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The use of the GEST method to estimate greenhouse gases uptake or emissions in the absence of data for a raised bog

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Abstract: The paper is designed to present a method to estimate greenhouse gases (GHG) uptake or emissions in the absence of data for peat bog areas (GEST method). The paper presents the research results produced by a project on "Limiting CO_2 emissions via the renaturalisation of peat bogs on the Eastern and Central European Plain". The study area consisted of three peat bogs: Kluki, Ciemińskie Błota, and Wielkie Bagno (Słowiński National Park). The GEST method relies on the estimation of gas emissions on the basis of vegetation and water levels and greenhouse gas coefficients for each given habitat type provided in the research literature. The greenhouse gas balance was calculated for a baseline scenario assuming the lack of human impact and for a scenario taking into account human impact in the form of peat bog preservation. Initial research results indicate that there is a total of 41 GESTs in the studied bog areas and that a reduction in CO_2 emissions of approximately 12% will occur following what is known as renaturalisation by raising the groundwater level, felling of trees across the bog, and making changes in habitats.

Keywords: estimation greenhouse gases (GHG) uptake or emissions, GEST method, habitat, peat bog, water content

INTRODUCTION

Peat bogs are responsible for the storage of greenhouse gases, as well as their emission into the atmosphere. The carbon sink function offered by the peatlands is critical for achieving net-zero global carbon dioxide (CO_2) emission by 2050. It is estimated that peat bogs are capable to capture about 30% of the world's supply of soil organic carbon. According to Kleinen, Brovkin and Munhoven (2016), carbon stored in peatlands globally amounts from $500 \cdot 10^9$ to $615 \cdot 10^9$ Mg. This corresponds to an estimated from 60 to 75% of the carbon content in the atmosphere and 200% of the carbon content of forests. More recent studies have shown (Gumbricht *et al.*, 2017) that the above listed data are most likely underestimated due to the imprecise count of peat bogs in tropical and subtropical regions of the world. According to studies by Panai *et al.* (2017), carbon accumulation was at times larger during wetter and warmer conditions when *Sphagnum* was dominant, and smaller during periods of mixed *Sphagnum* and vascular plant (mainly sedges) growth under drier/unstable hydrological conditions. Currently, there is an increase in the number of dry periods, which is directly related to climate change, and it has caused extreme weather phenomena and required human intervention (Mikhaylov *et al.*, 2020; Lipińska *et al.*, 2023). It is also vital that peat bogs function based on an hydrological equilibrium that may be easily disturbed by drainage works and overall changes in water circulation patterns (Haapalehto *et al.*, 2011). Water drainage dramatically changes the natural system and make peat bogs to dry out, followed by the settling of the entire deposit. An artificial drainage network increases the depth and volatility of the groundwater table in peat soil, which reduces its retention capacity. In addition, the proportions between precipitation and evaporation change. According Taminskas *et al.* (2018), cyclic peatland surface variability is influenced by hydrological conditions that highly depend on climate and/or anthropogenic activity. A low water level decreases peatland surface and increases C emissions into the atmosphere, whereas a high water level leads to an increase of peatland surface and carbon sequestration.

Greenhouse gas emissions are usually calculated based on changes in the supply of carbon in the soil versus direct measurement data – chamber method or centrifuge method (Swenson *et al.*, 2019). The two methods are very accurate but also time-consuming and costly. That is why other methods have developed, which, based on theoretical data, make it possible to determine the amount of greenhouse gas emission or accumulation in peatlands. One such method is GEST (Couwenberg *et al.*, 2011; Hiraishi *et al.*, 2013; Haxtema, 2014). The study in this paper is designed to present a measurement method for greenhouse gas emissions produced by peat bogs. The method is called GEST or the greenhouse gas emission site type. The basic set of data consists of information about hydrologic and habitat conditions. This method is much easier to use and it is much cheaper. The present paper also provides initial research results generated under a research project titled: "Limiting CO_2 emissions via the renaturalisation of peat bogs on the Eastern and Central European Plain". The project partners responsible for the Polish part of the project are members of the Environmentalists Club (Pol. Klub Przyrodników). The project focused on actions designed to restore water composition to degraded peat bogs in Lithuania, Latvia, Estonia, Germany, and Poland. The purpose of the project was to return the bogs to their natural function of carbon storage, which is a goal consistent with the European Union's climate and energy policy.

