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Climatic Factors Affecting Wild Mushroom Foraging in Central Europe

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Abstract: Wild mushroom foraging has a long tradition in Central European countries. Protein from wild mushrooms is an important part of Central European diets and has served historically as a meat protein substitute. In view of climate change, this protein source may become scarce. This study investigated the effects of temperature and precipitation on wild mushrooms using the Dickey–Fuller test and ordinary least squares method. The results from the Czech Republic show that when the precipitation change was increased by one unit, the change in the amount of foraged mushrooms went up by twenty-seven tons, while the factor of temperature was found to be statistically insignificant. This indicates that with a decline in precipitation, possibly due to climate change, there will be a decline in the amount of wild mushrooms foraged.

Keywords: protein; meat substitute; wild mushrooms; Central European forest; climate change

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1. Introduction

European forests have provided the population with raw materials and fruits for centuries. At the same time, these forests have been shaped by human activity. Only approximately 2% of European forests are considered to be undisturbed by humans. European forests provide wild mushrooms [1] in addition to wood and wild fruits such as blueberries, raspberries, and cranberries. Mushrooms from forests are a highly valued source of food for humans, as they have been used as a substitute protein source (meat for the poor) or as a staple food in times of famine and, currently, as a supplement to a varied diet [2–4]. The benefits associated with the consumption of mushrooms are extremely important. Wild mushrooms are a source of fibre, proteins, vitamins, and minerals. Some mushrooms are beneficial for their medicinal properties or dietary properties, such as their content of cholesterol-lowering substances, improving diabetes conditions, and even cancer prevention effects [4,5]. Mushroom picking is considered an important recreational activity in Europe. Most mushrooms are not collected for commercial purposes but for home consumption. Especially among the inhabitants of Central Europe, mushroom picking is a national custom and a very widespread hobby. Mushrooms are an integral part of Central Europeans' diets. Moreover, mushroom foraging brings other benefits, such as healthy movement in the forest environment [6].

Forest ecosystems are an essential part of nature, but their protection is necessary, as well as the protection and research of wild fruits and mushrooms. Forests have adapted over the ages to the European environment, but today they are threatened by climate change and the increasing frequency of extreme weather events such as drought, wind, and torrential rainfall. Climate change has a major impact on wild mushroom production [1]. Many studies deal with the impacts of climate change, specifically the amount of precipitation, on mushrooms in various European locations such as Finland [7], Norway [8], and Spain [9,10]. Only a limited amount of research is focused on the area of Central Europe [10,11]. Little research is known that quantifies the impacts of precipitation and temperature on the quantity of foraged mushrooms in Central Europe. It is necessary to investigate precipitation and temperature as some of the factors that may influence the amount of mushrooms foraged every year. This manuscript is organized into several sections, starting with the conceptual framework and a literature review, followed by the methodology, results, and discussion, and finishing with conclusions.

2. Conceptual Framework and Literature Review

2.1. Forests of Central Europe

Wild mushrooms are mainly found in forests [12]. Most of Central Europe's forest areas are considered to be semi-natural forests. The structures and species compositions have changed significantly from the original natural forests. Table 1 shows the total areas and forested areas in Central European countries.

Table 1. Total area, forested area, and share of forest in selected Central European countries [13].

Country	Land Area *	Forest Area *	% of Land Area
Czech Republic	7721	2677	34.7
Austria	83,252	4029	48.8
Germany	34,886	11,419	32.7
Slovakia	4808	1946	40.5
Poland	30,619	9483	31.0

* Thousands of hectares.

In particular, tree species composition is shaped and maintained by forest management, which traditionally favours species with higher commercial use. The dominant tree species are determined by the cultivation systems based on regional forestry traditions and on local climatic and natural conditions [12]. Climate change has increased pressure on forests and threatened their stability and biodiversity. Adverse changes need to be optimized using forestry practices [14].

2.2. Climate Change

The forests of Central Europe, in general, have recently suffered due to climate change [15,16]. This is mainly manifested in more frequent episodes of drought. An important indicator of forest change is the overall composition of species, not only in terms of woody and herbaceous plants but also in the quantity and types of mushrooms. The species composition depends on the total amount of precipitation and its distribution during the year. In the mild climate zone, in which the forests of the area of interest lie, mesophytic plant species and fungi dominate in wet periods, while their predominance fades in dry periods. Trees show faster growth in wet periods. In the territory of Central Europe, models show an increase in the risk of drought in the future, most likely in summer and autumn [15]. Many species habitats in forest trees are defined climatically. A decrease in precipitation may have adverse effects on forests as well as mushrooms and berries [15]. In addition, precipitation may influence forest biodiversity [15].

