GEORGIKON FOR AGRICULTURE

A MULTIDISCIPLINARY JOURNAL IN AGRICULTURAL SCIENCES

Volume 27 **2023** **Number 2**

The Journal **Georgikon for Agriculture** (briefly: G. Agric) is published twice a year by Hungarian University of Agriculture and Life Sciences, Georgikon Campus. Articles of original research findings in all fields of agriculture and related topics are published in the Journal subsequent to critical review and approval by the Editorial Board.

Editorial Board

Georgikon is the predecessor of the Hungarian University of Agriculture and Life Sciences, Georgikon Campus founded by Count Gy. Festetics in 1797. Georgikon was among the first regular agricultural colleges in Europe that time.

Responsible Publisher is the Director of the Georgikon Campus, Hungarian University of Agriculture and Life Sciences, KESZTHELY.

HU ISSN 0239 1260

Examination of the profitability of poultry farms

Baromfitelepek jövedelmezőségének vizsgálata

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Abstract: Based on the data of the Test Plant System (FADN) operated by the Agricultural Economics Research Institute (hereinafter AKI), the authors examined the economic, profitability and liquidity situation of poultry farms. Period under review: 2010-2020. The income statement and profitability indicators of individual and corporate farms were examined separately. We have made a comparison of farms by size and evaluated the basic data of poultry holdings in a common table. Based on the results, it can be concluded that poultry farmers in Hungary are typically individual farms, however, the production value achieved on social farms was much more favourable. Based on a comparison of farm sizes, it can be said that the variability of the profitability indicators coincided over the period under review. For large and medium-sized farms, there was no significant differentiation between the values. While we have also seen significant volume differences in terms of liquidity, collateral, and labour income ratios for small economies.

***Keywords**: income, liquidity, subsidies*

Összefoglalás: A tanulmányban az Agrárgazdasági Kutató Intézet (továbbiakban AKI) által működtetett Tesztüzemi rendszer (FADN) adatai alapján a baromfitartó gazdaságok gazdaságossági, jövedelmezőségi, likviditási helyzetének vizsgálatát végeztük el. A vizsgált időszak: 2010-2020. Az egyéni és társas gazdaságok eredménykimutatását és a jövedelmezőségi mutatókat külön-külön vizsgáltuk. Elvégeztük a gazdaságok méret szerinti összehasonlítását, a baromfitartó gazdaságok alapadatait pedig közös táblázatban szerepeltetve értékeltünk. Az eredmények alapján megállapítható, hogy hazánkban a baromfitartók jellemzően egyéni gazdaságok, azonban a társas gazdaságokban elért termelési érték jóval kedvezőbben alakult. A gazdaság méretek összehasonlítása alapján elmondható, hogy a jövedelemezőségi mutatók változékonysága a vizsgált időintervallumban egybe esett. A nagy és közepes méretű gazdaságok esetében az értékek között jelentős differenciáltság nem mutatkozott. Míg a kicsi gazdaságok tekintetében likviditási, fedezettségi és munkajövedelmezőségi mutató tekintetében is jelentősebb volumenbeli eltérést tapasztaltunk.

***Kulcsszavak**: jövedelemezőség, likviditás, támogatások*

1. Introduction

Looking at the last decade, the profitability of poultry farmers is low, reaching only about 59% of crop producers' profits, but can still be considered more stable. After all, poultry farmers are best placed to adapt to extremely rapidly changing market conditions. As a result, the number of farms has not changed significantly (Bakota, 2019).

Internationally, more developed countries typically have industrial economies, covering the entire production process with the help of vertical integration.

Poultry production in EU countries is significantly affected by high production costs, due to the regulatory and animal welfare system established within the Member States (Csorbai, 2019).

Changes in the price of energy used in the sector showed a similar trend, with electricity prices increasing by 22%, natural gas by 99% and diesel by 50%. Acquisition prices also increased (Figure 1), but the growth trend in production costs was higher and therefore did not cover them. As the buying-in prices did not offset the increase in energy and feed costs, the profitability of the sector deteriorated. Due to the increase in consumer prices, domestic consumption decreased and sales in the grey and black economy increased, the proportion of which the Poultry Product Council estimates has increased from 15-25% to 35% within the sector.

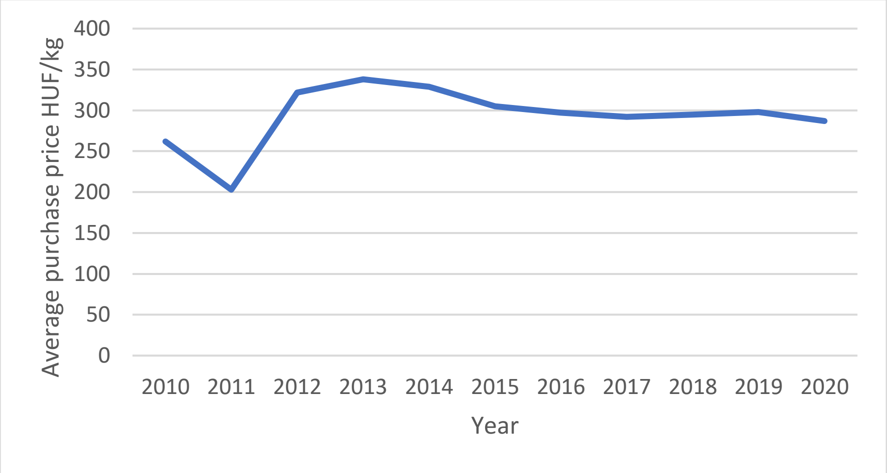

Figure 1. *Evolution of the purchase price of slaughter poultry 2010-2020.*

Source: KSH

Looking at direct aid for different types of economies, it can be said that their development is favourable, although there are significant differences (Table 1). In the case of poultry and dairy farms, it has a value of more than 50% of the gross farm income. In the case of pig farmers, this is less than 50%. Which is due to the specificity of the area payment system. In the case of cattle and sheep farmers, only the aid covered the income. This clearly shows the more favourable situation of poultry farmers (AKI, 2020).

Table 1. Share of gross operating income and grants in 2020

Type of economy	**Operating Gross income thousand HUF/farm**	**Direct subsidies thousands of HUF/farm**	**Share of direct grants and gross operating income %**
Poultry farmers	19907	10833	54
Pig farmers	25941	10312	40
Beef and sheep farmers	8675	10974	127
Dairy farms	36390	19918	55

Source: AKI Test Plant Information System Results 2020

Hungary's poultry population has been over 30,000,000 since 2014. (Figure 2) The laying flock is above 10,000,000 with smaller and larger fluctuations. Poultry stocks change rapidly during the year due to their short life cycle, producers have learned to adapt to market changes, and the size of the stock does not reliably reflect the development of annual production. The performance of slaughterhouses will also increase dynamically in 2012-2016. increased by 130 thousand tons, compared to the number of other slaughter animals, it can be considered an outstanding increase (Juhász et al., 2017). Similar growth is predicted in the coming years due to changing eating habits. In terms of consumption, it is projected to overtake pork by 2020 and to lead the world in meat consumption, which already happened in 2016 based on FAO data (Gergely, 2019).

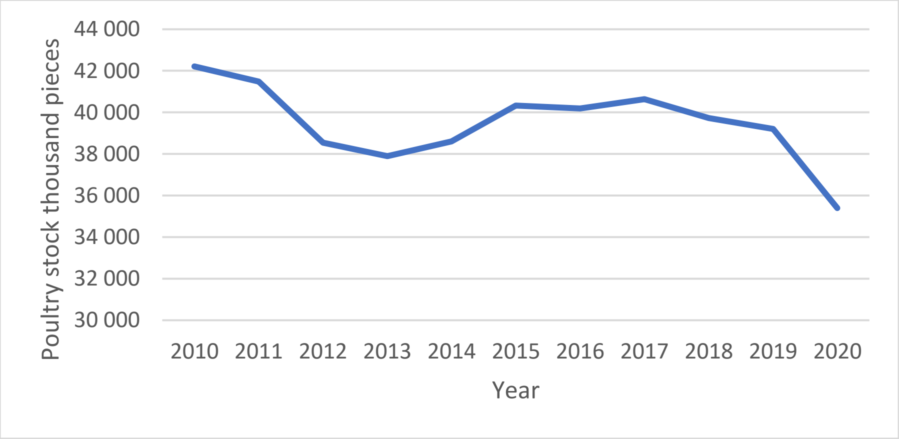

Figure 2. *Poultry stock in Hungary 2010-2020*

Source: KSH

The central problem of the Hungarian poultry sector is the deterioration of international competitiveness, which leads to sectoral market losses and, through this, the cessation of uncompetitive enterprises (Bakota, 2019).

2. Materials and Methods

In our studies, we used the data of the AKI Test Plant System (FADN). The database shows data from more than 1,900 test farms, representing 107,000 farmers with a Standard Production Value more than € 4,000. The examined period is 2010-2020. The database available to us did not contain the test farm data for 2019, so we were unable to perform their analysis. Our aim was to examine the profitability and liquidity indicators of poultry farms. We used two approaches in terms of farm type and farm size to highlight the data highlighting the significant differences. During our analyses, we used the results statement and economic data collected in the test farm system, and we examined the publications prepared by AKI. We organized our data using Microsoft Office Excel and performed analyses.

Indicators used:

Production-value proportional income = Profit before tax/production value*100
Total capital profitability= Profit before tax + interest paid/Liabilities * 100
Return on equity=Profit before tax/ Equity *100
Work-profitability = Profit before tax + personal income/ Annual labour unit (AWU = unit of work output, annual working time of 1 person in full-time employment, expressed in hours worked. 1 YEAR = 2200 hours of work. number of other payments.
Cash flow= After-tax profit+ Depreciation
Investments coverage= After-tax profit+ Depreciation/ Gross investment*100
Liquidity ratio= Current assets/ Short-term liabilities
Liquidity Quick Rate= Current Assets Inventories/ Short-term Liabilities
Equity ratio= Equity/Resources*100
Capital supply= Equity/ Fixed assets*100
Dynamic indebtedness ratio= Net liabilities/ Cash flow. Net liabilities are the amount of liabilities less the number of receivables, securities, and funds.
Capital supply= Equity/ Fixed assets*100
Dynamic indebtedness ratio= Net liabilities/ Cash flow. Net liabilities are the amount of liabilities less the number of receivables, securities, and funds.