STUDY AREA

The study area consisted of three peat bogs: Kluki (530 ha), Ciemińskie Błota (150 ha), Wielkie Bagno (630 ha). All three bogs are located in the southern part of Słowiński National Park (SNP) (Fig. 1). The bogs are currently degraded to a substantial extent and are covered with woodland-type vegetation. However, some bog areas still produce peat. The climate in the study area may be described as temperate. The annual precipitation average in 1986–2005 at the Łeba gauging site is 661 mm. The precipitation minimum is noted in April, while the maximum in September.

All the bogs feature a well-developed network of drainage ditches and canals. In addition to circumferential ditches, there are also ditches that cross the big east to west and north to south. Some ditches are at the overgrowth stage or started to disappear. Parts of the studied bogs are subject to flooding in the wet season, whereby water stagnates across open surfaces. The groundwater level tends to be low across large parts of the bogs due to drainage practices.

MATERIAL AND METHODS

The research work focused on the implementation of GEST method practices which rely on the estimation of selected greenhouse gas emissions based on vegetation and water content

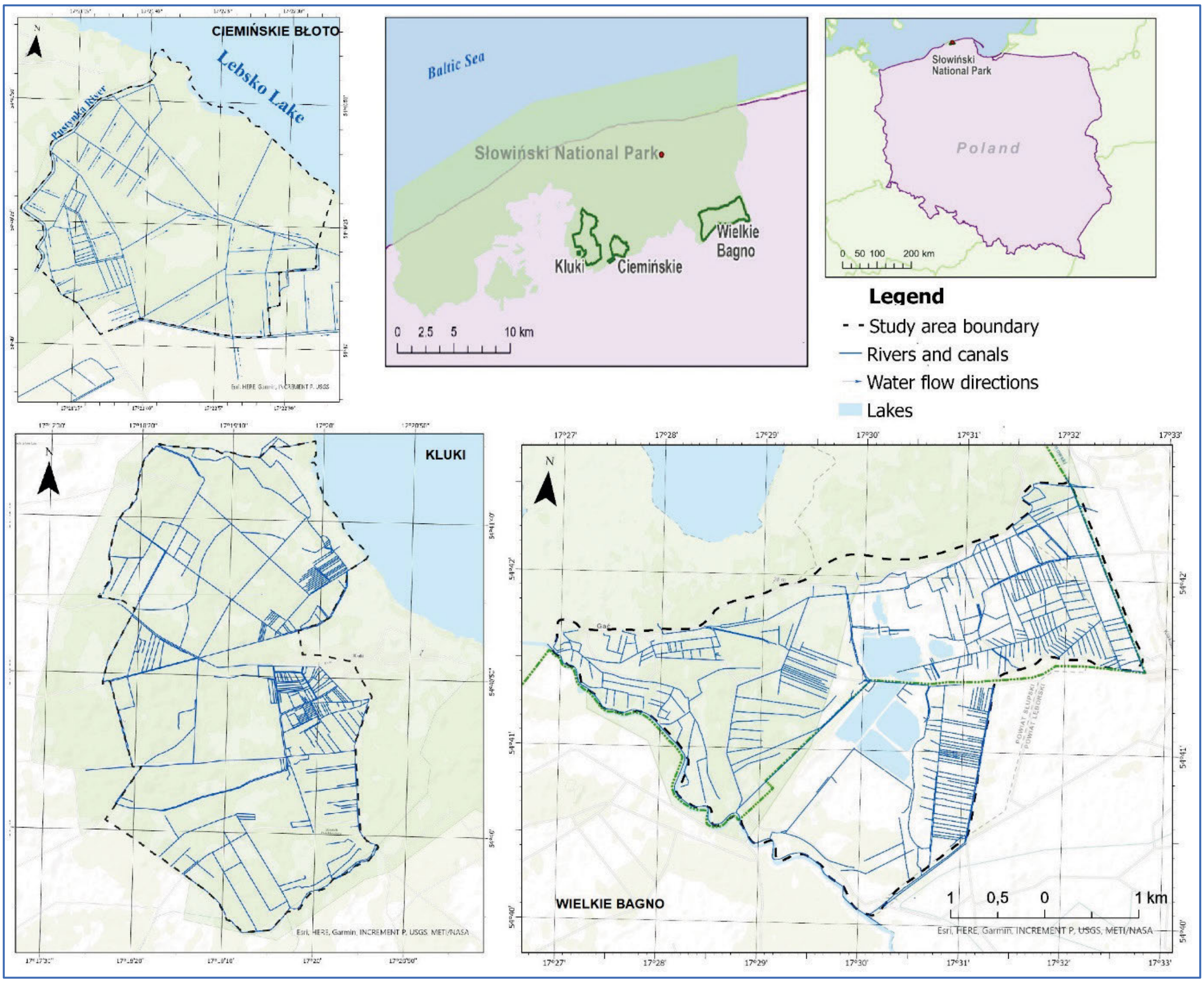

Fig. 1. Study area; source: own elaboration

data, as well as greenhouse gas balance coefficients provided in the literature for selected types of habitats (Couwenberg *et al*., 2011; Haxtema, 2014). This approach is similar to that employed to estimate greenhouse gas balance values at a single country level (Hiraishi *et al*., 2013). However, the GEST method is more detailed in terms of types of habitats and relies on three basic principles:

1) greenhouse gas emissions are substantially relative to the average, annual groundwater level;
2) groundwater level may be determined based on the presence or absence of special groups of plant species;
3) given a similar hydrology of a study area, local vegetation may be classified as a collection of specific types of greenhouse gas emissions.

Hence, the GEST method relies on the estimation of the greenhouse gas balance using dynamics for plant life and water circulation patterns assessed for a variety of scenarios, such as a basic scenario assuming the lack of action, and a scenario assuming "preservation" actions to be taken to save a bog. In effect, the GEST method allows to estimate GHG uptake or emissions in the absence of data at a given site, as well as to determine whether water retention and hydrologic conditions present in various habitats affect rates of gas emission and storage.