2.3. Mushrooms of European Forests

Forest mushrooms are macrofungi with a distinct fruiting body, which can be collected by hand and can be seen with the naked eye. In addition to edible mushrooms, which have been used since ancient times for consumption and as spices, there are other mushroom species, which are used in medicine or are poisonous, and their collection can cause health risks or even death [17]. Central Europe is rich in various types of mushrooms that grow both in pastures and meadows, as well as in forests [18]. Forest mushrooms require symbiosis with plant roots, and their species depend on the type of forest [19]. The production of fruiting bodies in forest mushrooms is still not well understood, because many factors affect the occurrence of mushrooms in nature. Weather conditions play a key role but do not fully explain the growth and productivity of wild mushrooms [18]. Mycorrhizal fungi are dependent on photosynthetically fixed carbon produced by their associated trees, and the physiological state of host trees can generally affect fungal growth [18]. The European tradition of mushroom foraging is very significant and dates back to the Palaeolithic Age [20]. Mushrooms are collected mainly for personal consumption. A detailed study of the mushroom tradition and the linguistic diversity of mushroom local names suggests that mushrooms played an important role as food for poor people in times of famine and were preserved in local gastronomic posts [20]. Mushrooms are rich in protein, as presented in Table 2.

Table 2. Protein in some edible mushrooms (as % in dry matter) [21].

Name (Latin)	Protein (% in Dry Matter)
Boletus edulis	26.5
Agaricus arvensis	56.3
Cantharellus cibarius	53.7
Lactarius deliciosus	29.8
Morchella esculenta	14.2

The data in Table 2 indicate that mushrooms have relatively high protein contents compared with other non-animal protein sources [21].

According to Vacik et al. [20], forest mushrooms represent an important supplement to the diet of many European residents. Local cuisines incorporate mushrooms, and their sale represents a significant additional income in the poorer rural areas of some countries. The foraging and sale of mushrooms is widespread in Poland, Ukraine, and other countries. The Czech Republic can be considered a "mushroom superpower", wherein mushrooms are traditionally collected for the local cuisine, and [22] states that the most important market commodities are represented by chanterelles and porcini mushrooms. In Austria and Germany, mushroom picking is more of a recreational activity for personal consumption [20]. In European countries, mushroom lovers are often organized in mycological societies for the exchange and sharing of taxonomic knowledge [23]. Information on the various mycological societies in Europe can be found on the homepage of the European Mycological Association [23]. Mushroom incidence is also affected by foraging itself. Excessive trampling of forest soil is not beneficial to fungi, as it damages the mushroom bed [24]. Moreover, some of the rare and endangered species are listed in the so-called Red List in the Czech Republic, and some mushroom-producing locations are protected as mycologically valuable [25]. Therefore, mushroom foraging should be subject to regulation.

2.4. Wild Mushrooms and Climate Change

Climate change causes extreme weather fluctuations, especially more pronounced and frequent droughts and uneven precipitation that often comes in torrents. These causes are behind changes in the species compositions of forests, the spread of pests, and changes in the herbaceous layer of forests [15,16]. They can also affect the production and species composition of mushrooms. The activity of mycelia decreases, cold-loving types of fungi retreat, and heat-loving and dry-loving fungi spread. In years when there is no rain in the months with the highest activity of mushroom growth, there is a decrease in mushroom production. The dates for mushroom picking are moving to spring, and the mushroom season is longer in autumn. The amount of mushrooms in forests is also affected by the human factor, such that if the harvest is small, fruiting bodies are collected, and they cannot reproduce with spores. However, based on numerous studies, precipitation seems to be the most important factor [8–10,24].

One of the prominent countries of Central Europe regarding mushroom foraging is the Czech Republic [22]. Data for mushroom foraging in the Czech Republic between 1994 and 2021 are presented in Figure 1 [26]. These are the latest publicly available data.

