MONITORING AND DIAGNOSTICS OF FOREST CONDITION USING SOUND SENSORS AND ARTIFICIAL INTELLIGENCE TECHNOLOGIES

Alexander Bogomolov
Financial University under the Government of the Russian Federation, 49, Leningradsky avenue, 1259932, Moscow, Russian Federation
E-mail: aibogomolov@fa.ru

Abstract. The article examines the state of the planet's forests based on statistics and threats to their existence, which are proposed to be diagnosed based on sound signals emitted by the forest, recorded using special sensors and recognized using artificial intelligence. References are given to studies of the reaction of plants to stressful situations, technologies for recording plant sounds and forest sounds. The results of forest assessment are proposed to be presented in visual form on the interactive forest map. Linking the forest sound field with the interactive map will facilitate early diagnosis of possible forest diseases and prevent the spread of epidemics, as well as the use of interactive maps of the planet's forests in simulation models of global development will clarify the limits of civilization growth and move these limits to a later date.

1. Introduction
The current environmental crisis is the result of the breakdown of the systemic balance between human society and Nature. The search for ways and methods to overcome crisis situations is associated with the emergence of a new scientific direction - global modeling. One of the founders of a systematic approach to the study of global processes is the Russian revolutionary and scientist A. A. Bogdanov, who developed the basic provisions of system analysis and self-organization, which he outlined in his work entitled "Tectonics" [1,2]. In the future, system dynamics, the theory of multilevel hierarchical systems, and mathematical forecasting became tools for modeling global processes. A distinctive feature of global models is "globality" in two dimensions: subject and spatial. Global models should take into account economic, demographic, environmental, social and political factors in their relationship. The inclusion in global socio-ecological models of the state and dynamics of the change of the "green lungs" of the planet - forest areas, will more accurately determine the "growth boundaries" of human civilization.

One of the factors for global modelling should be the state of the planet's forests, the area of which is rapidly decreasing due to human activities, fires and epidemics. Real-time monitoring of the state of forests and diagnosis of threats to them have become possible due to the development of information technologies and signal recognition methods based on machine learning and artificial intelligence technologies. In the future, we will consider the basis for setting the task of creating technologies for tracking the state of the forest from sound signals emitted by it, their further registration, recognition and display.
2. Materials and methods

The research method used is analysis and synthesis of research results in various fields of knowledge: ecology, information technology, global modeling, artificial intelligence.

The first simulation models of global development were created by J. Forrester [3] and D. Meadows [4] in the early 1970s at the initiative of the Club of Rome. J. Forrester's Mir-2 model [Forrester 1971] analyzed in its entirety the effects of current trends in population growth and production in the face of resource constraints and growing global pollution. The results of the simulation demonstrated the instability of the global system and the possibility of a deep crisis in the first half of the 21st century. Thus, the models showed the importance of the problem of the physical limits of world development, especially resource depletion. The Mir-2 model is based on the principles of system dynamics - a method for studying complex systems with nonlinear inverse relationships. The world in the model is considered as a single system of various interacting factors. Among the subsequent models of global development can be mentioned models of A. Herrera, J. Kaya, V. Leontyev, Guishiani, Gelovani and others [5-9]. A common feature of these and similar models was spatial differentiation, a huge number (hundreds and thousands) of variables, equations and parameters, and the ability to control.

The deterioration of the global ecology taken into account in the model can be expanded by including it and the rate of extinction of forests. All factors in global models are interconnected, and changing one affects all others. Therefore, it is important to take into account the dynamics of each of the significant factors in the global model. One of these factors is the crisis state of the forests of the planet.

One of the hallmarks of this crisis is changing landscapes. Only about 28% of the area left on the planet, not affected by economic activity; over 40 years, Africa has lost 23% of the forest, and Latin America - 38%. In general, forest extinction in 12 years (total forest loss of 2.2 million km²) was significantly higher than its growth (0.8 million km²); the area of combined growth and degradation is 0.2 million km². About half of the loss of forest falls on the tropical belt; the largest increase is also recorded there, although the ratio of losses to growth there is most strongly shifted towards losses (Table 1). According to estimates, the tropical forest disappears at an accelerated rate, and this acceleration is about 2 thousand km²/year. The highest rate of forest degradation is noted in the tropics of South America - in Argentina, Paraguay and Bolivia.

| Forest by zone       | Loss (km²) | Growth (km²) |
|----------------------|------------|--------------|
| Tropical             | 1105786    | 247233       |
| Boreal (subarctic)   | 606841     | 207100       |
| Subtropical          | 305835     | 194103       |
| Moderate             | 273390     | 155989       |
| Total                | 2291851    | 804425       |