3. Results

Table 2. Evolution of the number of poultry farms in the test farm system 2010-2020 Source: AKI

Individual farms										
Pointer	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2020**
Number of farms in the sample, pcs	70	72	108	112	106	114	106	106	101	104
Number of farms in the observed population, pcs	6841	6843	6843	6186	5821	6793	5415	5415	5415	1924
Standard production value,1000 HUF/farms	12915.6	11948.9	8501.7	9572.6	10592.9	9055.9	13785.7	13785.7	12967.01	26887.05
Corporate farms										
Pointer	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2020**
Number of farms in the sample, pcs	48	43	44	49	51	46	52	52	46	58
Number of farms in the observed population, pcs	402	402	402	333	320	343	442	442	442	350
Standard production value 1000 HUF/farms	358485	248645.2	314950.6	486306.9	355280.2	365332.2	219690.8	228559.6	267577.9	548719.4

The listed indicators were not recalculated, we worked with the values specified by AKI. The basic data of the test operational information system are presented in Table 2. The number of individual farms increased steadily until 2012. Then it decreased in 2013-14, the growth in 2015 will almost reach the level of 2012, then by 2016-17 we will see a large decrease again. A similar trend can be observed in the case of corporate farms, but in terms of this type of economy, the increase in 2016-17 exceeded the value in 2012. However, in terms of the number of farms, the number of corporate farms lagged significantly behind that of individual farms, and between 2010 and 2012 their number barely exceeded 400. In terms of STÉ, the periods of 2010-11 and 2016-17 can be said to be favourable for individual farms, when they significantly exceeded the value of HUF 10,000 thousand / farm.

In the case of corporate farms there are some overlaps with individual farms, here the favourable periods (with STÉ over HUF 350,000 thousand) are 2010,2013-2015, however, the last two years of the examined period showed a serious decline in the case of these farms. The difference in magnitude between the data for 2018 and 2020 also results from a methodological shift. In 2018, the average size of agricultural land used by individual farms is 3.29 ha / farm, and the size of the poultry population is 8.63 animals / farm. In the case of corporate farms 13.8 ha / farm and 180 livestock / farm. In 2020, the same data for individual farms: 6.83 ha / farm and 18.55 livestock / farm; and in the case of corporate farms 11.02 ha / farm and 355.69 livestock / farm. it is therefore clear that the number of animals has doubled for both forms of company.

Table 3. Development of profitability indicators for individual holdings 2010-2020

Source: AKI

Pointer	2010	2011	2012	2013	2014	2015	2016	2017	2018	2020
Profitability in proportion to production value, %	3.15	5.33	11.6	8.21	10.57	14.08	14.81	14.81	14.13	7.93
Profitability of total capital, %	4.17	7.92	15.08	9.66	12.9	16.09	15.39	15.39	14.62	6.89
Return on equity, %	5.14	11.8	20.07	12.82	16.68	19.64	18.92	18.92	18.16	8.96
Work-profitability, tFT/ AWU	1070.1	1475	2706.2	1864.7	2509	3064.3	4248.9	4249.8	4236	4606.09
Cash flow, tFT/farm	979.4	152.7	613.4	464.4	985.8	1160.6	3622.4	3623.2	3547.04	4798.17
Investment coverage %	86.2	12.1	150.2	45.1	120.4	106	232.4	232.4	263.83	60.98
Liquidity quick rate	1.68	1.14	1.26	1.19	1.6	1.73	3.85	3.85	4.63	3.34
Liquidity ratio	2.08	1.53	1.59	1.62	2.22	2.47	5.09	5.09	5.68	4.03
Equity ratio, %	69.36	63.64	73.82	71.54	75.68	80.49	80.8	80.8	79.93	74.78
Capital supply, %	111.38	109.67	111.69	104.31	118.95	119.31	119.72	119.73	127.99	110.05
Dynamic indebtedness index, year	0.02	4.81	-0.12	1.4	-0.28	-0.36	-0.28	-0.28	-0.7	-0.14

We started our studies by analysing individual farms. During the period under review, the farms produced positive results every year. Profitability as a proportion of production value enjoys continuous and dynamic growth rates (30.2%) over the period under review until 2018, after which we can see a drastic decrease in 2020. In the case of the profitability of total capital, we were able to observe continuously alternating values, the highest value was reached in 2015 by 16,09 %, followed by stagnation and decrease. The profitability of equity showed significant variability over the period under review, its maximum was registered by 20.07% in 2012. It also recorded its lowest figure in 2010 at 5.14%. In terms of work-related productivity, we have seen a steady increase in work profits. Looking at the values of cash flow, it fell drastically from 2010 to 2011 (HUF 152.76 thousand /farm), then, apart from 2014, it showed a significant increase and in 2020 the maximum value of the period was registered with a value of HUF 4798.17 thousand/farm. We used the two indicators to examine liquidity, we got lower differentiation values in the analysis of the rapid rate, while at the general liquidity rate there were also very differences in volume and dispersion. In the last two years of the study period, both values were reduced. When examining the share of equity, we can see that it continued to increase until 2017, followed by a continuous decrease until 2020. In the case of capital supply, only values above 100% were recorded in the AKI database, which can be considered favourable. In terms of dynamic indebtedness, its highest value was registered in 2011 (4.8 years) and the lowest value in 2015 (-0.36 years).

Table 4. Development of profitability indicators of corporate farms 2010-2020

Source: AKI

Pointer	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2020**
Profitability in proportion to production value, %	1.43	1.65	2.25	2.7	3.97	6.91	6.42	6.43	8.33	3.88
Profitability of total capital, %	4.64	5.39	5.75	6.25	7.16	11.81	4.76	4.79	8.49	4.24
Return on equity, %	4.27	6.57	7.52	9.17	12.1	21.17	8.66	8.7	14.14	6.38
Work-profitability, tFT/ AWU	2367.3	2371.6	2667.6	3130.2	3601.3	5532.1	5854.6	5893.8	7530.91	6699.16
Cash flow, tFT/farm	34070.6	21112.1	30718.3	50340.3	41955.3	50326.5	49018.3	51341.5	81617.38	95855.8
Investment coverage %	65.1	56.2	45.2	50.9	57.1	172	117.9	116.7	114.14	54.69
Liquidity quick rate	0.6	0.67	0.74	0.55	0.7	0.78	1.32	1.31	1.23	0.93
Liquidity ratio	1.13	1.06	1.15	1.2	1.21	1.53	1.97	1.98	1.86	1.4
Equity ratio, %	50.26	42.21	48.31	57.42	52.23	52.69	52.6	52.72	58.15	62.52
Capital supply, %	80.05	76.47	93.84	92.91	87.8	94.28	75.19	75.53	86.99	97.64
Dynamic indebtedness index, year	2.88	3.35	2.14	1.95	1.83	1.57	2.82	2.79	1.29	1.16

In the case of corporate farms, it can be said that in 2010-2020. there was no loss-making year between. Examining the profitability of the production value, we experience significant differences between the two examined economic forms. In the case of corporate farms, the profitability ratio proportional to the production value will remain below 3% until 2013, then it will approach 4% in 2014 and will exceed 6% in 2015-2017, reaching a maximum of 8.33% in 2018. and then dropped drastically by 2020. Return on total capital and equity peaked in 2015 (11.81%; 21.17%) and then decreased significantly by the end of the period. Analysing the profitability of work, we can see that it showed a steady increase until 2018 and by 2020 a decrease was observed. In terms of cash flow, we can see that smaller and larger decreases and increases alternate between 2010 and 2020. However, with continued volatility, it achieved slow growth by the end of the period and was well ahead of the end-period value observed for individual farms. Regarding the coverage of investments, it can also be stated that it was characterized by significant variability. It peaked at 172% in 2015 and has been steadily declining since then. The liquidity rapid rate increased with minor major fluctuations, with its maximum value recorded at 1.32 in 2016. The same trend of change can be observed for the liquidity ratio. The share of equity in 2011 and 2012 did not reach 50 %. The "corresponding value above 30%" according to the literature was still significantly higher. Capital supply was able to increase in aggregates with continuous variability, but still did not reach the values observed for individual economies. The dynamic indebtedness indicator showed an improvement from 2010 to 2020, but still lags the performance of individual economies.

In the second part of our analysis, poultry farms are examined by size. Large farms with more than 50 livestock are considered large farms. As a result of the methodological change, the poultry population of large farms changed from the average value of 194.9 livestock / farm in 2018 to 336.2 in 2020.

Table 5. Development of profitability indicators for large farms 2010-2020

Source: AKI

Pointer	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2020**
Profitability in proportion to production value, %	28.8	40.4	38.9	35.2	37	34.6	37.3	37.3	9.24	4.43
Profitability of total capital, %	12.3	19.4	17.4	14.3	14.8	13.3	13.7	13.7	9.7	4.82
Return on equity, %	13.7	22.1	19.4	15.7	16.4	14.8	14.9	14.9	15.51	7.06
Work-profitability, tFT/ AWU	7837.8	14124.5	14309.9	11844.7	12823.2	12030.4	14172.2	14143.1	8116.45	6050.31
Cash flow, tFT/farm	10203	18271.4	19146	17884.8	18101.3	17068.5	42674.7	42591.9	80660.1	18813.2
Investment coverage %	168.4	132.2	139	131.7	105.7	104.9	258.4	257.9	125.36	55.93
Liquidity quick rate	2.2	1.9	2.3	2.9	2.7	3.1	4.9	4.9	1.4	0.98
Liquidity ratio	3.3	3	3.6	4.4	4	4.6	7	7	2.09	1.46
Equity ratio, %	83	84.3	87.1	88.3	87.9	88.1	90.4	90.4	61.4	64.52
Capital supply, %	110.8	115.4	120.9	123	120.2	121.8	124.8	124.8	91.76	98.02
Dynamic indebtedness index, year	0	-0.1	-0.5	-0.8	-0.7	-0.9	-0.6	-0.6	0.99	1.06

In the examination of large economies, we observed continuous variability in terms of the development of proportional profitability in production value, but it is striking that the large decrease in profitability in the last two years will fluctuate between 28.8 and 40.4% in 2017 between 2018 and 9.2% in 2018 and to 4.43% in 2020 The same trends can be observed in the profitability of total capital, although the rate of decline is not so great. A similar trend was observed for labour profitability. It increased overall from 2010 to 2017 and then declined in subsequent years. Considering the composition of the indicator, there may be several reasons for the increase in after-tax profit and/or the wages paid and, conversely, the decrease in the unit of the annual workforce. In terms of cash flow and investment coverage, the trend described so far can also be observed. The change in the value of the liquidity ratio and the rapid rate also shows the same trend, which assumes that the ratio of inventories to current assets is relatively constant over the period under review. The value of the two indicators is adequate, dropping to critical levels in the last two years. The share of equity is high, even in less favourable years (2018; 2020) it is above 60%. The financing of fixed assets with open-ended funds is also adequate, although it has fallen below 100% in the last two years. The dynamic indebtedness indicator will only take positive value in 2020 in the rest of the year the stock of receivables and funds exceeds the value of liabilities. This is unfavourable if the farm is unable to recover its claims in time and thus short-term liquidity is impaired. In the last two years, however, the value of the indicator has already become positive as liabilities have increased.