Work using the GEST method begins with selecting vegetation that is homogeneous in terms of physiognomy, structure, ecology, and floristics. The next step consists of vegetation mapping using the Braun-Blanquet method in order to select characteristic or dominant groups of species and assign to them certain hydrologic and chemical characteristics associated with their place of occurrence. This includes the groundwater level, trophic state, and pH. While calculations were important, so was fieldwork. The purpose of fieldwork was to collect representative soil samples in order to determine the C to N ratio, pH in the upper layer of peat (depth: 0–30 cm), and any fluctuations in groundwater levels. A monitoring network was established in order to monitor groundwater levels using 63 piezometers and automated gauges, as well as 17 water level gauges to measure the water level on canals and ditches.

Greenhouse gas emissions calculations for non-woodland GEST areas were performed based on CO_2 per hectare. The result was multiplied by a constant determined for each GEST type (Herrmann *et al*., 2018). For areas where the quantity of greenhouse gas emissions cannot be clearly determined, water level measurements were used instead as an additional set of data designed to help to assess greenhouse gas emissions. In forested GEST areas, the estimation of emissions, and in particular CO_2, was performed using a combination of data on gas emissions for open unused peat bogs with similar hydrologic characteristics and growth rates for wood biomass. The emission of greenhouse gases is also estimated herein for two specific scenarios: (1) with carbon stored in forest biomass, (2) without carbon stored in forest biomass.

As noted earlier, greenhouse gas emission calculations were performed for two distinct scenarios: (1) no intervention designed to increase the water content in peat bogs or the basic scenario, (2) with intervention designed to increase groundwater and biotic state of peat bogs or the renaturalisation scenario. The basic scenario assumes that current emissions in the bog will remain relatively constant over a period of 30 years. Emissions will not be reduced, but emission calculations with and without forest biomass (known as sequestration from trees) will be performed, given that the area is wooded. Additionally, it was assumed that tree stand produce fewer emission due to unstable hydrologic conditions. In the scenario where peat bogs become renaturalised, current emissions in the study area will change over a period of 30 years due to the renaturalisation process. In spite of this, the bogs will remain forested to some extent. Hence, emissions estimates will be produced with and without forest present. This scenario does not assume any major changes in vegetation. A change in vegetation in the direction of peat formation will occur gradually due to natural processes associated with increased water level driven by the presence of ditch barriers. The new water conditions in the study area will trigger a change in vegetation, which will be used to recalculate emission levels given a new GEST assumption.

