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VEGETATION SURVEYS FOR MONITORING CO_2 GEOLOGICAL STORAGE SITES: A CASE STUDY FROM TWO ANALOGUE SITES FROM ROMANIA

Lia STELEA[1, 2], Alexandra-Constanța DUDU[1], Corina AVRAM[1], Gabriel IORDACHE[1], Constantin-Ștefan SAVA[1]

[1]National Institute for Research and Development on Marine Geology and Geoecology – GeoEcoMar, 23-25 Dimitrie Onciul Street, District 2, 024053, Bucharest, Romania
[2]University of Bucharest, 4-12 Regina Elisabeta Blvd, District 3, 030018, Bucharest, Romania

Corresponding author email: lia.stelea@geoecomar.ro

Abstract

Carbon capture and storage (CCS) is a promising solution for reducing carbon emissions, but the risk of CO_2 leakage requires monitoring. As part of project PN 23300404, we aim to develop an environmental monitoring methodology for onshore geological storage sites, evaluating vegetation surveys as a monitoring tool. In 2024, we conducted combined vegetation and geochemical surveys at two sites: Bodoc, an analogue for safe storage, and Băile Lăzărești, an analogue for CO_2 leakage. Using a grid-based sampling approach, we measured soil-flux and concentrations alongside floristic observations. At Bodoc, no significant relationship was observed between CO_2 levels and vegetation state. In contrast, at Băile Lăzărești, areas with high CO_2 concentrations had sparse vegetation and exposed soil, though these features were also present in some low-CO_2 areas due to landscaping. Follow-up surveys are planned for next year to determine the natural variability of the vegetation. Currently, we conclude that vegetation surveys have the potential to be used for leakage identification.

Key words: *CO_2 geological storage, monitoring, vegetation surveys, soil flux, natural analogues.*

INTRODUCTION

The sixth IPCC report (IPCC, 2023) states that the rise in average global temperature measured since preindustrial times is most likely caused by the anthropogenic greenhouse gas (GHG) emissions. Carbon capture and storage is a solution to reduce GHG emissions, recommended by the IPCC as needed, in order to achieve the climate targets (IPCC, 2022). One of the main challenges related to the deployment of this technology is mitigation of potential leakage risk and also assessing its potential impact on ecosystems (West et al., 2005).

The impact of a potential CO_2 seepage from an anthropogenic reservoir on vegetation is relevant considering that this information can be used as an early indicator of leakage (Noble et al., 2012).

Several studies have been made worldwide, based on natural analogues, highlighting the relationship between increased CO_2 concentration in soils, vegetation health and/or substitution of species. The effect of CO_2 can be direct or indirect through pH changes and the remobilisation of nutrients or toxic compounds (Noble et al., 2012). There have been two research directions: the first using controlled leakage sites and the second using natural analogues. The first research direction uses experimental field sites where CO_2 has been injected into soil and documents the effects on the ecosystems. The most important experimental sites are the ZERT site (Keith et al., 2009; Male et al., 2010) and ASGARD site (West et al., 2009). The second research direction is related to natural sites where CO_2 releases are present, such as Germany – Laacher See (Krüger et al., 2009, 2011), Greece – Florina basin (Ziogou et al., 2013), Italy - Latera (Beaubien et al., 2008; Oppermann et al., 2010) Slovenia – Stavešinci (Macek et al., 2005, Pfanz et al., 2007) and the United States – Mammoth Mountain (Bergfeld et al., 2006; Biondi & Fessenden, 1999; McFarland, Waldrop & Haw, 2013).

From previous research it was observed that botanical changes are site and species specific (Noble et al., 2012). Vegetation changes also depend on factors like soil moisture and pH (Krüger et al., 2011). In general, plants are resistant to an increase in CO_2, with no obvious response at moderate concentrations (Bouma et al., 1997). Plants can show a decrease in height, root respiration and rooting depth (Nobel & Palta, 1989; Vodnik et al., 2006). They can also present yellowing or browning of leaves and other signs of stress following a rapid flux of CO_2 (Pfanz et al, 2011; West et al., 2009). Grasses generally dominate the high CO_2 sites (Beaubien et al., 2008; West et al., 2009). Depending on site, there can be potential bioindicator species like *Polygonum arenastrum* (Krüger et al., 2011), *Polygonum aviculare* (West et al., 2015) and *Minuartia glomerata* (Ziogou et al., 2013). Dead vegetation (e.g. Bergfeld et al., 2006) or the lack of plant cover (Beaubien et al., 2008) can also be indicators.