Table 6. Development of profitability indicators for medium-sized farms 2010-2020

Source: AKI

Pointer	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2020**
Profitability in proportion to production value, %	29.6	40.6	39.4	34.7	35.5	37	36.9	37	11.44	9.02
Profitability of total capital, %	10.9	17.3	16.6	13.3	13.2	12.5	11.4	11.4	11.05	6.59
Return on equity, %	11.8	19.4	18.1	14.5	14.1	13.4	12	12.1	13.85	8.98
Work-profitability, tFT/ AWU	5620.1	9407.6	9970.8	8584.8	9265.3	10000	9968.7	10019.8	5014.53	5341.61
Cash flow, tFT/farm	3328.4	5512.6	5497	4404.2	5058.9	4558.4	12464.5	12525.8	10414.7	9281.86
Investment coverage %	231.8	222.9	214.2	145.8	183.4	94.9	316.9	318.5	159.17	49.56
Liquidity quick rate	3.7	2.8	3.4	3.7	4.6	4.8	9.1	9.1	2.63	1.98
Liquidity ratio	4.8	3.8	4.7	5	6.1	6.2	11.5	11.6	3.44	2.55
Equity ratio, %	88	87.4	89.8	90.1	91.9	91.8	93.5	93.5	79.46	71.73
Capital supply, %	126	132.5	134.9	132.9	139.2	134.8	135.6	135.7	120.23	107.36
Dynamic indebtedness index, year	-1.8	-1.4	-1.7	-2.2	-2.5	-3	-1.4	-1.4	-0.43	0.25

For medium-sized farms, in 2018 the average agricultural area was 13.3 ha / farm, and the number of poultry was 32.2 livestock / farm, the same data in 2020 were 9.5 ha / farm and 30.9 in this size category. The return on production value ratio is better, but the return on total capital ratio is worse than on large farms. However, for medium-sized farmers, the decline in 2018-2020 was smaller. Looking at profitability indicators, as in large economies, we can see that the most favourable year is 2011 and the worst is 2020. For medium economies, the profitability of work indicator is much lower than in large economies. The liquidity ratio and rapid rate are much higher (twice in 2016) than in large economies. The same can be said about the share of equity, although the difference is not so great. In the last two years of the period under review also saw a significant decrease. The equity ratio is also more favourable than medium-sized economies. Between 2013 and 2017, it will not fall below 90% and even in the most unfavourable years it will not fall below 70%. Fixed assets are covered with equity well over 100 % throughout the period. Dynamic indebtedness, on the other hand, is negative every year except 2020 for the 10-year period under review, which may raise financing problems in the short term.

Table 7. Development of profitability indicators for small farms 2010-2020

Source: AKI

Pointer	2010	2011	2012	2013	2014	2015	2016	2017	2018	2020
Profitability in proportion to production value, %	24.7	32.3	35.8	32.5	32.7	29.6	36.3	36.4	15.55	4.31
Profitability of total capital, %	7.8	11.2	11.2	9.9	8.8	8	9	9	13.85	3.34
Return on equity, %	8.4	12.1	12	10.6	9.2	8.4	9.3	9.3	17.91	4.72
Work-profitability, tFT/ AWU	2620.4	3930.5	4437.2	4141.9	4250.2	4218.3	5047.2	5053.2	2708.61	2275.44
Cash flow, tFT/farm	866.6	1126	1402.9	988.1	1025.4	751.6	2636.2	2639.3	1712.23	1129.05
Investment coverage %	173.5	205.6	295.8	193.8	237.8	83.5	655.6	656.4	390.94	108.9
Liquidity quick rate	6.5	5	5.1	6.3	9	9.9	32	32	4.56	5.61
Liquidity ratio	7.6	6	6.2	7.6	10.4	11.3	35.6	35.6	5.22	6.08
Equity ratio, %	89.4	90.6	92.7	93.1	95	94.9	97.1	97.1	77.14	68.98
Capital supply, %	135.4	138.1	137.5	142.1	150.1	146.3	156.4	156.4	134.98	1326.21
Dynamic indebtedness index, year	-3.9	-3.2	-3.2	-4.6	-6.5	-8.7	-3.1	-3.1	-0.95	-2.08

The profitability of small farms lags medium and large economies, but this lag is only small. The same trends are observed, in the last two years the value of all indicators has deteriorated. The labour income is half the value shown in medium-sized economies. However, the liquidity ratio and the value of the rapid rate are higher than those of both large and medium economies. This is a consequence of the stock of low short-term liabilities, as the dynamic indebtedness indicator has taken a negative value every year without exception for the same reason. It is true for each year of the investigation for small farms that the receivables (i.e., receivables) are larger than those of debts. In 2014, capital supply takes in values above 150 % in 2014, which is not typical for either medium and large economies. Overall, the share of equity for the whole period is higher than for the other two size sizes.

4. Conclusions

When comparing individual and corporate farms, the values of the profitability indicators change according to the same tendencies, but the values of individual farms significantly exceed those of corporate farms. The exception to this is the profitability of labour, but it is a special indicator that is distorted by the special situation of family farms and the recognition of income. In terms of liquidity indicators, there is an increase can be seen for both types with greater or lesser variability. It can also be pointed out here that the liquidity indicators of individual economies are better developed than those of corporate farms. Regarding capital structure indicators, the same can be said for the previous one's dynamic indebtedness, the order that has characterized so far is reversed for corporate holdings throughout the period under review, while for individual farms only 5 years its value was above 0 and the maximum was 4.81 years (2011), while for corporate farms the highest was 15.19 years (2007).

Based on the comparison of economy size, we can conclude that all the profitability indicators, except the indicator of labour income, describe the same curves during the period under review, and differences in volume are negligible. It is important to mention that we have seen the lowest values in 2020. Liquidity indicators have also moved in the same direction for all three types. The difference in volume for these indicators was already significant. Small farms achieved the highest values. Thus, it can be said that small farms are more liquid than those of medium and large farms. For all three farm sizes, the capital structure indicators showed almost the same variability. The differentiation between the values did not prove to be significant here either, except for the coverage indicator. Regarding dynamic indebtedness, it can be concluded that it has developed contrary to the order established for liquidity indicators.

Acknowledgements

The publication is supported by the EFOP-3.6.3-VEKOP-16-2017-00008 project.

References

AKI 2020: Tesztüzemi információs rendszer eredményei 2020, AKI Budapest

Bakota Bettina, P. Z. 2019. A magyar mezőgazdaság 2018. évi eredményei. *Gazdálkodás*. **63** (3) 229–249. https://doi.org/10.22004/ag.econ.290404

Csorbai Attila, d. F. 2019. A magyar baromfiágazat helyzet 2018-ban. Budapest: Baromfiterméktanács.

Gergely Andrea, F. V.-R. 2019. Magyarországon főtevékenységként baromfi- és sertéságazattal foglalkozó vállakozások pénzügyi helyzetének vizsgálata. *Acta Carolus Robertus.* **9** (2) 41–54. https://doi.org/10.33032/acr.2019.9.2.41

Juhász A., Dr. Fazekas S., Győrffy B 2017. A Magyar mezőgazdaság és élelmiszeripar számokban 2016. AKI. pp. 23–25.

Analysis of information content on hypertemporal UAV images

Hipertemporális UAV felvételek információtartalmának elemzése

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Abstract: Today, the data provided by drones extremely useful information for professionals. The processing of large data sets collected by UAVs, on the other hand, may require different methodological elements based on the properties of the sensors placed in each camera system. The sensors placed on the carrier devices can significantly influence not only the collection of data, but also the evaluations appropriate for the given purpose. The data sets created by the sensors can be characterized by different geometric, spectral and temporal resolutions for each camera system. We can characterize the information content of the spectral layers of the Bayer-type CFA filter (Color Filter Array) and Global Shutter sensors by calculating information-theoretic entropy. If we have different spectral, geometric, and temporal data series available after the recording, the processing can be done by processing the data series separately or together. In the case of aerial photographs with different characteristics, data fusion procedures can also be used in the data processing process, which poses many challenges for remote sensing specialists. Properly performed data fusion can further increase the potential of the data. In our article, we present the information content-based processing of our environmental protection aerial surveys carried out in the sample area of Kis-Balaton. During image processing, we performed geodesic-based and pattern-matching-based integration of the data, the results of which are also presented with an entropy-based analysis of the images. We extended our investigations to the most frequently used image classification procedures in practice, and we also present the analysis of the error matrices related to the analysis of the result images of the procedures and the obtained Kappa indices. All of these were done in the manner described above because they do not require unique solutions and farmers, or users can do them even with basic knowledge.

Keywords: *UAV, hypertemporal, multispectral, plant protection, classification*

Összefoglalás: Napjainkban a drónok által szolgáltatott adatok rendkívül hasznos információkat szolgáltatnak a szakemberek számára. A UAV-k által gyűjtött nagy méretű adatsorok feldolgozása viszont eltérő módszertani elemeket igényelhetnek az egyes kamerarendszerekben elhelyezett érzékelők tulajdonságai alapján. A hordozó eszközökön elhelyezett érzékelők nemcsupán az adatok gyűjtését, hanem az adott célnak megfelelő kiértékeléseket is jelentősen befolyásolhatják. Az érzékelők által létrehozott adatsorokat az egyes kamerarendszerekre vonatkozóan eltérő geometriai, spektrális és időbeli felbontás jellemezheti. Információelméleti entrópia számításával jellemezhetjük a Bayer típusú, CFA filtert tartalmazó (Color Filter Array) és a Global Shutter érzékelők spektrális rétegeinek információtartalmát. Amennyiben a felvételezést követően eltérő spektrális, geometriai és időbeli adatsorok állnak rendelkezésünkre, a feldolgozás történhet az adatsorok külön-külön vagy ezek együttes feldolgozásával. Az eltérő tulajdonságú légifelvételek esetében az adatfeldolgozás folyamatában adatfúziós eljárásokat is alkalmazhatunk, mely számos kihívást jelent a távérzékeléssel foglalkozó szakemberek számára. A megfelelően elvégzett adatfúzió tovább növelheti az adatokban rejlő lehetőségeket. Cikkünkben bemutatjuk a Kis-Balaton mintaterületén végzett, környezetvédelmi célú légifelvételezéseink információtartalom alapú feldolgozását. A képfeldolgozás során elvégeztük az adatok geodéziai alapú és mintaillesztés alapú integrálását, melynek eredményeit a felvételek entrópia alapú elemzésével is bemutatjuk. A vizsgálatainkat kiterjesztettük a gyakorlatban leggyakrabban alkalmazott képosztályozó eljárásokra is, továbbá bemutatjuk az eljárások eredményképeinek elemzéséhez kapcsolódó hibamátrixok elemzését és a kapott Kappa-indexeket. Mindezeket azért végeztük a fentiekben ismertetett módon, mert nem igényelnek egyedi megoldásokat és a gazdák vagy felhasználók alapismeretek mellett is elvégezhetik.

