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ECOACOUSTICS FOR ENVIRONMENTAL MONITORING

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Abstract: The article shows the feasibility of ecoacoustic research for environmental monitoring. Ecoacoustics or the ecology of the soundscape is recognized as a new approach to the study of terrestrial, freshwater and marine systems of various landscapes. Sound is considered as a tool for examining different species of animals and inhabitants of different ecological spheres. Factors influencing the results of ecoacoustic studies, such as deforestation, natural and anthropogenic impacts, have been identified. Significant changes in the technology of instruments and analytical methods of acoacoustics are shown. Passive acoustic monitoring is provided by a new generation of digital recorders capable of capturing the sounds of nature at different sampling frequencies and at different times of the day, combined with satellite data. The modern model of detection and identification of ecoacoustic events EEDI and the capabilities of three working web platforms: REAL, Ecosounds and Pumilio are considered. The results of a model experiment on accounting for fluctuations and changes in the frequencies of the soundscape using modern equipment in a certain area, depending on weather conditions, are presented.

Keywords: Acoustics, monitoring, eco-acoustics

Introduction. Ecoacoustic monitoring is one of the modern approaches for assessing the state of biodiversity in the XXI century and is considered as a kind of environmental monitoring. Thanks to the development of acoustic sensor methods, a fundamentally new way of studying and preserving biodiversity has emerged, which focuses on the recognition and monitoring of individual biological species, as well as on the analysis and description of the soundscape using acoustic indices. For the first time, the use of the term "ecoacoustics" or "ecology of the soundscape" was proposed in 2014 at a scientific meeting in Paris, although research in this direction began in the 60s of the last century [1].

Ecoacoustics in general is an ecological study related to the interpretation of ecological sound (birds, animals) for environmental monitoring. Sound is also considered as an ecological attribute, which can be used to study a wide range of applications, including diversity, abundance, behavior and dynamics of animals in the environment using special environmental devices, which will be discussed later. Thus, ecoacoustic studies can cover terrestrial, freshwater and marine systems of a particular landscape, and ecoacoustics is recognized as an approach to the study of communication and the census of animal species over long periods. Using acoustic recorders, Stuart H. Gage and Almo Farina in Michigan studied and interpreted the patterns of the soundscape during May 2016 by time of day and days using power indicators and six soundscape indices. The authors received comprehensive information about the fluctuations and frequency changes of the soundscape in a given area, depending on weather conditions [1].

Devices. In recent decades, there have been significant changes in the technology of instruments and analytical methods of acoacoustics [2]. For example, a microphone is an important sensor because it is the only device that can serve many purposes for environmental research when connected to a recorder. The array of environmental attributes that can be determined using a microphone is quite wide compared to other types of available sensors (sense of smell, taste, sight, touch). However, there are many pitfalls, including changes in species composition during the season and time of day, as well as the possibility of incorrect identification of species. Errors in species identification occur due to the fact that an observer cannot be in several places at the same time [3]. Over the past decade, analog has been replaced by digital tape recorders. Clocks were added to the recording devices so that recordings could be made at a certain time, and other environmental sensors were built into the same recording machine. Today, sound recorders can be programmed according to project objectives, can store multiple recordings on removable digital media, and can remain active in the field for months without interference. Modern acoustic sensors allow acoustic identification of species in terrestrial and aquatic ecosystems; vocal behavior of specific organisms and their physiology; study of noise pollution; measurement of ecological processes in a climate change scenario [3]. Monitoring of sound biodiversity includes several factors that determine how successfully it can be completed.

Factors. Sound as a tool for the examination of different species of animals and inhabitants of different ecological spheres was used in the last century. Bird observation was carried out by listening to the morning chorus of birds, and the definition of the species was based on the difference in the signals listened to over a long period of the experiment. Similar monitoring methods used sound to determine the occurrence of amphibian species and abundance using night signaling [4]. For example, based on a survey of breeding birds of North America, an assessment of the ecological state of the region was carried out. Day and night organisms use acoustic information in terrestrial and aquatic systems for communication and location detection in the environment [5]. This information is very common in nature, and its origin can be geophonic, bionic or technophonic.

There are three main components that allow sound-producing species to survive: a place to live, a place to reproduce, and food resources. Different types of vegetation provide these opportunities, but differ in different ecosystems. For example, there are more vocal species in the tropics, because there are more types of vegetation there than in ecosystems of temperate latitudes and deserts. The more types of vegetation, the more vocal species. Many vocal organisms in northern ecosystems migrate to southern areas where there are more abundant resources for survival. Unfortunately, in recent decades, the Earth's ecosystems have been degraded. These losses are due to deforestation and habitat fragmentation caused by the expansion of arable land and pastures. The loss of biodiversity caused by humans is defined as a serious and complex problem worldwide, and threats to species and ecosystems will continue, which affects their eco-acoustic characteristics.

Another factor is seasonal changes caused by climatic changes or physical disturbances in the Earth's system due to large-scale natural phenomena or changes in land use, which can also be measured by recording sounds in a certain place. In temperate regions, changes in animal behavior occur as the seasons change. In spring, migrating populations of marine and terrestrial animals (mammals, fish, birds) move from wintering grounds to breeding grounds, which can be far away and require a lot of energy. Food and habitat resources change, and during this period the sounds produced by these organisms vary as they enter the breeding cycle [6].