Romania offers a great potential for this type of studies, since there are many sites that could be used as natural laboratories. Considering this, two natural analogues have been selected as test areas in the framework of a nationally funded research project started in 2023 and aiming to develop an environmental monitoring methodology. The two selected sites are Bodoc (Covasna County), a natural analogue for safe storage and Lăzărești (Harghita County), a natural analogue for leakage of CO_2 in the near environment. On these two sites gas measurements and vegetation surveys have been conducted in September 2024.

MATERIALS AND METHODS

Study areas

Bodoc site corresponds with a carbonated mineral water reservoir. The location used for measurements is on a pasture for cattle on the outskirts of the Bodoc commune along the Borviz brook.

Geologically, the Bodoc area is located at the western limit of the Cretaceous flysch, intensely folded and faulted. The Cretaceous flysch deposits (Sânmartin-Bodoc strata) are composed of an alternation of sandstones, marls, shales and conglomerates. In the deposits of the basement rock there are medium depth aquifers and in the upper side there are post tectonic deposits of the sedimentary cover, with shallow aquifers.

The conglomerate facies, located in a synclinal structure, are strongly affected by tectonic movements (a series of transverse faults), responsible for the migration of mineral waters to the surface (Mutihac, 1990).

Bodoc is known for its mineral waters. On the left bank of Borviz brook there is the well F1 SNAM Talomir (presently in conservation) in Upper Pliocene-Quaternary deposits and on the right bank there is the well F2 SNAM, with oligomineral mineral water (SNAM, 2025).

Băile Lăzărești is situated next to Lăzărești village, within Cozmeni commune, approximately 16 km North-East from Băile Tușnad. It is renowned by highly concentrated carbon dioxide emissions which can exceed 85% in volume (Dudu et al., 2024). From a geological point of view, Băile Lăzărești area is situated on a succession of geological deposits, from the Cretaceous flysch (Sânmartin-Bodoc, Barremian-Albian strata) at the base, to the terrace deposits. The deep geological structure of the area is dominated by a fault system that includes geological complexes, facilitating the migration and distribution of post-volcanic emissions, such as mofettas or mineral water springs (Mutihac, 1990).

Flux and concentration measurements of soil gases

Soil flux and concentration measurements were done using the West Systems portable fluxmeter equipped with CO_2, CH_4 and H_2S sensors. The measurements were done at Bodoc site on two perimeters, one along the brook valley (P4) and one on a pasture for cattle (P3), with a variable sampling distance of 2 or 5 m. In total, 244 points were measured.

At Lăzărești site, gas measurements were done also on two perimeters, one in the area with the most important touristic features (basin, mineral spring and wet mofettas) (P1) and one on a hill recently landscaped on three terraces (P2). The sampling point were 5 m apart. 52 sampling points were measured in total.

Concentration and flux data was processed using FluxRevision software, provided by West Systems.

Vegetation surveys

The quantitative vegetation survey was done in the same place or in the immediate vicinity of the measurement point for gas flux and concentration, in order to correlate the dominance of a given type of vegetation and the concentrations of gases at the soil level at the same place. We used a rectangular quadrant with the sides of 50 cm placed in the points where gas measurements were done.

The interior of every quadrant was digitally photographed with the camera of a Xiaomi Poco M3 mobile phone in order to have a visual record and to analyse the abundance of different categories of vegetation and soil coverage. Digitally, by using the software GIMP 2.6, a grid of 25 points situated at equal distance was created inside the quadrant and the category where each element belongs for each point was selected.