***Kulcsszavak**: drón, hipertemporális, multispektrális, növényvédelem, osztályozás*

1. Introduction

Light is electromagnetic radiation that can be broken down into different wavelength ranges. In the VIS (Visible, i.e., red [R], green [G], blue [B]) range, the colour bodies found in the vegetation are primarily reflected, meaning that the condition of the vegetation can be well examined with this range. The NIR (Near Infrared) range is generally used in agriculture for testing the fitness status of vegetation, similarly to the RedEdge band, but the latter is not sensitive to atmospheric conditions and soil reflectance but is sensitive to canopy characteristics and on the chlorophyll content (Clevers et al., 2001; Kozma-Bognár, 2012).

A non-negligible question of spectral tests is how many channels, i.e. bands, the used sensor can simultaneously record at a moment in time. From this point of view, we distinguish between multi- and hyperspectral recording. The difference between the two methods is on the one hand in the number of simultaneously recorded bands (multispectral: 4-20 bands, hyperspectral: >20 bands; Council of the European Union, 2009), and on the other in the width of the band ranges. In the case of the multispectral method, the bandwidths are usually large (50-120 nm), while in the case of hyperspectral recording they are much smaller, even 1 nm (Kozma-Bognár, 2012). As a result, the spectral resolution of the images is also much higher in the case of hyperspectral images, since the spectrum is continuous, while with the multispectral method the resulting spectrum consists of discrete band ranges.

While the use of hyperspectral sensors is common in satellite remote sensing (Bácsatyai and Márkus, 2001; Mucsi, 2013; Lillesand et al., 2015), it is not yet widespread in drone technology. This is due to the high cost and weight of hyperspectral camera systems on the one hand, and the limited size of the payload that drones can carry on the other. Despite this, more and more manufacturers are developing ever smaller size and weight hyperspectral camera systems that can be mounted on UAVs (Unmanned Aerial Vehicles, i.e., "drone"), thanks to their wide applicability - and their more cost-effective use compared to satellites (Adão et al., 2017; Nex et al., 2022). In contrast, many manufacturers currently produce high-quality multispectral camera systems especially for UAVs (e.g., Micasense, Parrot, Sentera, Yusense), which usually contain 6 channels: in addition to RGB, RedEdge (~717 nm) and NIR (~842 nm) bands.

Using RGB and/or RedEdge, as well as the NIR range, several indices have been created, which are primarily used to examine vegetation (Lussem et al., 2018; Solymosi et al., 2019; Feng et al., 2021). The scope of the study does not allow for a detailed presentation of the indices, so only the NDVI and NDRE indices need to be mentioned due to the methodology used.

Both the normalized red border index (NDRE; 1) and the normalized vegetation index (NDVI; 2) provide information on the health status, or fitness, of the vegetation. While the NDVI index considers the R (i.e., red) band, the NDRE index uses the RedEdge band instead of the R band based on the following formula:

$$\text{NDRE} = (\text{NIR} - \text{RedEdge}) / (\text{NIR} + \text{RedEdge}) \qquad (1)$$

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}) \qquad (2)$$

In the case of certain plants (e.g., corn), in the late life stage, the upper leaves absorb more of the red-light range, so the lower leaves do not contribute to the calculation of the NDVI index, i.e., the index will not show the real state. This is eliminated by the NDRE index, by calculating with the RedEdge band instead of the red band, since the light range is utilized to the same extent by the lower leaves of the plant, so the calculated NDRE index will already show a real picture (Carlson and Ripley, 1997; Maccioni et al., 2001).

By the temporal resolution of the image recordings, we mean the frequency of image creation. Like spectral resolution, multi- and hyper-temporal recording can also be distinguished in this case. Both cases have in common that the frequency of recording is much higher than the sampling frequency required for observing temporal processes – i.e., half the frequency of the examined temporal process (Shannon theorem: Shannon, 1948). Time is the fourth dimension; it differs from the x, y, z (spatial) dimensions in that it is asymmetric – that is, it only flows in one direction – and is difficult to imagine (we see the effects of the passage of time, but do not perceive it directly; Piwowar et al. 1998). The difference between the multi- and hypertemporal methods is the frequency of recording. There is no unified position regarding the frequency, for example Kleynhans (2011) draws the line between multi- and hypertemporal recording at a frequency of 8-30 days. Based on the recommendation of Piwowar et al. (1998), multitemporal data can be processed if the following three requirements are met:

1. It should be univariate (recording of the same parameter at different times).
2. Include time slices, each of which contains the same area (image pixels and resolution must match perfectly).
3. They should be radiometrically consistent (i.e., the images should be made with the same sensors).

In our opinion, the above can be completed with general user knowledge. However, as previously highlighted - Enyedi et al. (2016) and Vastag et al. (2019), in the case of devices where we work with sensors that do not contain discrete bands, and a significant part of the VIS sensors of UAV devices contain such, i.e., Bayer-type sensors, the actual data content of the image and its reliability are determined by the imaging algorithms. However, these differences can even exceed 100% - Enyedi et al. (2016). These data cannot be improved with subsequent (geometric, atmospheric or radiometric) corrections either, as they are procedures prior to their implementation. If, on the other hand, we create a single image band from the data of the entire Bayer sensor, then the data can be corrected, but we cannot create indexes, and most known classification methods cannot be used because of the single band. After taking the above into account, as well as comparing discrete-non-discrete sensors, we worked on the basis of reflectance values during the tests.

2. Materials and Methods

2.1. Presentation of applied technology

The images were made with a DJI Phantom 4 rotary-wing quadcopter drone, the camera parameters of which are as follows:

- Camera type: FC300X
- Sensor type: Sony EXMOR 1/2.3"
- Effective pixel: 12.4 M
- Image size: 4000 x 3000 px
- FOV: 94°
- Focal length: 20 mm
- Aperture: f/2.8
- Shutter speed: 8-1/8000 s

The Phantom 4 type drone only has an RGB sensor, however, the Sentera company produces accessories that can be used to connect various Sentera camera systems to DJI drones. Thus, two types of Sentera camera systems can be connected to the used Phantom 4 drone, with which either NDVI vegetation index (includes 625 nm red and 850 nm NIR band) or NDRE index (720 nm RedEdge and 840 NIR) in addition to NDVI the camera can record. Thus, recording will not be single axis, but RGB on a separate axis and NDVI and/or NDRE on a separate axis. The latter, i.e., the "dual" NDVI, NDRE camera system, was connected to the Phantom 4 drone, so the drone took NDVI and RE (only RedEdge instead of NDRE index) images of the area at the same time in addition to RGB images.

2.2. Presentation of study area

The investigated area is located on the Kis-Sziget of the Zimány part of the Kis-Balaton landscape, which is no longer an independent island and has an area of ~4200 m^2 (Figure 1). Kis-Balaton itself is part of the Balaton Uplands National Park, which is highly protected, so you can only enter with a permit. The area - together with Lake Balaton - forms an independent ecological system, which is also unique in the world, and even enables the temporal examination of vegetation changes caused by climate change (Soós et al., 2014). Thus, the monitoring of vegetation with a UAV is increasingly becoming an indispensable method for research in this direction.

3. Applied methodology

The images were made with the DJI Phantom 4 drone mentioned in the previous chapter and its FC300X type RGB camera (resolution is 1969 x 4879), and the NDVI and RedEdge images (resolution is 2271 x 5619) were made with an NDVI, NDRE, RedEdge camera (Sentera Double 4K True) located on a separate axis – that is, as a kit that can be installed on the Phantom 4 drone. The images were taken in the year 2020, with an average frequency of 12 days, at the same time of the day, at an altitude of 100 m, and of course always from the same area. The dates are as follows: January 2, 15, 26, February 14, 29, March 10, 27, April 8, 18, 26, May 8, 18, 30, June 13, 24, July 6, 19, 30, August 9, 20, September 2, 11, 22, October 1, 19, 27, November 1. The images were taken by flying on the same route, during which average VIS – 44.08±1.19, NDVI – 22.81±1.62, RE – 22.78±1.67 images were taken. The images were taken with 70%/80% (Side/Frontal) overlap. The difference in the number of images between the two cameras was mainly caused by the different viewing angle, while the difference between the flight times was due to the different weather conditions. The images were aligned with the Agisoft PhotoScan 1.4.3 program with factory default settings, separately for the RGB and separately for the Sentera sensor, image alignment - dense cloud – DEM - Orthophoto in order.

The photos taken (3 channels, counting 27 times, a total of 81 image files) were taken in raw, i.e., RAW (36-bit) format, which were converted into the lossless 16-bit TIFF image format, which is also lossless, but more suitable for further processing. After the conversion, the images were joined by channel, that is, the RGB, NDVI and RedEdge images were copied into one image file. We separated the RGB images based on the three bands (red, green, blue), so we created three more new image files, so a total of six new files were available, which contain 27-27 channels, where one channel means one image, following each other in chronological order. In other words, the images belonging to the same band were copied "to each other", so 27-channel TIFF images were created, where one channel represented one recording. In this case, the sequence lasted from 01/02/2020 to 11/01/2020, but from the point of view of the method, it does not matter which time (channel) is visible, that is, which recording is in the top position of the data cube.

The TIFF files joined by bands were further processed with ENVI (5.6.2) software, where the main purpose of the processing was the classification of the joined image files by bands. Since the classification was done using supervised methods, the first step was to select the known areas, i.e., the ROIs (Region of Interest). During the designation, we separated four types of vegetation: tall golden cane, sedge, reed, and shrub. Variations caused by phenological phases were not investigated in this work. In the sedge-reed areas, this is justified, but neither farmers/professionals with general preparation nor the factory-provided software solutions currently allow this. The tall golden cane and shrub parts were clearly separated in the area.