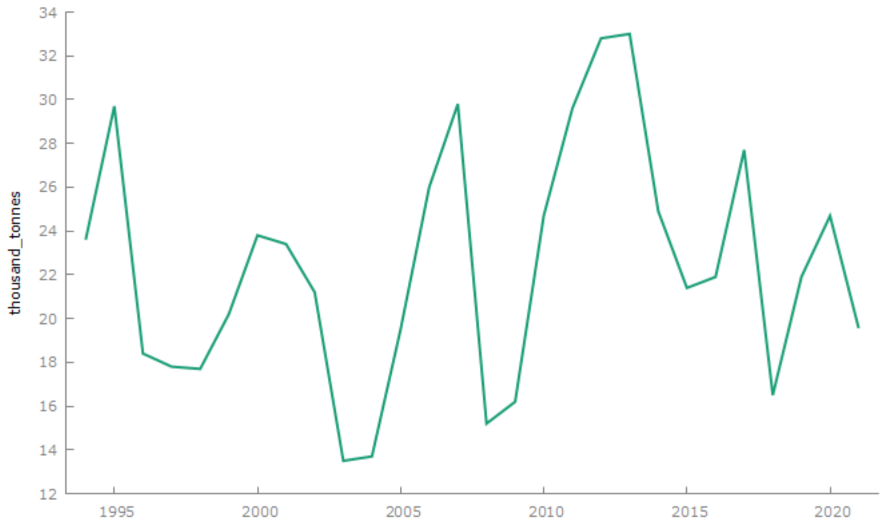

Figure 1. Amount of wild mushrooms harvested in Czech forests between 1994 and 2021.

The data suggest a relatively stable, yet fluctuating amount of wild mushrooms foraged every year. There are many socioeconomic, regional, as well climatic conditions that may explain this fluctuation [7,27]. It is important to investigate the factors that may influence the amount of foraged wild mushrooms.

As already mentioned, climate plays an important role in wild mushroom availability as they are most likely sensitive to temperature and precipitation [10,15]. Recently, precipitation in the territory of the Czech Republic tends to be more of a torrential nature [15]. Furthermore, precipitation is limited mostly to certain areas [15]. Thus, the forests of the Czech Republic capture less water, because during torrential rainfall the water flows away and is not absorbed. Generally, the pan-European trend is a shift towards a warmer climate. Rainfall will be unevenly distributed with more frequent torrential rains and will come in the growing season. Moreover, there is a higher probability of diminished winter snow cover.

It is possible to expect extremity in climatic phenomena, namely, drought, torrential rains and storms, and windy events. In general, this climate trend will have an effect not only on trees and the plant layer of forests but also on fungi [16,28].

Temperature (expressed in degrees Celsius), precipitation (expressed in millimetres), and amount of mushrooms foraged are illustrated together in Figure 2 [29,30].

While the amount of foraged wild mushrooms seems to be related to precipitation based on the graphical representation, a rigorous investigation must be conducted to determine to what extent temperature and climate influence the number of mushrooms foraged in Czech forests.

This will help to test the existence of this relationship. Furthermore, this investigation will help to quantify this relationship. Similar studies that investigated how climate conditions affect wild mushroom incidence were conducted in Northern Europe, specifically, Finland and Norway [8], Austria [10], the United Kingdom [10], and Spain [9] These studies, however, do not provide a quantitative expression of this relationship.

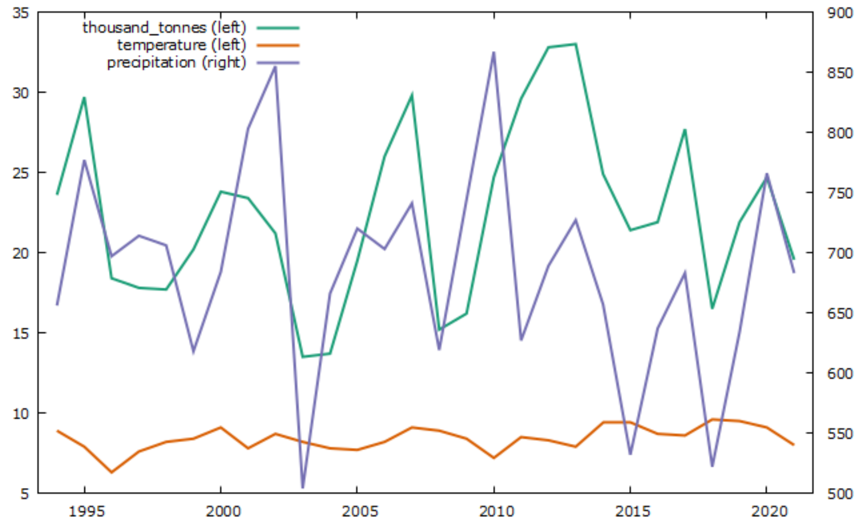

Figure 2. Precipitation, temperature, and amount of wild mushrooms foraged in Czech forests between 1994 and 2021.