For the quantitative survey there were used 107 points for Bodoc (Figure 1) and 52 points for Băile Lăzărești (Figure 2). Although in Bodoc area there were gas measurements done in 213 points, we chose just some of them for the vegetation survey, for logistic reasons. Also, four points with blurry photographs were eliminated.

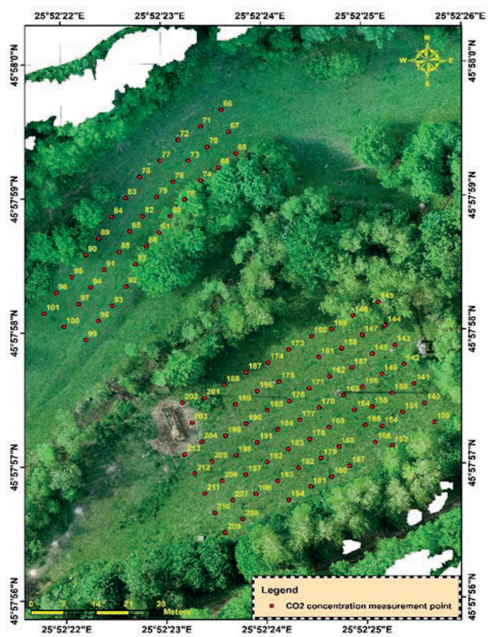

Figure 1. The network of points used at Bodoc for gas measurements and vegetation survey

Figure 2. The network of points used at Băile Lăzărești for gas measurements and vegetation survey

For this survey we intended to do a quantitative evaluation through the presence and dominance of some wide categories of herbaceous or small-sized plants, also considering their apparent state of health. Where possible, the main taxa of herbaceous plants were identified in order to offer us further clues about the character of the plant community.

The most common genera and species were readily identified, while the less common ones were identified using the mobile application iNaturalist (iNaturalist, 2024) through its dedicated function, with its observations georeferenced and made public through the GBIF (GBIF, 2024) network.

The following soil coverage categories were used:

1. dicotyledonous angiosperms (dicots) not known as indicators - healthy organs;
2. monocotyledonous angiosperms (monocots) - healthy organs;
3. herbaceous angiosperms - withered, yellowed, brown or dried organs;
4. mosses;
5. pteridophytes;

6. external (tree leaves, branches, litter etc.) or unidentified (shaded) elements;
7. bare ground;
8. known indicator plants from other studies: *Polygonum sp*., *Minuartia glomerata.*

The criteria according to which the categories 1 and 2 were selected are primarily from literature, where it was concluded that the monocotyledonous angiosperms are generally more frequent than dicotyledonous in areas with high CO_2 (Krüger et al., 2009; Krüger et al., 2011; Noble et al., 2012; West et al., 2009). Category 3 was selected because very high CO_2 emissions can make the plant organs appear yellow or brown (West et al., 2009), or can lead to their death (Bergfeld et al., 2006). Categories 4 and 5 can be dominant in certain locations although literature does not specify whether their presence is related to given CO_2 concentrations. Category 6 is neutral. At the highest level, long-term CO_2 emissions categories 7 or 8 can appear, bare ground or indicator plants. Concerning the latter, the genus *Polygonum* must be mentioned with the species mentioned as indicators in the literature *Polygonum arenastrum* (Krüger et al., 2009) and *Polygonum aviculare* (West et al., 2015), possible other members of the genus, as well as *Minuartia glomerata* (Ziogou et al., 2013), which was not found in the study area. However, the presence of *Polygonum* sp. isn't an unequivocal indication for the presence of high CO_2, being a very common genus present in anthropically disturbed areas.

Using the program Microsoft Excel and the photographs, as well as mapping techniques, we tried to highlight relationships between the percentual composition of soil coverage categories and the flux and concentration of the gases CH_4, CO_2 and H_2S. This was tested for both Bodoc and Băile Lăzărești.

RESULTS AND DISCUSSIONS

Flux and concentration measurements of soil CO_2

Four perimeters for the soil CO_2 concentrations were used: P1 and P2 at Băile Lăzărești, P3 and P4 at Bodoc, all considered separately.

