements. These offer a powerful metaphor of the way human creative expression can interplay within a composite live ecosystem while still respecting its structure and finding an unobtrusive co-existence with it.

Conclusions: 'saving for knowing'

Today, with the silent force of climate change, potentially all primary undisturbed ecosystems (either protected or not) are facing damage to their species composition. Consequently, the original acoustic system within which species vocalizations used to collocate is also endangered.

Urgent 3D recordings of vanishing primary environments can save the sonic memory of these habitats from oblivion. Also, the opportunity to archive these primordial sounds allows both researchers and artists to deepen systematic principles on which they rely, and to learn more about the aesthetic and functional organization of which nature is capable, if unimpeded by human intervention. Taking this into account, soundscapes of pristine ecosystems should be taken as targets of patrimonialization in their own right. The patrimonialization process of

7 The number of loudspeakers depends on various factors, including (a) the dimension of the theatre (which has been engineered to be scalable from 5- to 20-metre diameter); (b) the shape of terraces (convex or concave); (c) the decoding order (i.e. the mathematical process which defines the ambisonics) of the 3D sound field desired.

primary soundscapes would need to accomplish actions on two different levels:

1. *Conservation*. For its intrinsic focus on loss of systemic behaviour rather than on loss of distinct species, soundscape can be taken as a distinct marker to document damages of ecosystems. This entails investment in construction of a digital archive of paleo-soundscapes to be stored for future generations. This archive can be made available for analysis and scientific dissemination. Further, an action of (repeated, longitudinal) archiving of soundscape could also provide a repository of proxies that may document an ecosystem's damage and loss, adding criteria for the description of programmes such as the IUCN Red List of Ecosystems.
2. *Communication*. Initiatives to make 3D soundscapes available to contemporary audiences (in venues such as museums, cultural institutions and public sites) are a powerful means to disseminate knowledge about these ecosystems. As a matter of fact, with regard to increasing public ecological awareness, visuals (including scientific illustrations, photographs, documentaries and movies about species loss, environmental pollution, etc.) have played an almost exclusive role and been used since 1960 as 'evidence' to solicit people's 'environmental awakening'. However, rather than being a peripheral vehicle for sensorial experience, soundscapes can serve as a powerful and novel tool in communicating about ecological and conservation issues. Sound-based art projects offer an immersive experience of the environment and let people connect with natural phenomena aesthetically, sensorially and intuitively.

Science-based art projects can play an important role in finding new strategies for environmental education, attracting the broad public and stakeholders on issues of conservation and sustainability and eventually influencing global conservation policies. Contemporary art-mediated dissemination of soundscapes can, thus, serve to connect people to the direct experience of natural phenomena, building a crucial bridge between nature and culture and raising awareness about the value of protecting biodiversity today increasingly endangered by human pressure and climate change.

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