Epidemics of tree diseases are one of the factors contributing to the destruction of forests. Forest epidemics have recently spread extremely rapidly, thanks to the intensification of international ties and globalization. The list of freely, and more often unwittingly, introduced species is constantly growing. Among the new species there are pathogens to which local plants do not have immunity. Because of this, the disease can take on the nature of an epidemic, which leads to the mass death of forests. This happened, for example, with oak groves in California (see Sudden oak death), which have been
disappearing since the 90s due to the introduction of the new parasite Phytophthora ramorum for them, and now the disease is spreading in England.

The crisis situation with the "green lungs" of the planet is the Siberian taiga.

The planetary role of the Siberian taiga is really huge. This is perhaps the last relatively clean piece of sushi. At least the largest - neither the Amazon jungle, nor even the forests of northern Canada compare with Siberia. Siberia, being the "green lungs" of the planet, performs environmental functions on a planetary scale - it supplies oxygen, cleans water, saves the atmosphere from harmful emissions. However, forest fires and pests, in addition to lumberjacks, may lead to the fact that there will soon be no forests in Siberia. This can lead to a systemic crisis of planetary scale, causing a chain of negative consequences of planetary scale. In the global models of civilization development, it is necessary to introduce such a factor as the total area of the planet's forests and their condition.

The threat of the spread of pests is especially relevant for the Tomsk region and the Krasnoyarsk Territory. Scientists fear that in a few decades, a significant part of the taiga will become impassable, and the other part will be destroyed by evil insects.

If scientists do not soon invent radical ways to control pests, then all fir forests will be destroyed without any lumberjacks. Taiga is devoured by the Ussuri polygraph and Siberian silkworm.

In Siberia, the Ussuri polygraph settled an area of 700 by 700 km from the Salair ridge to the Yenisei (this is approximately equal in size to the territory of France). In the Kemerovo Region alone, from 2003 to 2009, he "ate" about 30-40 thousand hectares of coniferous forest.

Large foci of the Ussuri polygraph of botany are recorded in the Novosibirsk and Kemerovo regions, in the Krasnoyarsk and Altai territories, the Altai Republic and the Tomsk region [13].

Another attack is the Siberian silkworm. He destroys larch, fir, cedar. In the Krasnoyarsk Territory last year, more than 500 thousand cubic meters of wood damaged by silkworms were cut down. Experts fear that pests from Siberia will penetrate the European part of the country. So, the Ussuri polygraph has already reached Moscow, where he attacked a collection of fir trees of the Main Botanical Garden named after N.V. Tsitsina RAS.

It is necessary to stop the spread of this pest at the earliest stage, if you are late, then it will be almost impossible to do this. Thus, it is necessary to identify as early as possible negative phenomena and trends that pose a threat to the forest area. The process of their identification can be called diagnosis of forest diseases. Early diagnosis of these processes requires the development of fundamentally new approaches, appropriate technologies and diagnostic models.

The fact that the kingdom of flora is much more complicated than it seems has long been known. In recent years, scientists have discovered that plants under stress can emit signals that can be recorded and recognized. Recently, experts from Tel Aviv University for the first time recorded sounds that produce plants under normal conditions, and sounds when they are experiencing stress, for example, when dehydrated [13].

All this scientists found out thanks to artificial intelligence. A special algorithm was taught to recognize the state of the plant, recording the intensity and frequency of oscillations emanating from green experimental subjects and distinguish them from the rustle of leaves, the sounds of rain, wind and other noises.

Trees also produce sounds that can be recorded using a specially designed microphone that can transmit these sounds to a remote recording device (Fig 1).
How exactly do plants make sounds? Previously, specialists using sensors located directly on the stems recorded vibrations due to the so-called cavitation (the formation and explosion of air bubbles inside the xylems). Xylems are plant analogues of vessels, the main task of which is to deliver water and useful substances from the roots to the leaves.

Scientists suggest that the sound effects they identified may be associated with cavitation. However, even if the experimenters’ guess is correct, for some plant species, it is not obvious that the source of the sounds of other plants is also cavitation.

The phenomenon discovered by Israeli experts may have profound biological meaning. In a preprint of a scientific article on the bioRxiv website, the authors claim that the results of the experiment they obtained will help change their view of the hitherto considered "silent" kingdom of plants.