P3 at Bodoc is the pasture for cattle, where the minimum concentration recorded is 413.8 ppm, the average 427 and the maximum is 483.5 ppm. P4 at Bodoc is close to the Borviz brook, with the minimum concentration recorded as 420.4 ppm, the average 438 ppm and maximum as 474 ppm (Figure 3).

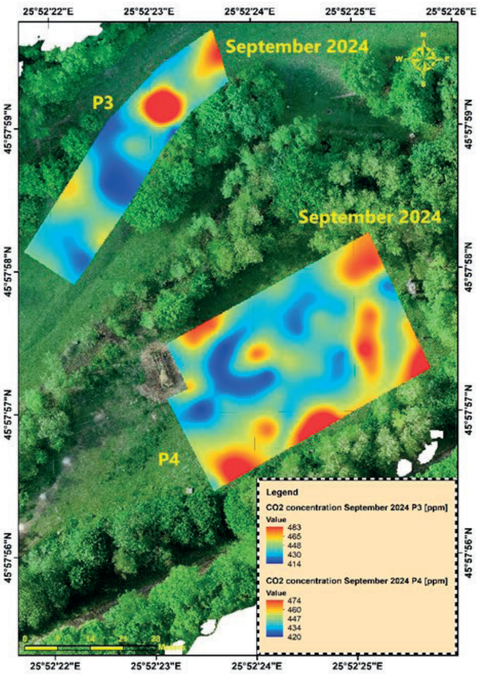

Figure 3. CO_2 concentrations at Bodoc

All these values are close to the background level and do not exceed 500 ppm. On the other hand, Băile Lăzărești have a minimum value of 516.6 ppm in P1 and a maximum measured value of 25863.2 ppm (Figure 4) and an average of 3240 ppm. However, the maximum measured value is not the maximum value for the area, which is probably found in the mofetta set up for tourists close to point 44 (Figure 2).

The perimeter P2 on the hillside has generally above background levels of CO_2, with a minimum of 428.9 ppm, an average of 743.7 ppm and a maximum of 1764.2 ppm (Figure 4).

Vegetation survey at Bodoc

The herbaceous vegetation consists of a cattle pasture in the vicinity of oak forest (Figure 1), with a slight slope in the upper area and flat in the brook area, separated by a slope with ungrazed vegetation. The upper area is shaped like a wide stripe, with the orientation NE-SW.

In the pasture area, the plants are generally no more than 5 cm high from the ground up, due to grazing, except some taxa like *Cirsium arvense*, *Urtica* sp. and *Plantago* sp. Grazing made the species hard to identify. The plants were generally affected by the drought, being withered, yellowed or dried as a result of unusually hot a hot and dry summer and autumn. More vigorous are the plants found close to Borviz brook or in the shade of the surrounding trees and shrubs. The human influence is visible because the upper part bears the traces of a construction's foundation and the lower part, next to the brook, contains several boreholes.