3. Materials and Methods

3.1. Questionnaire Data, Temperature, and Precipitation Data

The data regarding wild mushroom foraging in the Czech Republic were obtained from reports published by the Ministry of Agriculture of the Czech Republic [26]. The reports contain summary information on the state of forests and forest management in the Czech Republic. The mushroom harvest data were published in the "Non-marketed Forest Production and Visits of Forest" section. The original research worked with the same methodology every year. The data collection was performed within the so-called omnibus survey, a quantitative research method in which the data from many subjects are collected during the same interview. The subjects were asked by trained interviewers with F2F (face-to-face) questioning. The process was realised through the CAPI (Computer Aided Personal Interview) method with the usage of notebooks. The total number of conducted interviews was around one thousand every year (1994–2021). The average number of respondents was 1019, with the lowest value of 1000 in 2013 and the highest value of 1035 in 2014. In other years, the number of interviews varied within this range. A representative sample was achieved using quota sampling, which considered the following factors: gender, age, education, size of the municipality of permanent residence, and size of the region [26].

Data about climate were derived from publicly available statistics from the Czech hydrometeorological institute [29,30]. The data about temperature and precipitation showed large differences in rainfall over the past thirty years. Regarding the units of measurement, the temperature was reported as the average annual temperature in degrees Celsius and the precipitation as the average annual precipitation in millimetres.

3.2. Stationarity Test

According to Kočenda [31], one of the critical issues in determining the relationships between time series is the test for the nature of the time series, i.e., their (non)stationarity, also called unit root tests. The Dickey–Fuller test is among the most common unit root tests. There are two main versions of this test: the simple version, usually called just the "Dickey-Fuller test", and the augmented version.

The simple version of the Dickey–Fuller test is based on three types of equations depending on whether neither intercept nor trend are included, only intercept is included, or both intercept and trend are included. Because it was important for this study to test the level stationarity and the trend stationarity, the following two equations were used:

$$\Delta y_t = \mu + \gamma y_{t-1} + \varepsilon_t \quad (1)$$

$$\Delta y_t = \mu + \beta t + \gamma y_{t-1} + \varepsilon_t \quad (2)$$

The first equation (Equation (1)) is used to test the level stationarity, and the second equation (Equation (2)) tests the trend stationarity. The models are subsequently tested via the *t*-statistic using the following formula (Equation (3)):

$$t_{DF} = \frac{\hat{\gamma}}{SE(\hat{\gamma})} \quad (3)$$

The null hypothesis is set as $\gamma = 0$, meaning it is about a unit root time series. The alternative hypothesis assumes that $\gamma < 0$, in other words, a stationary time series.

The augmented version of the test is analogous to the simple model. The advantage of the augmented model is that it enables testing of the unit root in the autoregressive processes of the higher order. The basic equations are based on the simple ones. However, they are completed by lagged differences.

$$\Delta y_t = \mu + \gamma y_{t-1} + \sum_{i=1}^{K} \rho_i \Delta y_{t-i} + \varepsilon_t \quad (4)$$

$$\Delta y_t = \mu + \beta t + \gamma y_{t-1} + \sum_{i=1}^{K} \rho_i \Delta y_{t-i} + \varepsilon_t \quad (5)$$

Again, the appropriate equation is chosen depending on whether neither intercept nor trend are included, only intercept is included, or both intercept and trend are included. As the aim was to test the level stationarity and the trend stationarity, analogous models to the simple ones were chosen (Equations (4) and (5)). The formulation of the null and alternative hypotheses, as well as the process of testing via the t-statistics, stay the same, as in the example of the simple Dickey–Fuller test.