The coordination and cooperation of plants increases the possibility of their survival in difficult conditions. Probably, this feature is inherent in forest plants. Plant collaboration is key to improving their chances of survival. As it turned out, plants are able to warn of approaching danger, pest attacks and drought.

Plants are not so passive creatures. They react to light, humidity, changes in gravity and the chemical composition of the soil, they can send chemical signals to each other and even share useful substances with neighbors through the roots, resorting to the help of fungi.

But can they, like animals, hear sounds and make them themselves? In the world, not many scientists ask this question.

Such hypotheses go back to the debate of biologists of the late 19th century about whether plants are “smarter” than we think, whether they respond to signals like animals and whether we can talk about any behavior in the flora. Perhaps with the light hand of the Bengali encyclopedist scientist of that time, Jagdish Bos, who believed that plants feel pain and emotions, urban legends appeared about the ability of the ficus on your windowsill to distinguish between a human voice or better grow to classical music.

For fidelity, the researchers trained a machine learning algorithm on the data of their observations so that it "by ear" distinguished these plants in different states. The algorithm with 70 percent accuracy determined whether the plant is normal, or in a state of stress.

In the recognition of sounds and images, machine learning methods based on neural network algorithms are used. Recently, neural networks have made considerable progress in the field of object recognition and video scenes. These achievements have been made possible by learning from massive datasets with marked objects [16]. But in the field of understanding sounds, neural networks have not yet shown such progress. Specialists from the Laboratory of Informatics and Artificial Intelligence (CSAIL) of the Massachusetts Institute of Technology corrected this drawback by developing a system for machine learning of recognition of sound signals SoundNet [16], (Fig. 2).

CSAIL employees used about 2 million Flickr videos (26 TB of data) to train the neural network, as well as a database of annotated sounds - 50 categories and about 2000 samples.

Figure 1. Register tree sounds with wearable electronic phonoscope [14].
Although the SoundNet was originally intended to bind the sound signals of objects to their images, it is able to learn to recognize the sound signals of an object in various states, which allows us to talk about the possibility of using it to recognize the sounds of plants (wood, forest).

3. Results

Early detection and recognition of forest beeps can help prevent an epidemic that is dangerous to the forest, natural or human-induced, resulting in forest loss.

In the future, the forest can be equipped with miniature sound wave recorders of individual trees - we call them "beacons" that cover the entire forest and create its general "sound field," which can be an indicator of its well-being or an indicator of the onset of disaster. Recording such a sound field presents no particular technological difficulties compared to verification and identification. Here, however, the existing capabilities of artificial intelligence may come to the rescue. The use of artificial intelligence in solving environmental problems is practiced in many countries, including Russia.

The problems of forests and forestry in Russia are dealt with by the Federal Forestry Agency, which is under the jurisdiction of the Ministry of Natural Resources and Ecology of the Russian Federation. The leading organization for forest accounting is the Federal State Budgetary Institution (FSBI) ROSLESINFORG. In its activities, it uses, among other things, the interactive map of the forests of Russia (Fig.3), which is based on the geographic information system - a key tool for collecting, storing, processing, information about forests for strategic management decisions.

Linking the forest sound field to an interactive map and recognizing it requires additional research, but it will contribute to the early diagnosis of possible diseases and the prevention of the spread of epidemics, as well as the inclusion of interactive maps of the planet's forests in simulation models of global development will make it possible to clarify the limits of the growth of civilization and take timely measures that will move these limits to a later date.
4. Discussion

The consideration of the forests of the planet as a "living" system has not yet reached the level that has already been achieved in the study of living organisms, including humans. The resource approach prevails in the study and use of the forest. The underestimation of the role of the forest in the history of development and the existence of civilization is also manifested in its absence in the models of global development of civilization. Few studies of the plant world have shown that it emits and exchanges various signals, responds to hostile influences and tries to reduce possible negative consequences.

According to Israeli scientists, for the first time they managed to show that plants make sounds, and, apparently, it was during stress. It is really possible to recognize them in relation to certain types of processes that threaten them. The reason for the appearance of sound signals may be the phenomenon of cavitation - a process in which air bubbles are formed in xylem (the main water-conducting tissue of the plant) during drying, which burst, causing very quiet vibrations. However, it is not obvious that specialized stress signals were recorded, and not random sounds that arose due to damage to the equipment. Also, it would not interfere with checking whether sounds differ in different species of plants.

There are the possibility and results of recording the sounds of wood and forest in general, for example, forest fire, sheleste of leaves, the sound of an ax hitting a tree, etc., recorded in mp3 format, which can be listened to on some sites on the Internet, which indicates the technical possibility of recording sound signals of forests [18,19].