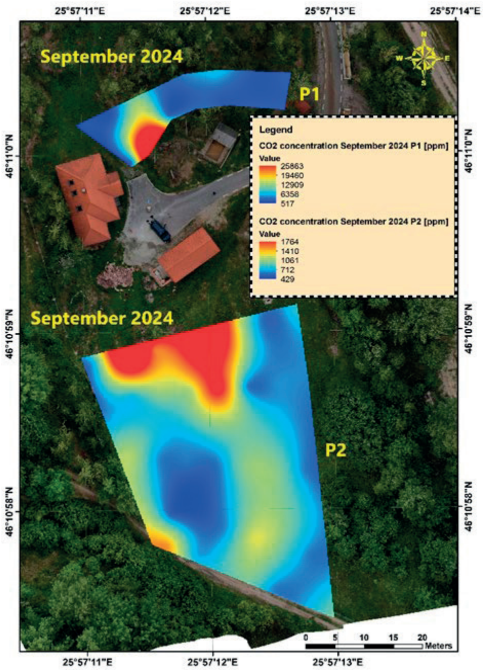

Figure 4. CO_2 concentrations at Băile Lăzărești

Vegetation survey at Băile Lăzărești

The study area has a strong anthropic footprint, being enclosed with a fence and has built structures for balneotherapy and some terracing works. The area has a marked, but not steep slope, with Northern exposure. The herbaceous vegetation doesn't have signs of intervention through grazing or mowing, but can be prevented to grow through treading, mulching or by the presence of balneotherapy constructions (Figure 2). Where present and their growth is not impaired, the herbaceous plants are generally vigorous. Some plants are yellowed in appearance. The trees and shrubs at the site are birches (*Betula pendula*), some small-sized willows (*Salix capraea*) and juniper (*Juniperus communis*).

Mosses are present, without being identified by genus or species. The pteridophytes found are *Lycopodium clavatum*, *Equisetum* sp., *Athyrium filix-femina* and *Pteridium aquilinum*. The dicotyledonous angiosperms are dominated by the families Asteraceae and Fabaceae, especially by the genus *Trifolium*.

Among the monocotyledonous angiosperms dominates the order Poales, with the family Poaceae with the genera *Poa* and *Phleum* and the species *Agrostis capillaris* and *Dactylis glomerata*. We can also find the families Cyperaceae and Juncaceae from the same order.

Comparative analysis

Comparing the two surveys, Bodoc has much more dry or yellowed vegetation compared with Băile Lăzărești, from exposure to the sun and drought probably (Figure 5). The shaded areas have greener plants, especially dicots. From a taxonomical viewpoint, in Băile Lăzărești dominate the monocots, approximately twice as abundant compared to dicots. In Bodoc area healthy monocots and dicots have approximately equal proportions, although the stressed angiosperms tend to be monocots, especially in the sunny areas (Figure 6). Dry or withered angiosperms were generally not identified by class, because they were harder to distinguish. In Băile Lăzărești, the stressed angiosperms (almost completely monocots) are found mostly in balneotherapy and terraced areas (Figure 7). We consider than the effect is probably caused by human activity. An important mention is the absence of the indicator plants from all photographed quadrants. Although *Polygonum aviculare* was present in both areas, it wasn't found where gas measurements took place, but in the surrounding areas, disturbed by treading.

As neutral elements there are mosses, more frequent in Bodoc, and pteridophytes, more frequent in Băile Lăzărești. Due to the anthropically removed vegetation in Băile Lăzărești, there is a higher percentage of bare ground. In Bodoc, bare ground is present on patches of at most a few centimetres in length.