After the designation of the ROIs, the classification followed, for which we used two methods, the Maximum Likelihood (ML) and the Spectral Angle Mapper (SAM) method. Based on experience, Maximum Likelihood results in the most accurate classification, while the Spectral Angle Mapper method is effective when there are relatively many shadows in the image (Schowengerdt, 1997; Kozma-Bognár, 2012,). The prepared image files (RGB, NDVI, RE) (images from 27 to 27 times) were classified using the above two supervised methods.

We analysed the Overall Accuracy, which can be expressed as several pixels per image or as a percentage. When examining the accuracy of the results, it is also appropriate to compare the Commission/Omission and Producer Accuracy/User Accuracy values (Appendix 1.), and to consider the Kappa coefficient, which is an indicator of the match between the classification and the real values. A Kappa value of 1 indicates a perfect match, while a value of zero indicates no match (Richards-Jia, 2005). Table 2 summarizes the hit accuracies and Kappa values associated with each classification procedure. We created an error matrix to check the created classes, so it is possible to objectively compare the results of the classification of each band, and the matrix also reveals the relationships between the classes (Kevi, et al. 2023). For the objective evaluation of the error matrices, we used a multivariate statistical method - cluster analysis.

To examine the information content of each band, Shannon's entropy was calculated for each band at each time point (Shannon, 1948). With the help of this, it is possible to clearly see which band contains the largest information content (thus the most colour shades, which are important during classification), i.e., which band has the highest entropy value.

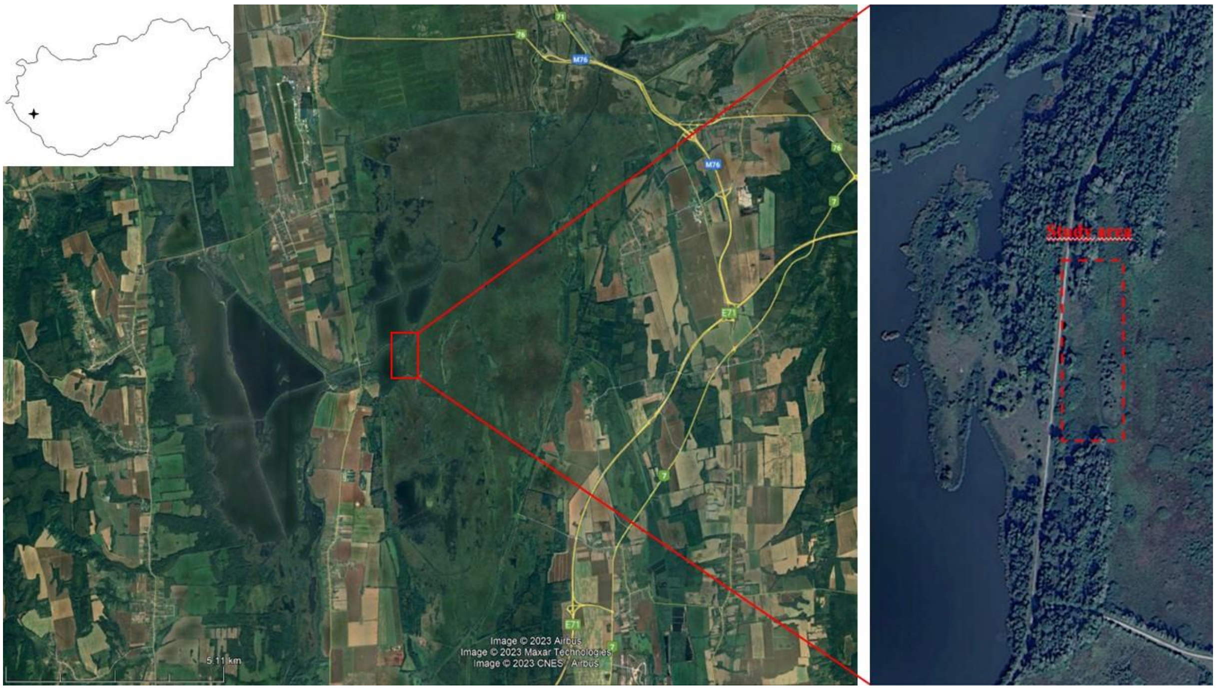

Figure 1. *Location of the study area (Kis-Sziget: red dotted area, projection WGS84)*

The vegetation of the area is characterized by sedges, reeds, and tall goldenrod, which is of adventitious North American origin, while the woody vegetation is mainly composed of various willows. These four vegetation types completely cover the investigated area, which can be separated from each other spectrally (VIS + NIR) and represent discrete pixels based on the resolution of the recordings. In terms of vegetation, the biggest problem is the presence and expansion of tall goldenrod. This weed species is characterized by the fact that, relatively quickly, it can form stable closed stands with few species in just four years, displacing the original, site-specific plant types (Pinke and Pál, 2005).

4. Results, evaluation

4.1. Comparison of classification methods

Comparing the image results of the classifications is difficult to perform and can lead to subjective interpretation, so the differences can be seen objectively on the error matrices. From both the classified images and the error matrices - as well as from Table 1 - the Maximum Likelihood (ML) method generally performed better than the Spectral Angle Mapper (SAM) method (see Appendix 1. for the Commission/Omission and Producer Accuracy/User Accuracy values). This is most striking when examining the aggregate accuracy values of the bands.

Table 1. Overall accuracy and Kappa coefficient of classes by band and method

Band	Method	Overall Accuracy	Kappa Coefficient
RGB	Maximum Likelihood	48.60	0.30
	Spectral Angle Mapper	40.64	0.18
R	Maximum Likelihood	82.67	0.76
	Spectral Angle Mapper	53.84	0.38
G	Maximum Likelihood	87.16	0.82
	Spectral Angle Mapper	60.09	0.46
B	Maximum Likelihood	79.56	0.72
	Spectral Angle Mapper	52.96	0.37
RedEdge	Maximum Likelihood	33.94	0.09
	Spectral Angle Mapper	26.24	0.02
NDVI	Maximum Likelihood	37.94	0.13
	Spectral Angle Mapper	36.09	0.09

If we compare the values of the individual groups within the bands, it is mostly significant only in the case of the R, G, B bands that the ML method gives better results than the SAM method. This statement is not entirely true for the classification results of the RGB, RE (RedEdge) and NDVI bands, it is also clearly visible from the comparison of the values of the aggregated accuracy.

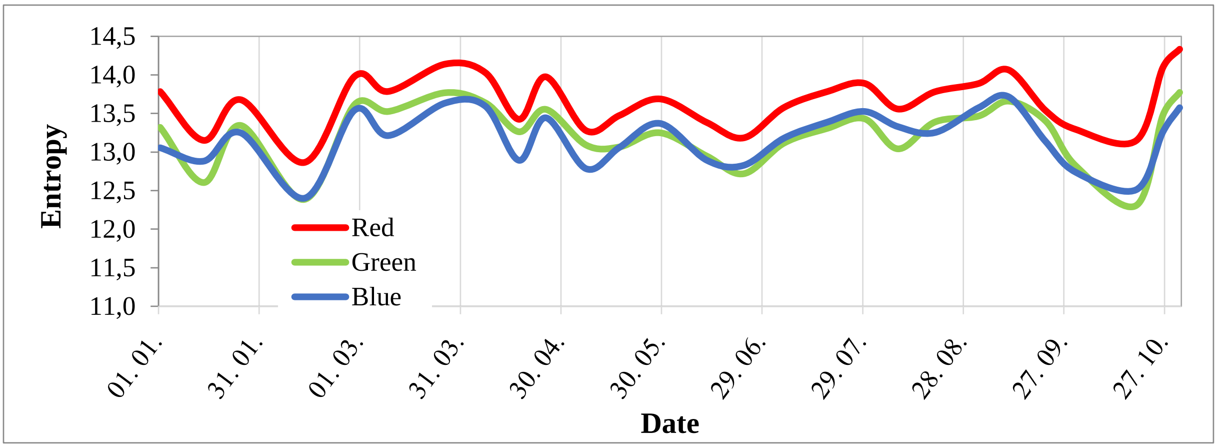

Figure 2. *Entropy values per band of RGB images*

Overall, the classification of the G (green) band using the ML method gave the most accurate results, although based on the entropy of the bands, the red band contains the most information (Figure 2), while the worst parameters were given by the classification of the RE band using the SAM method. In terms of the classes, the golden point, which is important for the tests, can best be observed by classifying the G (green) band with the ML method.

4.2. Interpretation of results

It helps to interpret the results if we can decide whether the result is acceptable or not for a group classified with a specific band and method. In the previous chapter, we presented the results classified by the given method and band based on accuracies, so it can be said for each group whether the result is adequate or not. This evaluation - that is, whether a group is "good" or not - can also be examined objectively, namely with a multivariate statistical method, clustering. In this case, we know the producer's and user's accuracy, the probability of commission and omission from the class for each group. These provide the input data of the method, based on which we want to classify the group into reliable and unreliable categories, that is, we want to classify them into 2 clusters (k-means clustering).

As a result of the clustering, two groups were created, the general parameter values of which are shown in Table 2. Group 1 contains the band/method/ROI combinations that lead to bad results, since their accuracy is low (<37%), but the probability of commission and omission is high (>63%). On the other hand, Group 2 contains those band/method/ROI combinations that gave good results, as their accuracy is high (>75%) and the probability of commission and omission is low (<25%).

Table 2. Average parameter values of two groups obtained as a result of clustering

Group / Parameter	Producer’s accuracy	User's accuracy	Commission	Omission
Group 1.	35.6	37.4	62.6	64.4
Group 2.	81.4	75.4	24.6	18.7

An important question is which band/method combinations belong to the identified groups, since this way it is possible to specify which of the above combinations should be used later, if we want to use hypertemporal images for classification. Figure 3 helps in this, based on which the above question can be clearly answered, so if we want to achieve adequate accuracy, one of the bands R, G, B must be used and classified using the Maximum Likelihood method. The reason for the accuracy of these three bands is probably the change in the green and red pigments of the vegetation during the vegetation period, the effect of which is reflected in the variance of the RGB values of the pixels - this is also shown by the entropy of the bands over time (Figure 2). This assumption is further supported by Figure 3, which shows that the classification of the images of the G (green) band gives the most accurate results.