RESEARCH RESULTS

Initial research results indicate that the peat bogs studied are home to a variable number of GESTs, as determined on the basis of habitat information and water circulation patterns. In the Kluki peat bog, a total of 11 different GESTs were identified, of which six were open bogs, four woodland-type bogs, and one was mixed-type. Then, in the Ciemińskie Błota bog, a total of 10 different GESTs were identified, of which six were open bogs and four were woodland-type bogs. Finally, in the Wielkie Bagno peat bog, a total of 20 different GESTs were identified, of which 16 were open bogs and four were woodland-type bogs.

These results were then used to calculate CO_2 emissions in the two scenarios discussed in this paper. Table S1 summarises greenhouse gas emission estimates produced by using the GEST method in both studied scenarios and illustrates the potential for reduction.

Initial research results show that once renaturalisation work is completed in the study area, a reduction in CO_2 emissions occur from 18,802.8 Mg CO_2-eq. per year to 16,507.23 Mg CO_2-eq. per year which translates into a reduction of 12.21%. Renaturalisation works included tree felling across the studied peat bogs, raising the groundwater level, and changes in habitats. Damage to the ditches were particularly important, as they raised the groundwater level. As a result, there was an increase in the amount of stagnant water on the surface of the peatlands. An example of this can be the extremely dry period in 2021. Then, in the Ciemińskie Błota bog without damming (modelling), the flooded area of the bog accounted for only 2% of the total, while with damming (measurements), the flooded area it was 8% (Fig. 2).

The average reduction for all of the bogs studied in the project (German, Polish, Lithuanian, Estonian, Latvian bogs) was about 25%. Hence, the 12.21% value obtained herein was much smaller than the average for the five European countries taking part in the research project.

In order to determine whether the results obtained using the GEST method were close to the values obtained directly in the field, results were compared. It was possible thanks to our own measurements performed in 2018 using the chamber method (Fig. 3). After converting the results in the year concerned for the entire bog, the average CO_2 emission was 16,338.7 Mg CO_2-eq.