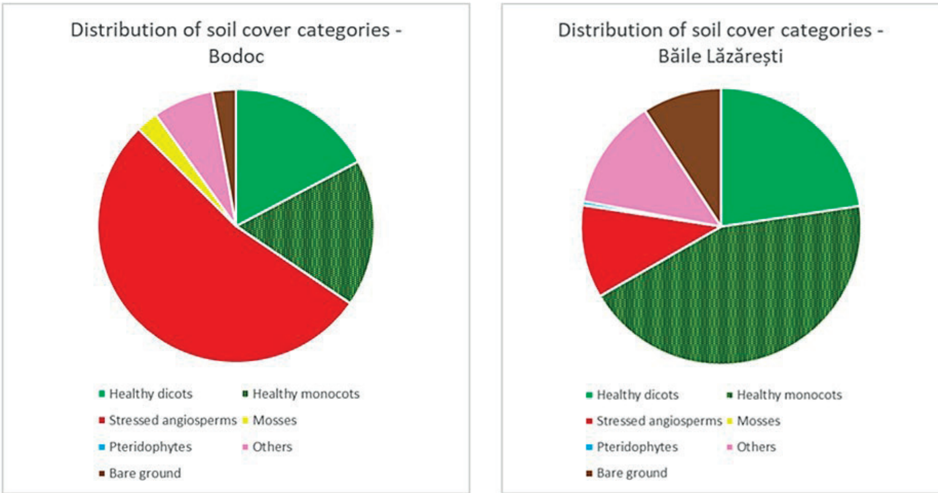

Figure 5. Distribution of soil cover categories at Bodoc and Băile Lăzărești

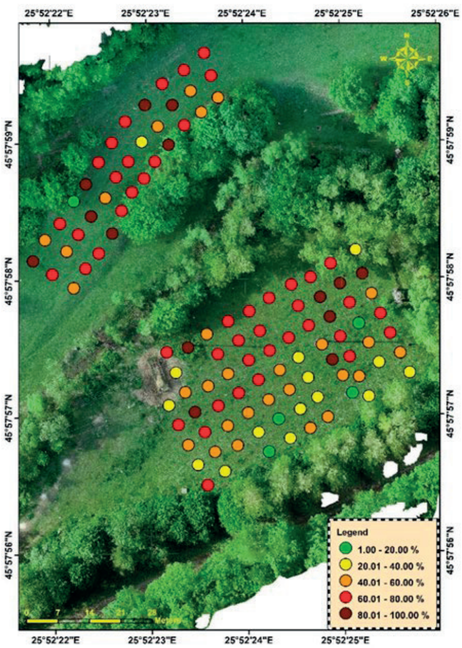

Figure 6. Stressed angiosperms at Bodoc (percentage of total soil coverage)

At Bodoc, most plants found are either stressed or dried. Healthy dicots predominate in the south-western part, which is an area shaded by trees. Healthy monocots seem to be distributed randomly. Increasingly towards the north-west, grows the relative dominance of the monocots over dicots, as well as that of the stressed plants of both classes. The most stressed plants and the most patches of bare ground are found in the upper, North-Western part (Figure 6).

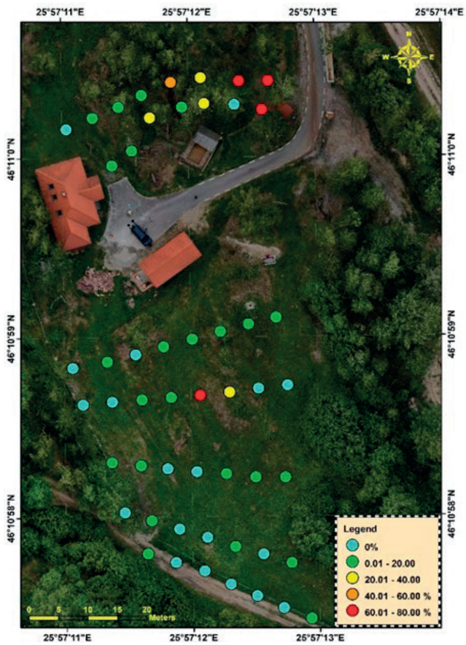

Figure 7. Stressed angiosperms at Băile Lăzărești (percentage of total soil coverage)

For Băile Lăzărești, most plants appear healthy, with a dominance of monocots. The dicots are mostly found in the upper Eastern part, while the monocots are mostly found to the South-West. The most stressed plants are found in the lower, northernmost area, close to the spa facilities and in the areas where terracing works were done (Figure 7).

The relationship between the vegetation survey and the gas measurements in Bodoc and Băile Lăzărești

For Bodoc, we couldn't highlight the relationships between the composition of soil coverage categories and the higher fluxes or concentrations of CH_4, CO_2 and H_2S. The areas where slightly higher concentrations are present aren't significantly different floristically from the neighbouring areas which have smaller fluxes or concentrations.

For Băile Lăzărești, the points with the highest fluxes and concentrations of CO_2 and other gases are associated with the scanty vegetation, with some dried plants and exposed soil. Plants that are present are predominantly monocots (Poaceae), with some dicots (*Trifolium* sp.). The same soil coverage pattern is present on the stretches of soil where have not been recorded higher concentrations of CO_2 or other gases following the measurements. It is not excluded that those points may indicate intermittent gas sources, but which haven't been captured by measurements.

CONCLUSIONS

The survey represents a preliminary assessment of the herbaceous vegetation from the two studied areas, considering its usage as a bioindicator for carbon dioxide emissions. The selection of the coverage categories was made considering those present in the literature.