3.3. Ordinary Least Squares

If the time series are stationary or made stationary by differencing and de-trending, then the ordinary least squares method can be used to determine the relationships between the time series, also called regression analysis [32].

The theoretical regression function represents the model of the dependent variable, which is the amount of foraged mushrooms with systematic changes in the independent variables, in our case, precipitation and temperature. The empirical regression function is considered to be an estimate of the ideal model. For every single observation, the following formula applies:

$$y_i = \eta_i + \varepsilon_i \quad (6)$$

In this equation (Equation (6)), η represents the theoretical regression function. y_i is the value of the dependent variable, and ε_i is the deviation of y_i from η_i. The regression function contains the regression parameters denoted by the Greek letter β. Therefore, the term η_i can be expressed as:

$$\eta_i = (x_i, \beta_0, \beta_1, \ldots, \beta_p) \quad (7)$$

The existence of error terms leads to the fact that the linear regression parameters must be calculated to minimize the deviations from the model. Because the deviations are measured in squares, the ordinary least squares (OLS) method is appropriate. It is based on the following condition:

$$Q = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} (y_i - \eta_i)^2 \ldots min \quad (8)$$

The condition can be rewritten by substituting the term η_i for the function itself:

$$Q = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} \{y_i - f(x_i, \beta_0, \beta_1, \ldots, \beta_p)\}^2 \ldots min \quad (9)$$

The most common type of regression function is linear regression, which was also applied in this study.

4. Results and Discussion

Before the relationships between the variables can be examined, it is necessary to look at some descriptive statistics of the analysed time series, specifically the dependent variable. This is illustrated in the Table 3.

Table 3. Descriptive statistics for the variable "harvest" (28 observations in 1994–2021).

Mean	Median	Minimum	Maximum
22.441	21.9	13.5	33

The results suggest that there is a large range in the time series, as the minimum differs considerably from the maximum. The mean of the time series is relatively close to the median, which suggests that the data have a symmetrical distribution.

Based on the methodology, the stationarity of the time series was examined. This was conducted using the augmented Dickey–Fuller test for all variables. The results are presented in Table 4.

Table 4. Augmented Dickey–Fuller test for variable harvest, temperature, and precipitation.

Variable	Model	τ-Statistic	p-Value
Harvest	With intercept	−3.81324	0.002787
	With intercept and trend	−4.14468	0.005344
Temperature	With intercept	−3.37643	0.01182
	With intercept and trend	−4.58899	0.001027
Precipitation	With intercept	−4.72155	<0.0001
	With intercept and trend	−5.22828	<0.0001

The results of the augmented Dickey–Fuller test suggest that only the amount of foraged wild mushrooms, precipitation, and temperature are stationary, and, hence, it is possible to explain the amount of foraged mushrooms by the amount of precipitation and temperature.

Therefore, a linear regression was performed to examine the relationship between these two time series. Firstly, all variables were put into a regression model wherein the temperature was statistically insignificant. Therefore, a model with the amount of foraged mushrooms and precipitation was estimated. The results of the linear regression are presented in Table 5. For the sake of interpretation, both time series were differenced.

Table 5. Linear regression of precipitation change against foraged mushrooms change.

Model	t-Statistic	p-Value
$\hat{y}_i = -0.176699 + 0.0270694 \cdot x_i$	3.372	0.0024

Significance level $\alpha = 0.05$.

The results show that when the change in precipitation increased by one unit, the change in the amount of foraged mushrooms increased by twenty-seven tons.

The results indicate that precipitation plays a crucial role in the growth and development of wild mushrooms in the region of the Czech Republic. Precipitation provides the necessary moisture for the fungus to grow and develop its fruiting body, which is the edible part of the mushroom. It is also related to the fact that wild mushrooms are typically found in areas with high humidity and adequate rainfall, and their growth is strongly influenced by the amount of precipitation received [8,9]. Also, the fruiting body of the mushroom is composed of the cap and the stem, and its size and shape are influenced by the amount of moisture available. When the soil is dry, the fruiting body will be smaller and will not grow as tall [8,9]. On the other hand, when the soil is moist, the fruiting body will be larger and more robust. The cap will be more rounded and the stem will be thicker, allowing the mushroom to better withstand environmental stressors such as wind and rain [8,9].