Further, many species of organisms do not make audible sounds, but those that make acoustic signals may depend on organisms that do not. Therefore, the presence of those that do not make sounds can be deduced by quantifying the sounds for those that make sound signals. For example, we can consider birds and their food sources. The wood thrush sings a beautiful song in untouched forests, searches for and feeds on worms and other food that is found on the forest floor. Although food sources do not make audible sounds, thrush wood would not have appeared in the habitat if not for the resources found there. When we hear the sound of a thrush, we can conclude that there are food resources nearby, and thus determine trophic interactions.

Methods. The use of passive acoustic imaging technology is an alternative method compared to visual readings of individual species and communities of living beings [7]. This methodology has been widely used to identify groups of species such as baleen whales [8] and bats [9]. Moskvik et al. (2013) also used passive acoustic imaging in search of the ivory-billed woodpecker (Campephilus principalis) [10], a species found in the old growth forests of the southeastern United States and considered endangered or possibly extinct [11]. This method can also be used to monitor habitats on large spatiotemporal scales both on land and in the marine [12, 13]. Passive acoustic monitoring is provided by a new generation of digital recorders capable of capturing the sounds of nature at different sampling frequencies and at different times of the day. Programmability, waterproof batteries with a long service life, a large amount of memory (for example, 32-64 GB) and data transmission via the global mobile communication system (GSM technology) are some of these new features of eco-acoustic monitoring. In particular, the commercial market currently offers a wide range of microphones, including complex and expensive ones or less expensive ones that capture acoustic information at close range [14, 15]. In addition, the new indicators allow processing acoustic files, returning data-rich and meaningful information [16].

As for traditional biodiversity indices, they can be divided into two macrogroups: α-diversity and β-diversity indices, which assess intra-group and intergroup diversity, respectively. Earlier methods used in acoustic research were based on a simple measurement of the amplitude or sound pressure level (SPL) (sound energy, usually expressed in dB or RMS). Sequentially, acoustic indices were focused on other parameters of recorded sounds, from considering the complexity or entropy of acoustic emissions to sequentially taking into account time, frequency and amplitude, or by calculating the contribution of each component of the soundscape (biophony, geophony and technophony) [17]. Thus, the ecoacoustic approach makes it possible to collect important information about the physiology and ecology of sound-producing species in terrestrial and aquatic environments.

Acoustic signals of animals are full of meaningful information because acoustic signals are true ecological codes used to convey the position in the habitat, health status, access to resources and social

dominance [18]. Passive recording should be considered in combination with satellite images. Acoustic information is collected in the immediate vicinity of the sensor and provides details inaccessible to satellite images. Often the assessment of biodiversity requires the collection of field data in a narrow time frame, and this is possible with a set of acoustic sensors deployed in a regular grid. The sensor matrix can cope with the heterogeneity of the landscape and can accurately describe the distribution of acoustic communities and indirectly the distribution of resources [19]. Passive registration has led to a change in the methodology of conducting field surveys, since the sensors are relatively inexpensive, do not require the presence of experts and do not violate the environment. This makes it possible to develop and implement sensor networks for long-term monitoring projects in remote and disadvantaged regions, as well as in coastal and deep-water areas.

The Ecoacoustic Event Detection and Identification (EEDI) model may limit the analysis to the processes of interest. The two main factors that can be evaluated are time and acoustic signature. Time is how long and when the acoustic community is active. An acoustic signature characterizes an acoustic community according to its frequency ranges. The EEDI model is based on the use of ACI indicators: ACIft, ACIftevennness and ACItfevenness [20]. ACIft measures the distribution of information over time when differences in sound amplitude between frequencies are estimated. ACIftevenness measures how ACIft is distributed over a time step (for example, one minute). ACItf is a measure of the differences between different amplitudes along each frequency range and reflects the importance of each frequency at which an acoustic event occurs. ACItf is directly used to describe the acoustic signature.

In addition, on Ecosounds.org a copy of the bioacoustic workbench, a software package designed to help environmentalists work with very large volumes of environmental audio data, has been posted. Over time, several digital acoustic libraries have appeared, facilitating the analysis, archiving, management and access to large libraries of acoustic recordings. These include those developed and described by the Cornell Ornithology Laboratory, Macaulay Library and Arbimon (2016) [21].

Thus, the power of the soundscape in different frequency intervals can give an idea of the changes in the daily models of the soundscape and the living organisms living in them (animals, birds and plants). They can be used to identify dawn and sunset choruses, as well as to identify various elements of the soundscape, which includes elements of the weather and the conditions of the species living in them.

Conclusions: ecoacoustics studies sounds within the biosphere and characterizes ecosystems at various spatial and temporal scales, which has consequences that can affect many ecological processes. There is a great need to popularize the value of ecoacoustics for environmental monitoring. Ecoacoustics can quickly provide information useful to resource managers. The public is increasingly aware of the fact that "If we don't measure it, we won't be able to predict it". The idea of listening to the sounds of the environment to determine its "health" should be inherent in the understanding of the scientific community and the public.

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