The floristic composition of the two areas is too different, thus they cannot be compared among themselves. The Bodoc study area is a cattle pasture, and in the case of Băile Lăzărești, there is an ecosystem without mammalian herbivores, but affected anthropically. Băile Lăzărești has plants of colder climate and higher humidity.

The vegetation succession in Bodoc is not related to the variations in CO_2. In Băile Lăzărești area, on stretches with higher CO_2 flux and concentration, the vegetation is partially absent and the soil is exposed, which could be due to gases, anthropic intervention or a mix of both.

As this is a preliminary study, there is a need for more detailed studies to make a better characterization of the vegetation of the area, using a denser sampling grid and, if possible, identifying all species present.

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REFERENCES

Beaubien, S.E., Ciotoli, G., Coombs, P., Dictor, M.C., Kruger, M., Lombardi, S., Pearce, J.M. & West, J.M. (2008). The impact of a naturally occurring CO_2 gas vent on the shallow ecosystem and soil chemistry of a Mediterranean pasture (Latera, Italy). *International Journal of Greenhouse Gas Control 2*(3).

Bergfeld, D., Evans, W.C., Howle, J., & Farrar, C.D. (2006). Carbon dioxide emissions from vegetation-kill zones around the resurgent dome of Long Valley caldera, eastern California, USA. *Journal of Volcanology and Geothermal Research*, *152*(1-2) 140–156.

Biondi, F., & Fessenden, J.E. (1999). Response of lodgepole pine growth to CO_2 degassing at Mammoth Mountain, California. *Ecology*, *80*(7), 2420-2426.

Bouma, T. J., Nielsen, K. L., Eissenstat, D. M. & Lynch, J.P. (1997). Estimating respiration of roots in soil: Interactions with soil CO_2, soil temperature and soil water content. *Plant and Soil*, *195*: 221–232.

Dudu, A.-C., Pavel, A. B., Avram, C., Catianis, I., Iordache, G., Rădulescu, F., Lupașcu, N., Dragoș, A.-G., Dobre, O., Sava, C.S. (2024) Environmental assessment of the area with natural CO_2 emissions in Băile Lăzărești. *Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, 13*.

GBIF (2024) https://www.gbif.org/ accessed September 2024

iNaturalist (2024) https://www.inaturalist.org/, accessed September, 2024.

IPCC (2022). Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.002

IPCC (2023). Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35–115, doi: 10.59327/IPCC/AR6-9789291691647

Keith, C.J., Repasky, K.S., Lawrence, Rick L., Jay, S.C., & Carlsten, J.L. (2009) Monitoring effects of a controlled subsurface carbon dioxide release on vegetation using a hyperspectral imager. *International Journal of Greenhouse Gas Control 3*: 626–632.

Krüger, M., West, J., Frerichs, J., Oppermann, B., Dictor, M.C., Jouliand, C., Jones, D., Coombs, P., Green, K., Pearce, J., May, F., Moller, I. (2009). Ecosystem effects of elevated CO_2 concentrations on microbial populations at a terrestrial CO_2 vent at Laacher See, Germany. *Energy Procedia I*: 19331939.

Krüger, M., Jones, D., Frerichs, J., Oppermann, B. I., West, J., Coombs, P., Green, K., Barlow, T., Lister, R., Shaw, R., Strutt, M., & Moller, I. (2011). Effects of elevated CO_2 concentrations on the vegetation and microbial populations at a terrestrial CO_2 vent at Laacher See, Germany. *International Journal of Greenhouse Gas Control*, 5(4), 1093–1098.

Macek, I., Pfanz, H., Francetik, V., Batic, F., & Vodnik, D. (2005). Root respiration response to high CO_2 concentrations in plants from natural CO_2 springs. *Environmental and Experimental Botany*, *54*(1)

Male, E. J., Pickles, W. L., Silver, E. A., Hoffmann, G. D., Lewicki, J., Apple, M., Repasky, K., & Burton, E. A. (2010). Using hyperspectral plant signatures for CO_2 leak detection during the 2008 ZERT CO_2 sequestration field experiment in Bozeman, Montana. *Environmental Earth Sciences*, 60, 251–261.