The use of modern information technologies, the attraction of artificial intelligence methods to recognize forest signals, will possibly lead humanity to a greater understanding and conservation of Nature.

The world of plants, including forests, is a complex multilevel network structure, the elements of which are interconnected and capable of communication with each other. The global task of preserving the plant world of the planet and, most importantly, the "green light" planets - forests - cannot be solved if we do not learn to hear and understand the languages of the plant world.

5. Conclusion

If you consider the forests of the planet as living systems, then the most promising way to preserve and develop them seems to be to recognize their signals and, on their basis, take appropriate measures to eliminate the factors that threaten them. Appropriate information technologies for recording audio signals already exist, but methods for recognizing these signals based on artificial intelligence still require additional research. Also, the inclusion of "sound fields" of forests in interactive maps of the planet's forests and in simulation models of global development will make it possible to clarify the limits of the growth of civilization and move these limits to a later date.

6. References

[1] Bogdanov A A 1929 Universal organizational science: tectology 3 ed part 3 (L-M: Book) 221 p
[2] Anisimov O S 2002 Organizational ontologies and analysis of activity systems A A Bogdanov and modern methodology (Moscow: FGOU ROsAKO AIC) 532 p
[3] Foerster H von, Mora P and Amiot L 1960 Doomsday: Friday, 13 November, A D 2026 Science 132 pp 1291–1295
[4] Meadows D H, Meadows D L, Randers J and Behrens W W III 1972 The Limits to Growth: a Report for the Club of Rome’s Project on the Predicament of Mankind (New York: Universe Books, Potomac Associated Book)
[5] Herrera A O, Scolnik H and Homez J 7–11 October 1974 World Model: report in the Proceedings of the Seminar on the Latin American model at IASA (Laxenburg, Austria)
[6] Kaya Y and Suzuki Y 1974 Global Constraints and New Vision for Development Technological Forecasting and Social Change no 6 (3) pp 277–297 no 6 (4) pp 371–388
[7] Gvishiani D M, Gelovani V A and Dubovsky S V 1985 *System modelling of global problems* Collection of works VNIISI 3 p 15
[8] Gelovani V A, Britkov V B and Dubovsky S V 2009 *USSR and Russia in global system (1985-2000): simulation results* (Moscow: URSS)
[9] Makhov S A 2013 Long-term macro model of world dynamics on based on empirical evidence *Computer research and modelling* no 5 (5) pp 883–891
[10] Hansen M C, Potapov P V, Moore R, Hancher M, Turubanova A, Tyukavina A, Thau D, Stehman S V, Goetz S J, Loveland T R, Kommareddy A, Egorov A, Chini L, Justice C O, Townshend J R G 2013 High-Resolution Global Maps of 21st-Century Forest Cover Change *Science* vol 342 p 850
[11] Boyd I L, Freer-Smith P H, Gilligan C A and Godfray H C J 2013 The Consequence of Tree Pests and Diseases for Ecosystem *Science* vol 342 p 823
[12] Why is the taiga dying? The future of Siberian forests is under threat Available at: https://nsk.aif.ru/sibir_1371/pochemu_gibnet_taiga_budushchee_sibirskih_lesov_pod_ugrozoy
[13] Lewin-Epstein O, Sharon R, Saban K, Perelman R, Boonman A, Yovel Y, Hadany L Plants emit informative airborne sounds under stress The reprint server for biology pp 47–58 doi: https://doi.org/10.1101/507590
[14] Bogomolov A, Nevezhin V, Piskun E and Khokhlov V 2020 Models of Frequency Characteristics of Ecological Systems and their Conversion to Sound Form *E3S Web of Conferences* no 161, p 01061 doi: https://doi.org/10.1051/e3sconf/202016101061
[15] Bolei Z, Agata L G, Jianxiong X, Antonio T and Aude O 2014 Learning Deep Features for Scene Recognition using Places Database *Advances in Neural Information Processing Systems (NIPS)* no 27
[16] Aytar Y, Vondrick C and Torralba A 2016 *SoundNet: Learning Sound Representations from Unlabeled Video* Massachusetts Institute of Technology NIPS
[17] Interactive map Forests of Russia Available at:
[18] Sounds trees download and listen online Available at: https://zvukipro.com/priroda/385-zvuki-derevev.html
[19] Tree/soundmap Available at: https://www.soundsnap.com/tags/tree