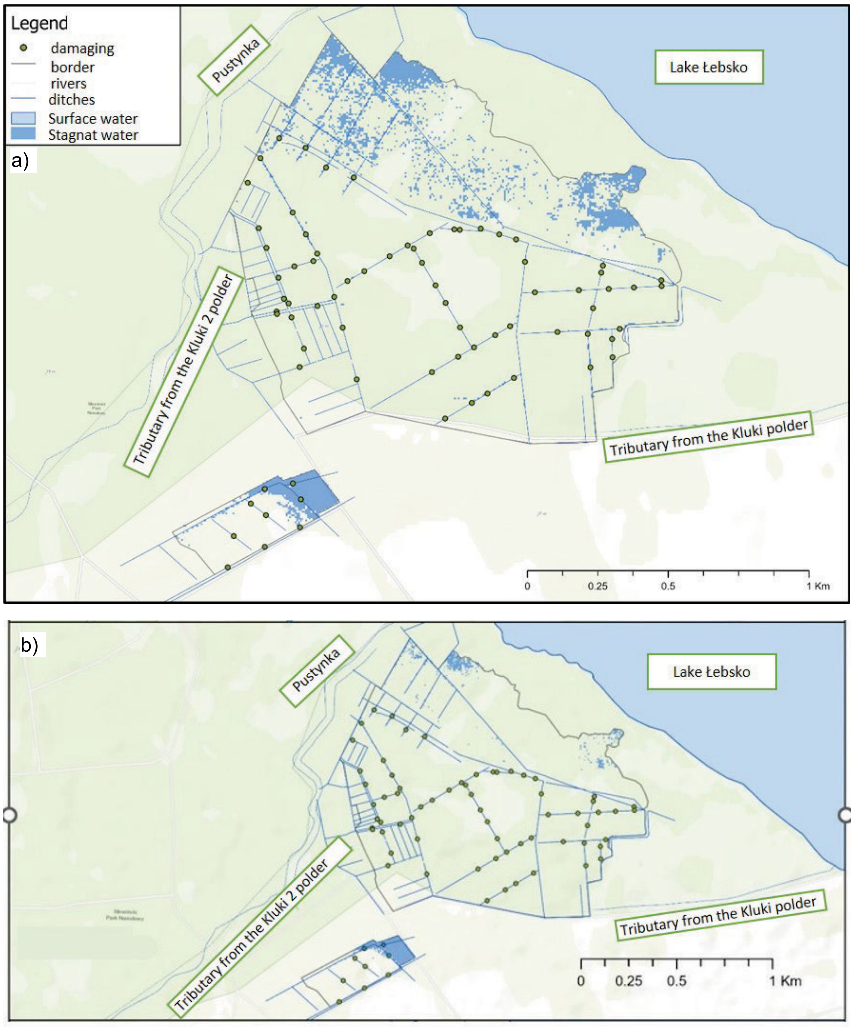

Fig. 2. Places of water stagnation in the peat bog in an extremely dry year (2021) a) with dams installed, b) without dams; source: own study

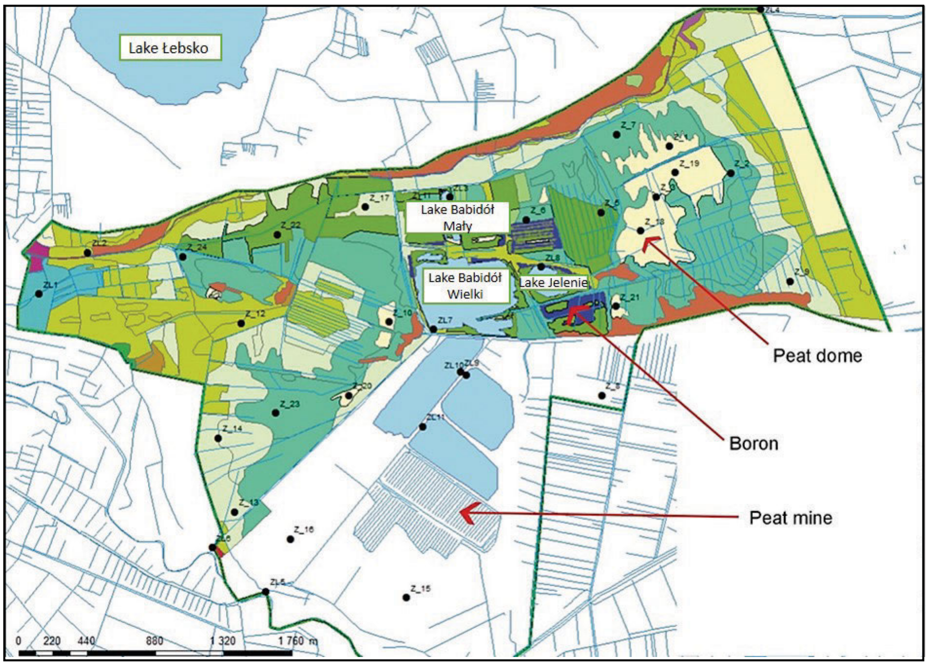

Fig. 3. Location of CO_2 emission points by the chamber method in Wielkie Bagno bog; source: own elaboration

per year. Comparing this result with the result obtained by the GEST method, it is lower by 2,464.1 Mg CO_2-eq. per year, which shows an overstatement of the result by about 13% using the GEST method. It should be remembered that these were annual (estimated) measurements that should be continued in order to compare them with the GEST method.

DISCUSSION

In connection with the functions they perform in the environment, it is very important to protect peat bogs. They are subject to progressive degradation due to changes in hydrological conditions (Yang *et al.*, 2018) and climate change (Hopple *et al.*, 2020; Ratcliffe *et al.*, 2020).

The purpose of the present paper is to show a method for the estimation of greenhouse gas emission in peat bog areas (GEST method) in the absence of measurement data, and to show what types of changes are possible in these areas through renaturalisation, especially the increase in water levels. Based on the results obtained, it can be concluded that the method is reliable and promising, however, it also has weaknesses that need to be improved. Naturally, the project described is not comparable to the type of emissions scale discussed in Kleinen, Brovkin and Munhoven (2016). The aim of the study was to demonstrate a concept and initiate a broader discussion on peat bogs as environmental protection areas, as well as functional elements of the global ecosystem. The surface area of peat bogs in Poland is estimated to be 1,211,000 ha. According to Joosten, Tapio-Biström and Tol (eds.) (2012), the estimated annual emissions from all degraded peat bogs in Poland is 25.8 mln Mg of CO_2 or 7.5% of the total emissions produced by the burning of fossil fuels. This places Poland in the top 10 of worldwide emitters of CO_2 from degraded peat bogs. This translates into a substantial contribution to the global balance of greenhouse gas emissions. For this reason, post-extraction recultivation is important to balance greenhouse gas emissions. It suggests that innovative methods of restoring peat-forming vegetation to bogs would improve the greenhouse gas balance and increase the environmental value of post-extraction pits. One of ways to bring back peat is hydrotechnical improvement designed to increase the groundwater level in the bog. Peatland chemical, physical and biological properties change over time in response to alterations in the long-term water table level. Such changes complicate ability to predict the response of peatland carbon stocks to sustained drying (Ratcliffe *et al.*, 2020). According to Premrov *et al.* (2021) the ability of peatlands to remove and store atmospheric carbon depends on the drainage characteristics.