McFarland, J. W., Waldrop, M. P., & Haw, M. (2013). Extreme CO_2 disturbance and the resilience of soil microbial communities. *Soil Biology and Biochemistry*, 65, 274–286.

Mutihac, V. (1990). *Structura geologică a teritoriului României*. Ed. Tehnică, București.

Nobel, P. S., & Palta, J. A. (1989). Soil O_2 and CO_2 effects on root respiration of cacti. *Plant and Soil*, 120, 263–271.

Noble, R. R. P., Stalker, L., Wakelin, S. A., Pejcic, B., Leybourne, M. I., Hortle, A. L., & Michael, K. (2012). Biological monitoring for carbon capture and storage - A review and potential future developments. *International Journal of Greenhouse Gas Control*, 10, 520–535.

Oppermann, B. I., Michaelis, W., Blumenberg, M., Frerichs, J., Schulz, H. M., Schippers, A., Beaubien, S. E., & Kruger, M. (2010). Soil microbial community changes as a result of long-term exposure to a natural CO_2 vent. *Geochimica et Cosmochimica Acta*, *74*(9), 2697–2716.

Pfanz, H. (2011). Life in dry, terrestrial mofette areas. *IEAGHG Summary Report of the IEGHG Workshop of Natural Releases of CO_2: Building Knowledge for CO_2 Storage Environmental Impact Assessments*, 25–26.

Pfanz, H., Vodnik, D., Wittmann, C., Aschan, G., Batic, F., Turk, B., & Macek, I. (2007). Photosynthetic performance (CO_2-compensation point, carboxylation efficiency, and net photosynthesis) of timothy grass (Phleum pratense L.) is affected by elevated carbon dioxide in post-volcanic mofette areas. *Environmental and Experimental Botany*, *61*(1), 41–48.

SNAM (2025) Deposit presentation. Specialized data on the deposit (in Romanian). *SNAM (National Society for Mineral Waters)*. Retrieved from: https://snam.ro/images/resurse/prezentare-zacamant-talomir-bodoc.pdf . Accessed 20.03.2025.

Vodnik, D., Kastelec, D., Pfanz, H., Macek, I., & Turk, B. (2006). Small-scale spatial variation in soil CO_2 concentration in a natural carbon dioxide spring and some related plant responses. *Geoderma*, *133*(3–4), 309–319.

West, J.M., Jones, D. G., Annunziatellis, A., Barlow, T. S., Beaubien, S.E., Bond, E., Breward, N., Coombs, P., de Angelis, D., Gardner, A., Gemeni, V., Graziani, S., Green, K.A., Gregory, S., Gwosdz, S., Hannis, S., Kirk, K., Koukouzas, N., Kruger, M., Libertini., S., Lister, T.R., Lombardi, S., Metcalfe, R., Pearce, J.M., Smith, K.L., Steven, M.D., Thatcher, K., Ziogou, F. (2015). Comparison of the impacts of elevated CO_2 soil gas concentrations on selected European terrestrial environments. *International Journal of Greenhouse Gas Control 42*: 357–371.

West, J. M., Pearce, J. M., Coombs, P., Ford, J. R., Scheib, C., Colls, J. J., Smith, K. L., & Steven, M. D. (2009). The impact of controlled injection of CO_2 on the soil ecosystem and chemistry of an English lowland pasture. *Energy Procedia*, 1, 1863–1870.

West, J. M., Pearce, J., Bentham, M., & Maul, P. (2005). "Issue Profile: Environmental issues and the geological storage of CO_2." *European Environment 15*: 250–259.

Ziogou, F., Gemeni, V., N. Koukouzas, N., de Angelis, D., Libertini, S., Beaubien, S. E., Lombardi, S., West, J.M., Jones, D.G., Coombs, P., Barlow, T.S., Gwosdz, S., Kruger, M. (2013). Potential environmental impacts of CO_2 leakage from the study of natural analogue sites in Europe. *Energy Procedia* 37: 3521–3528.