In the case of the "underpowered" bands (RGB, RE, NDVI), a probable error factor may be that the RE, NDVI images were not located on the same axis as the other RGB, R, G, B bands. This also resulted in slips occurring between the images (the slippage of successive images at the same time was below 0.25%, but this error increased during the joint matching of the entire images recorded at 27 times), i.e., the area was not the same for every image (the resolution, of course, did not change). These slippages could also cause classification inaccuracies. However, the inaccuracy of the RGB images is certainly surprising, and the solution to this question requires further investigations.

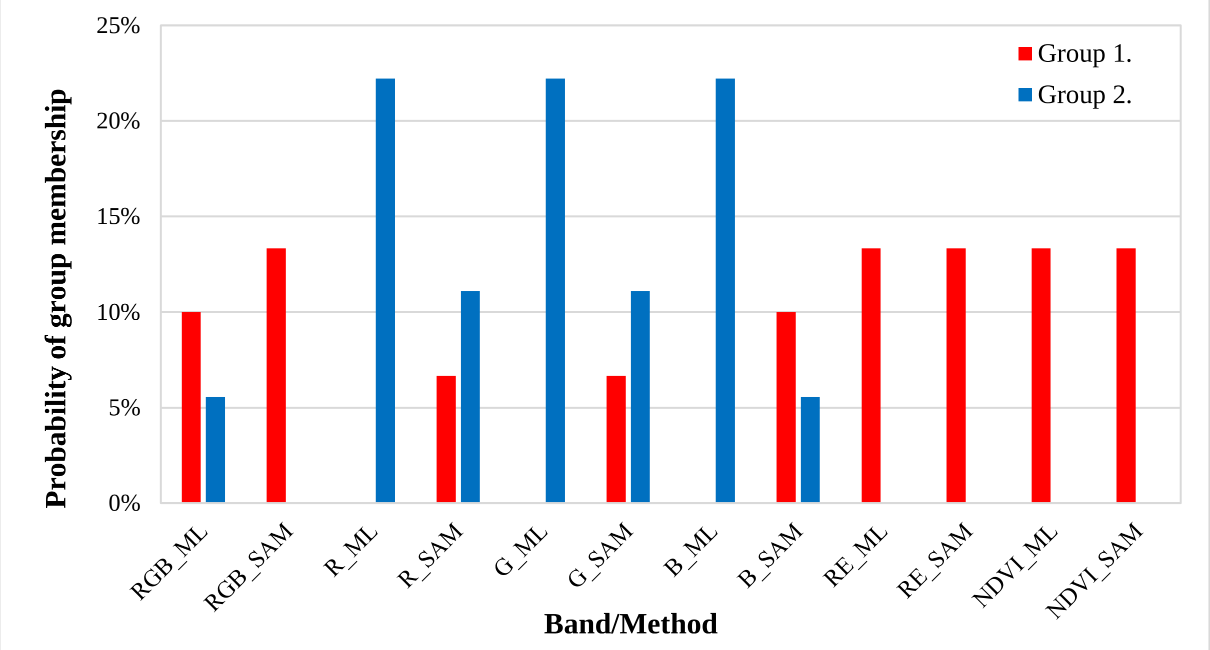

Figure 3. *Composition of groups obtained as a result of clustering based on band/method combinations*

5. Conclusions

Based on the conclusions drawn so far, it can be stated that RGB sensors are also partially suitable for vegetation monitoring studies using multitemporal images, namely, by evaluating the R band, adequate accuracy can be achieved, especially if the classification is carried out using the Maximum Likelihood method. It is important to point out that a perfect result can only be obtained by processing the panchromatic - that is, the images read directly from the sensor. The pixel values of RGB images contain data loss compared to the original recording, the extent of which we can only estimate, but this must be considered during interpretation.

When applying the methodology, it is worth paying attention to the recording of which time the topmost layer of the data cube contains, since this recording will be classified during processing. Of course, this also gives the possibility that if the recording of the data cube made at any time is placed in the top position, i.e., on the very first channel, then this recording is classified using the images made at all other times. In fact, this is where the efficiency of the method lies, that is, the classification is done using the images always made, so we get the most accurate classification possible (with the selection of the appropriate method).

When pre-processing the data, care must also be taken to ensure that the images are always taken from the same height and from the same area. In the case of multi-axis recording, this requirement is not fully met, so inaccuracies may occur during the classification (especially in the case of the SAM method), so it is more desirable to take single-axis images (e.g., using multitemporal sensors).

As a continuation of the work, after the methodological evaluation, it may be worthwhile to classify the images using the Maximum Likelihood method of the R band in such a way that the uppermost channel of the data cube is always a recording from a new time. In this way, a time series would essentially be created, with the help of which you can see the territorial changes of the goldenrod during the investigated vegetation period. This can lay the foundation for further nature conservation and intervention tasks, which would enable protection against the aggressively expanding adventive vegetation (in this case, tall goldenrod) within the territory of the Balaton-felvidéki National Park.

Acknowledgements

Project no. TKP2021-NVA-05 has been implemented with the support provided by the Ministry of Innovation and Technology of Hungary from the National Research, Development and Innovation Fund, financed under the TKP 2021 funding scheme.

References

Adão, T., Hruška, J., Pádua, L., Bessa, J., Peres, E., Morais, R., and Sousa, J. 2017. Hyperspectral Imaging: A Review on UAV-Based Sensors, Data Processing and Applications for Agriculture and Forestry. *Remote Sensing* **9** (11), 1110. https://doi.org/10.3390/rs9111110

Bácsatyai L., Márkus I. 2001. Fotogrammetria és távérzékelés. Kézirat, Sopron.

Carlson, T. N., and Ripley, D. A. 1997. On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment*. **62** (3), 241–252. https://doi.org/10.1016/s0034-4257(97)00104-1

Clevers, J. G. P. W., de Jong, S. M., Epema, G. F., van der Meer, F., Bakker, W. H., Skidmore, A. K., and Addink, E. A. 2001. MERIS and the red-edge position. *International Journal of Applied Earth Observation and Geoinformation*. **3** (4), 313–320. https://doi.org/10.1016/s0303-2434(01)85038-8

Enyedi, A. – Kozma-Bognár, V. – Berke, J. 2016. Comparison of imaging algorithms for remote sensing based on content and image structure, *Remote Sensing Technologies & GIS Journal*.**6** (6), 464-475.

Európai Unió Tanácsa 2009. A Tanács 428/2009/EK rendelete a kettős felhasználású termékek kivitelére, transzferjére, brókertevékenységére és tranzitjára vonatkozó közösségi ellenőrzési rendszer kialakításáról. Az Európai Unió Hivatalos Lapja. L 134/1. https://eur-lex.europa.eu/legal-content/HU/TXT/HTML/?uri=CELEX:32009R0428&from=en#ntr1-L_2009134HU.01000101-E0001

Feng, H., Tao, H., Zhao, C., Li, Z., and Yang, G. 2021. Comparison of UAV RGB Imagery and Hyperspectral Remote-sensing Data for Monitoring Winter-wheat Growth. https://doi.org/10.21203/rs.3.rs-170131/v1

Kevi, A., Berke J., Kozma-Bognár V. 2023. Comparative analysis and methodological application of image classification algorithms in higher education. Journal of Applied Multimedia 1./XVIII./2023 https://doi.org/10.26648/JAM.2023.1.002.

Kleynhans, W. 2011. Detecting land-cover change using MODIS time-series data. PhD Thesis. University of Pretoria. Pretoria.

Kozma-Bognár V. 2012. Hiperspektrális felvételek feldolgozásának és mezőgazdasági alkalmazásának vizsgálata. PhD Értekezés. Pannon Egyetem Állat- és Agrárkörnyezet-tudományi Doktori Iskola. Keszthely

Lillesand, T., Kiefer, R.W., and Chipman, J. 2015. Remote Sensing and Image Interpretation. Wiley, USA.

Lussem, U., Bolten, A., Gnyp, M. L., Jasper, J., and Bareth, G. 2018. Evaluation of RGB-based vegetation indices from UAV imagery to estimate forage yield in grassland. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. **42** (3), 1215–1218. https://doi.org/10.5194/isprs-archives-xlii-3-1215-2018

Maccioni, A., Agati, G., and Mazzinghi, P. 2001. New vegetation indices for remote measurement of chlorophylls based on leaf directional reflectance spectra. *Journal of*

Photochemistry and Photobiology B: Biology. **61** (1–2), 52–61. https://doi.org/10.1016/s1011-1344(01)00145-2

Mucsi L. 2013. Műholdas távérzékelés: Elmélet és gyakorlat. Szegedi Tudományegyetem Természeti Földrajzi és Geoinformatikai Tanszék, Szeged.

Nex, F., Armenakis, C., Cramer, M., Cucci, D. A., Gerke, M., Honkavaara, E., Kukko, A., Persello, C., and Skaloud, J. 2022. UAV in the advent of the twenties: Where we stand and what is next. *ISPRS Journal of Photogrammetry and Remote Sensing*. **184**, 215–242. https://doi.org/10.1016/j.isprsjprs.2021.12.006

Pinke Gy., Pál R. 2005. Gyomnövényeink eredete, termőhelye és védelme. Alexandra, Pécs.

Piwowar, J. M., Peddle, D. R., and LeDrew, E. F. (1998): Temporal Mixture Analysis of Arctic Sea Ice Imagery: A New Approach for Monitoring Environmental Change. *Remote Sensing of Environment.* **63** (3), 195–207. https://doi.org/10.1016/s0034-4257(97)00105-3

Richards, J. A. and Jia, X. 2005. Remote Sensing Digital Image Analysis: An Introduction 4th Edition, Springer, Berlin. https://doi.org/10.1007/3-540-29711-1

Schowengerdt, R.A. 1997. Remote Sensing. Models and Methods for Image Processing, 3rd Edition, Academic Press, Boston

Shannon, C. 1948. A Mathematical Theory of Communication. *Bell System Technical Journal*. **27**. 379–423.