Instead of just flooding the bog, it is important to establish an appropriate base level of groundwater. Good conditions for peat formation include a groundwater level of 1 to 22 cm below the surface of the bog (Tuittila, Vasander and Laine, 2004), and according to Taminskas *et al.* (2018) for Lithuanian peat bogs this value is 25–30 cm. Shallow water tables protect peatlands and their important carbon stocks from aerobic decomposition (Morris *et al.*, 2019). On the other hand, Lamentowicz *et al.* (2019) found that a critical level for proper bog functioning is at 11.7 cm below the bog surface. Below that level, a bog stops accumulating carbon and begins to emit it. Unfortunately, groundwater fluctuations were very high for the bogs analysed. At the majority of points, the maximum water level did not reach the required value. On Wielkie Bagno, fluctuations ranged from 43 to 113 cm below ground level. For the Kluki peatbog, the fluctuations varied from 26 cm above ground level to 126 cm below ground level, and for Ciemińskie Błota from 5 cm above ground level to 80 cm below ground level. The fluctuations are very high if compared to those from Estonian peat bogs, where the groundwater level amplitude was 3−22 cm in the bog domes and 3−14 cm in the forested lagg zones (Lode, Küttim and Kiivit, 2017).

It should be remembered that the degradation of groundwater-dependent ecosystems has to be counteracted and restoration is needed. However, ecological responses to restoration are largely unknown (Lehosmaa *et al.*, 2017). An example would be two renaturalised Irish peat bogs, where in one case CO_2 absorption (−49 ±66 g $C \cdot m^{-2} \cdot y^{-1}$) was observed, and in the other CO_2 emission (0.66 ±168 g $C \cdot m^{-2} \cdot y^{-1}$) (Renou-Wilson *et al.*, 2019).

Summarising, ecosystem restoration and, in particular, peatland restoration are considered a promising greenhouse gas mitigation strategy to move towards net zero emissions (Glenk *et al.*, 2021). According Martens *et al.* (2021) restoration of peatlands should be based on the use of rewetted peatlands because of the potential to reduce GHG emissions by stopping soil decomposition. Such a method was used in the area of the peat bogs studied.

CONCLUSION

Although the use of the GEST method for estimating greenhouse gas emissions appears to be an effective method, it does require familiarity with a given study area in terms of its biology and hydrology. The first calculations for Polish peat bogs show that the increase in water volumes have yielded positive results – approx. 12% decrease in CO_2 emission. This is a low value compared with the average for peat bogs from Lithuania, Latvia, Estonia or Germany (up to 25%). However, even a small reduction yields hope for the future. It is crucial to understand that these are initial results which need to be evaluated further. They should be supported by periodic field tests, for example using the chamber method. Yet, they do point to a fairly positive trend of CO_2 emission reduction.

It is also important to critically assess the method used in the study. First, the data in the GEST catalogue reflect only a few measurements in the field, especially for woodland types. Second, there are no data on emissions and the data used were transferred from similar types.

Comparing the data obtained from this method with the data provided by measurements, it can be noticed that the results are exaggerated in the GEST method. However, considering a short measurement period, one should not draw too far-reaching conclusions. Nevertheless, it seems to be a good method that could partially replace field measurements. It is also important to note that the calculations based on forest biomass relative to the carbon balance and the tree sequestration index are not the same for all regions.

In spite of a variety of shortcomings, the GEST method appears to have potential, and it is sensible to continue and improve this research approach.

SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at https://www.jwld.pl/files/Supplementary_material_Cieslinski.pdf.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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