Our results are in line with the results of other studies, e.g., [18,33]. According to Heegaard et al., an increase in precipitation does cause a higher yield of forest mushrooms, but other factors also come into play, such as wind and temperature [33]. Temperature primarily determines the onset of growth in spring, which has been more frequent in recent years, and the end of the growing season for the main mushroom species in autumn [18].

While our study does not provide evidence of the effect of temperature on mushroom foraging, according to Brazdil et al. [15] and Lovric et al. [6], substantial upward temperature fluctuations during the growing season primarily affect evaporation and are therefore the cause of drought, which is not beneficial to fungi. In the future, the occurrence of non-native thermophilic species can be expected in Central Europe and the Czech Republic [6,15]. Moberg et al. [23] mention that since the beginning of the 21st century, winters in Europe have been getting warmer, and the proportion of precipitation in the form of snow has decreased and may affect the future growth of wild mushrooms, which is also confirmed by our study. Other studies also confirm that mushroom yields are dependent on climatic conditions, especially rainfall [8–10,24]. Tahvanainen et al. [7] state that the different stratification of precipitation during the year affects both the amount and the types of fungi. Rainfall in August has an effect on porcini mushrooms, and rainfall in June and July affects the production of chanterelles. Their estimates are consistent with ours but imply a lower total amount of foraged mushrooms in Finland. Generally, the study confirms that high rainfall affects the abundance of fungi [34]. According to Kauserud et al. [8], total wild mushroom growth is higher due to the extension of the growing season. Kauserud et al. [8] study the dependence of forest mushroom production on climate change in the Nordic countries. The common trend of the extension of the season, and, therefore, the amount of mushrooms collected, is explained by the direct effect of the increase in autumn precipitation and the increase in autumn and winter temperatures in Norway [8]. Kauserud et al. [10] extend the previous study by including Austria, Great Britain, and the Nordic countries and conclude that there is a dependence of mushroom growth on climate change. Similarly, a study by Karavani et al. [9] discusses the interaction conditions between climate, soil moisture, and mushroom growth changes. The authors report, just like our study, the fundamental influence of precipitation on the quantity of forest mushrooms [9]. Similar to our study, Alday et al. [35] find that for Spain, precipitation affects the wild mushroom yield, while temperature does not affect it.

5. Conclusions

Wild mushrooms are an important product that can be harvested in the forests of Central Europe. In addition to their ecological importance, wild mushrooms also have medicinal properties. Some species have been used for centuries in traditional medicine to treat a variety of ailments, including cancer, cardiovascular disease, and infections. Modern research has also shown that certain wild mushrooms have anti-inflammatory, antioxidant, and immune-boosting properties. Furthermore, wild mushrooms are a valuable food source for both humans and wildlife. They are a healthy source of protein, vitamins, and minerals, and can be enjoyed fresh or dried.

Their abundance or scarcity is influenced by many factors, including temperature and precipitation. The conducted research proved the existence of a relationship between precipitation and the quantity of foraged wild mushrooms, including its quantitative expression. This result has also been confirmed by numerous studies and has important policy-related implications. As precipitation in Central Europe may be lower due to continuing climate change, the potential benefits of climate change mitigation policies should also include the value of foraged wild mushrooms. Surprisingly, our study did not confirm the impact of temperature on the amount of wild mushrooms foraged. This may be due to the nature of the data, and more detailed monthly data could confirm this link. This is also one of the limitations of our study, wherein monthly data on the amount of mushrooms foraged, temperature, and precipitation would be more appropriate yet were not available. Furthermore, it would be beneficial to collect data on individual wild mushroom species rather than totals. In addition, the sustainability of wild mushroom foraging should be further studied as wild mushroom foraging should be subject to regulation. For example, there could be a limit on the amount of mushrooms consumers can take from forests. Another way would be to limit the movement of visitors in forested areas, i.e., instituting no-take zones.

Overall, precipitation is a crucial factor in the dynamics of mushroom populations in a forest ecosystem. Hence, it influences the amount of protein available from wild mushrooms. The quantified results show by how much the amount of wild mushrooms is influenced by changes in precipitation. The decline in protein from wild mushrooms will have to be substituted with other forms of protein in an originally mushroom-rich diet. This would also lead to a higher carbon footprint related to other alternative protein sources from agriculture. This also shows another perspective on why the protection of mushroom-rich forests is necessary.

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