Solymosi, K., Kövér, G., and Romvári, R. 2019. The Development of Vegetation Indices: a Short Overview. *Acta Agraria Kaposváriensis.* **23** (1), 75–90. https://doi.org/10.31914/aak.2264

Vastag, V. K. – Óbermayer, T. - Enyedi, A. – Berke, J. 2019. Comparative study of Bayer-based imaging algorithms with student participation, *Journal of Applied Multimedia*. **14** (1), 7-12. https://www.jampaper.eu, https://doi.org/10.26648/JAM.2019.1.002

Appendix 1. Commission/Omission and Producer Accuracy/User Accuracy values of the ROI's

Blue - Maximum Likelihood				
Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	71,17	72,04	27,96	28,83
Sedges	70,40	77,25	22,75	29,60
Goldenrod	90,26	86,32	13,68	9,74
Bush	88,05	80,27	19,73	11,95

Blue - Spectral Angle Mapper				
Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	55,47	43,49	56,51	44,53
Sedges	34,56	53,20	46,80	65,44
Goldenrod	53,20	60,04	39,96	46,80
Bush	82,35	55,26	44,74	17,65

Green - Maximum Likelihood				
Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	82,25	74,72	25,28	19,75
Sedges	81,00	85,91	14,09	19,00
Goldenrod	94,28	94,33	5,67	5,72
Bush	94,45	92,90	7,10	5,55

Green - Spectral Angle Mapper				
Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	61,79	45,59	54,41	38,21
Sedges	33,28	58,81	41,19	66,72
Goldenrod	76,09	66,08	33,92	23,91
Bush	79,60	71,55	28,45	20,40

RedEdge - Maximum Likelihood

Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	34,26	34,58	65,42	65,74
Sedges	12,52	37,46	62,54	87,48
Goldenrod	73,23	33,99	66,01	26,77
Bush	7,37	24,13	75,87	92,63

RedEdge - Spectral Angle Mapper

Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	33,50	21,10	78,90	66,50
Sedges	40,97	34,82	65,18	59,03
Goldenrod	1,63	26,52	73,48	98,37
Bush	31,95	20,72	79,28	68,05

Red - Maximum Likelihood

Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	72,28	69,44	30,56	27,72
Sedges	76,85	80,99	19,01	23,15
Goldenrod	91,61	90,63	9,38	8,39
Bush	90,44	88,17	11,83	9,56

Red - Spectral Angle Mapper

Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	53,90	39,50	60,50	46,10
Sedges	25,66	54,14	45,86	74,34
Goldenrod	70,40	60,83	39,17	29,60
Bush	76,79	61,18	38,82	23,21

RGB - Maximum Likelihood

Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	16,14	37,61	62,39	83,86
Sedges	39,82	57,34	42,66	60,18
Goldenrod	76,86	48,99	51,01	23,14
Bush	55,56	43,62	56,38	44,44

RGB - Spectral Angle Mapper

Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	19,86	23,51	76,49	80,14
Sedges	52,27	49,95	50,05	47,73
Goldenrod	57,18	46,61	53,39	42,82
Bush	16,96	23,36	76,64	83,04

NDVI - Maximum Likelihood

Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	5,14	24,86	75,14	94,86
Sedges	58,69	41,83	58,17	41,31
Goldenrod	49,05	39,07	60,93	50,95
Bush	20,90	26,62	73,38	79,10

NDVI - Spectral Angle Mapper

Class	Producer Accuracy	User Accuracy	Comission	Omission
Reeds	6,75	21,44	78,56	93,25
Sedges	55,03	40,14	59,86	44,97
Goldenrod	53,25	37,13	62,87	46,75
Bush	8,32	19,63	80,37	91,68

The rearrangement of protected plant species in the Batyk fen meadow warns of drying out

Kiszáradásra figyelmeztet a védett növényfajok átrendeződése a Batyki-lápréten

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Abstract: Previous drainage and current climate change are drying out native grasslands at wetland areas, with the result that sensitive wetland species are gradually disappearing. The success of conservation interventions to prevent this – which are designed to retain water –, will be measured by the ability of the managed meadow to retain its water-demanding species. The Batyk fen meadow is one of the most valuable wet grasslands along the valley of the river Zala. Water retention interventions were also needed and carried out here in the year of 2012. Our work assessed the success of the intervention in conserving the meadow's protected plant species. Between 2019 and 2021, we assessed the protected species of the site and compared them with the values of protected plant species previously reported from the site according to ecological indicator indicators (relative soil moisture and relative temperature) and Borhidi's Social Behaviour Types (SBT). We found that 40 protected plant species are currently present on the site, which is a high number compared to previous data, the number of protected species has increased in the fen meadow. However, this increase is partly due to the intensity of the survey focused on such species between 2019 and 2021, partly because the appearance of species that are indicative of drier habitats, whereas many of the valuable fen species were no longer present. Ecological indicator numbers show that the most moisture-demanding species have disappeared from the site, with a concomitant predominance of species with better competitive ability over specialists. This suggests that further water retention in the Batyk fen meadow is urgently needed to conserve water-demanding fen species on the long term.

Keywords: *fen meadow, ecological indicator values, climate change*

Összefoglalás: A korábbi vízelvezetések és a napjainkban zajló klímaváltozás a hazai láprétek kiszáradását vonja maga után, ami azzal jár, hogy az érzékeny lápi fajok eltűnnek. Az ennek megakadályozására végzett, vízvisszatartást szolgáló természetvédelmi beavatkozások sikerességét az mutatja meg, ha a kezelt rét meg tudja őrizni vízigényes fajait. A Batyki-láprét a Zala-völgy egyik legértékesebb láprétje, ahol szintén vízvisszatartó beavatkozásokra volt szükség, amit 2012-ben végezték el. Munkánk során azt vizsgáltuk, hogy a rét védett növényfajainak megőrzésében mekkora sikerrel járt a beavatkozás. 2019 és 2021 között felmértük a terület védett fajait majd összehasonlítottuk ökológiai indikátorszámok (relatív talajnedvesség és relatív hőigény) és Borhidi Szociális Magatartás Típusai (SzMT) szerint a területről korábban közölt védett növényfajok értékeivel. Megállapítottuk, hogy a területen jelenleg 40 védett növényfaj fordul elő, ami a korábbi évekhez képest magas szám, azaz a védett fajok száma nőtt a réten. Ugyanakkor ezt a növekedést a szárazabb élőhelyekre utaló fajok adják, az értékes lápi fajokból sok nincs már jelen. Az ökológiai indikátorszámok alapján a leginkább nedvességtűrő fajok eltűntek a területről, ezzel egyidőben a specialistákkal szemben a jobb kompetíciós képességű fajok kerültek túlsúlyba. Mindezek alapján a Batyki-lápréten sürgető feladat lenne további vízvisszatartás elvégzése a vízigényes lápi fajok megőrzése érdekében.

***Kulcsszavak**: láprét, ökológiai indikátorszámok, klímaváltozás*

1. Introduction

Human activity plays an important indirect role in the conservation of natural values in many cases. In Hungary, in areas with good water supply, treeless grassland habitats were almost without exception created through human mediation of traditional land use. These grasslands were used for extensive livestock production, as pastures or as mowing areas to provide biomass for supplementary winter feeding. These habitats can be associated with a number of rare, protected and community-associated species whose survival can only be ensured if the grassland character is maintained.

The conservation status of grasslands is threatened by a number of factors, including the fact that their economic value has declined to a fraction of its former value due to the decline of extensive livestock farming, leading to their abandonment and, in the long term, to scrub encroachment and the spread of competitive species (Valkó et al., 2018, 2021, Bódis et al., 2021). In addition, abiotic environmental factors are also undergoing significant changes, with climate change threatening the value of grasslands in several respects, with prolonged hot periods and extreme rainfall patterns becoming more common, posing a particular threat to the water supply of wetland and well-watered habitats (IPCC 1998, Burrkett & Kusler 2000).

Among the most threatened wetlands are fens and fen meadows, which are difficult or impossible to restore once they have dried out. These meadows have been drained for centuries, and many drainage ditches have been created on them in order to create arable land. In many places, conservation efforts have sought to mitigate the impact of drainage by blocking ditches or creating water retention sluices. This was the case in the Batyk fen meadow, where interventions to retain water were carried out in 2012 (Futó et al. 2013).

In our study, by reviewing the literature on the flora of the wetland and comparing them with the results of our botanical inventory carried out between 2019 and 2021, we aimed to investigate how the protected plant species assemblage of the Batyk fen meadow has been transformed over the last almost 7 decades as a consequence of the external environmental and anthropogenic impacts on the fen meadow, with a particular focus on the wetland species.

2. Material and methods

2.1. Study site

The sampling area of our research is in the northern part of Zala county, on the borders of Batyk, Zalabér and Türje. The Batyk fen meadow is one of the most valuable wetland meadow habitat complexes near the Zala river, which preserves many protected species and even fen meadow specialists (Fülöp et al. 2022). The area is part of the Alsó-Zala-völgy (HUBF20037) Natura 2000 site.

Figure 1. *Location of the sampling area (marked with a red dot)*

2.2. Methods

Literature review

We searched the literature for references to the Batyk fen meadow and organised the localities that relate to the occurrence of currently protected or highly protected plant species into a database. On this basis, two earlier periods were separated: 1938–1955 and 1990–2019. The sources used for the 1938–1955 period are Jávorka, Zólyomi, Boros ined., Boros (1953), Domokosné Nagy (1955); for the 1990–2019 period Palkó (1992), Lájer (1999), Kovács (2005), Óvári (2014, 2019), Vikár (2016).

Field surveys

During the period 2019–2021, the entire area of the marsh was surveyed from spring to autumn, during different vegetation periods, and all protected plant species were recorded, with the aim of a complete survey. This information has been added to the literature database, with the period 2019–2021.

Ecological indicator values

We illustrate the qualitative changes in the protected species assemblage of the Batyk fen meadow using ecological values. The species can be classified according to their ecological requirements and their role in natural systems. The first such scales were developed by Ellenberg in 1950, and several domestic adaptations have been published. In our work we used the Relative soil moisture figures (WB) and Relative temperature figures (TB) from Borhidi's (1993, 1994) classification. We also used the Social behaviour type (SBT) classification from Borhidi (1995).

Relative soil moisture figures (WB):

A value between 1 (Plants of extremely dry habitats or bare rocks) and 12 (Water plants, most wholly submersed in water) where higher numbers represent higher amount of water supply in the soil of the habitat where the species are usually present (Table 1).

Table 1. Relative soil moisture figures (WB) categories based on Borhidi (1994)

Value	Category
1	Plants of extremely dry habitats or bare rocks
2	Xero-indicators on habitats with long dry period
3	Xero-tolerants, but eventually occuring on fresh soils
4	Plants of semidry habitats
5	Plants of semihumid habitats, under intermediate conditions
6	Plants of fresh soils
7	Plants of moist soils not drying out and well aerated
8	Plants of moist soils tolerating short floods
9	Plants of wet, not well aerated soils
10	Plants of frequently flooded soils
11	Water plants with floating or partly emergent leaves
12	Water plants, most wholly submersed in water

Relative temperature figures (TB):

A value between 1 (Subnival or supraboreal) and 9 (Eumediterranean evergreen belt) where higher numbers represent higher heat supply of the habitat where the species are usually present (Table 2).

Table 2. Relative temperature figures (TB) categories based on Borhidi (1994)

Value	Category
1	Subnival or supraboreal
2	Alpine, boreal or tundra
3	Subalpine of subboreal belt
4	Montane needle-leaved forest of taiga belt
5	Montane mesophilous forest belt
6	Submontane broad leaved forest belt
7	Thermophilus forest or woodland belt
8	Submediterranean woodland and grassland belt
9	Eumediterranean evergreen belt

Social behaviour type (SBT):

Values between -3 (alien competitors) and +10 (unique specialists), the higher numbers represent more valuable species (Table 3).

Table 3. Social behaviour type (SBT) categories based on Borhidi (1995)

SBT	Main traits	Value
Natural habitats		
Specialists (S)	Low competitiveness, sensitive indicators of certain ecological factors.	+6
Competitors (C)	Dominant species of natural communities.	+5
Generalists (G)	Species of wide ecological range or tolerance in the natural plant communities.	+4
Natural pioneers (NP)	Species of initial stages of succession series.	+3
Disturbed habitats		
Disturbance tolerants (DT)	Pioneer elements of secondary succession	+2
Weeds (W)	Plant species living in heavily disturbed, artificial habitats.	+1
Introduced alien species (I)	Plants alien to a region and flora intentionally introduced and acclimatized as potential useful crops.	-1

Adventives (A)	Alien species to region and flora. Not intentionally introduced.	-1
Ruderal competitors (RC)	Dominant weeds of natural flora, with the ability to transform the habitat and modify successional trends.	-2
Aggressive alien species (AC)	Alien to region or flora, invading the gaps of natural or semi-natural communities and became dominant.	-3

3. Results

A total of 40 protected plant species were recorded during our field surveys (Fülöp et al. 2022).

Changes in Relative Water Moisture figures (WB) between 1938 and 2021:

Although most protected species of Batyk fen meadow apparently preferred wet soils in all three time periods, the decrease in numbers of the water-dependable species is clear through time. In the 1938–1955 period 11 species were present with WB values between 9 („plants of wet, not well aerated soils") and 11 („water plants with floating or partly emergent leaves"), this decreased first to only 7 species, then this number further decreased to 6, along with the complete disappearance of species with the highest WB (10: „plants of frequently flooded soils" and 11: „water plants with floating or partly emergent leaves") values (*Menyanthes trifoliata*, *Peucedanum palustre*, *Ranunculus lingua*). Species with WB values of 8 („plants of moist soils and tolerating short floods") were present in largest numbers in all periods. The number of species belonging to WB categories 7 or less all increased, especially category 4 („plants of semi-dry habitats"). In the last two periods even a xero-tolerant species (WB=3), *Allium carinatum* were present in the area (Figure 1).

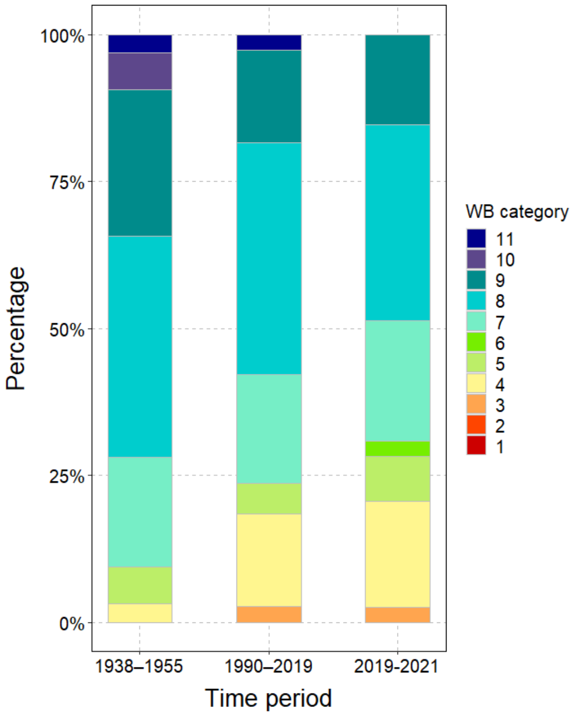

Figure 1. *Composition of WB values based on the species pool*

Changes in Relative temperature figures (TB) between 1938 and 2021:

During the assessed time period there was a distinct decrease in the number of species associated with the coldest climate category (TB=3, “subalpine of subboreal belt”) present in the area. The proportion of categories between 5 and 7 are increased, especially the number of species with TB=6 (“submontane broad leaved forest belt”). In this category in the first assessed time period only 3 species were recognized, after 2019 their number was 8.

The most populous category in all cases was the category 5 („montane mesophilous forest belt”), but before 1955 this only contained 46.8% of the species, in 2019–2021 it was 56.41%. The highest TB value found was TB=7 („thermophilus forest or woodland belt”), this included species *Fritillaria meleagris*, *Hemerocallis lilio-asphodelus*, *Anacamptis coriophora*, *Ornithogalum sphaerocarpum*, *Schoenus nigricans* after 2019. Before 1955 there were only 3 of these species, from 2014 there were 4. *Anacamptis coriophora* has disappeared from the area since 1955, and *Ornithogalum sphaerocarpum* and *Fritillaria meleagris* have been reported since 2014 (Figure 2).

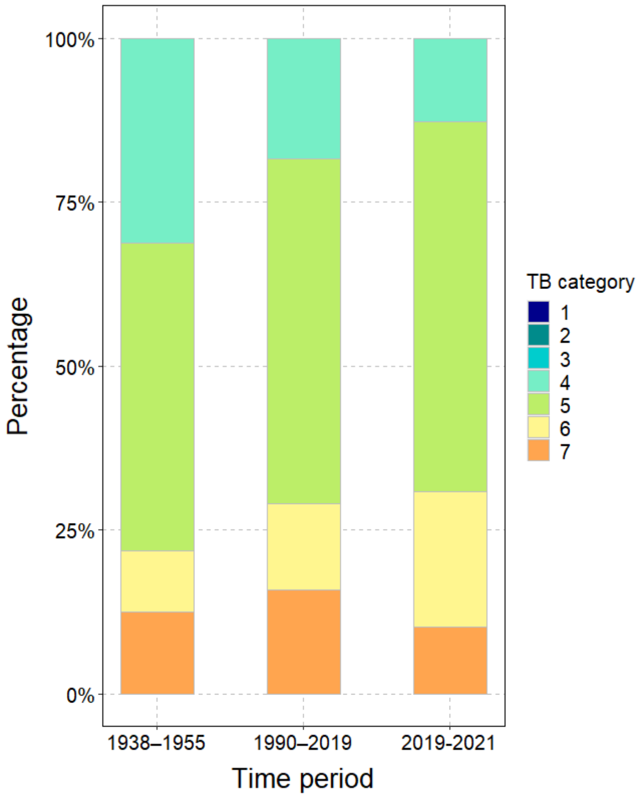

Figure 2. *Composition of TB values based on the species pool*

Changes in Social behaviour type (SBT) categories between 1938 and 2021:

In terms of social behaviour types, protected species observed on the Batyk fen meadow before 1955 ranged from specialists to natural pioneer species, with the clear dominance of specialists (48%). After 1990 disturbance tolerant species appeared as a new category and simultaneously the proportion of the two most valuable categories decreased. This tendency continued after 2019 and the number of generalist species became almost equal to the specialists. In overall, the number of protected species (viewed by 2022 legislature) increased from 31 to 37, then 40 (Figure 3).

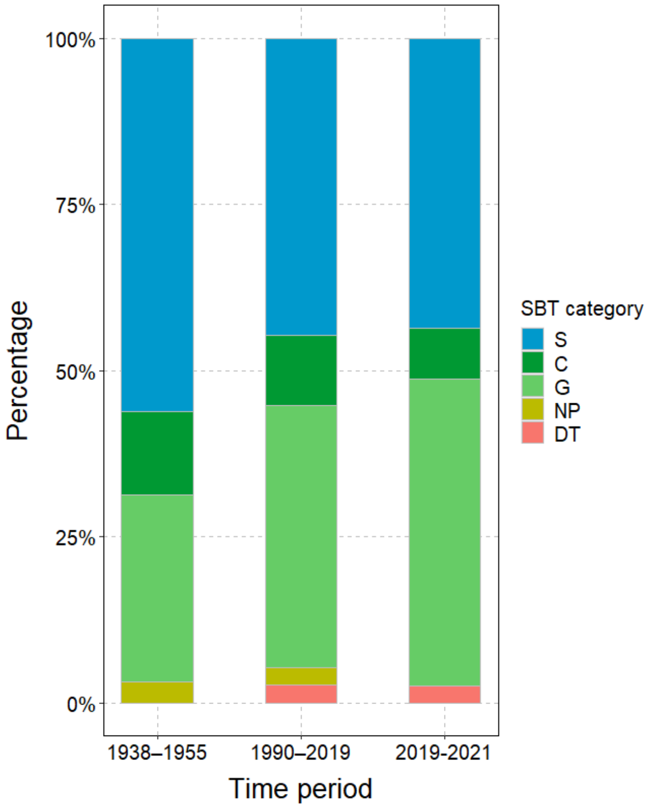

Figure 3. *Composition of SBT values based on the species pool*

4. Discussion

A significant proportion of the protected species associated with semi-arid or wetter habitats has disappeared from the area, while drought-tolerant species are present in significantly higher proportions.

Although the change in relative heat requirements is not as marked, the proportion of warmth-tolerant species has doubled, while the proportion of montane elements has halved.

Unique species were not previously abundant in the sample area, D. Nagy (1955) the time of the first detailed survey, fen meadow specialists made up the largest proportion of the species assemblage, but nowadays generalists have become predominant, while disturbance-tolerant species have also appeared.

Although the overall number of protected species has increased over time, specialists characteristic to the fen meadow were gradually disappearing. This tendency is linked with the decrease of number of species with the highest WB values. Among the specialists 5 species (*Dactylorhiza incarnata* subsp. *ochroleuca*, *Eriophorum latifolium*, *Menyanthes trifoliata*, *Pedicularis palustris*, *Ranunculus lingua*) became extinct in the area, which could not be counterbalanced with the appearance of 4 other specialists (*Dianthus superbus*, *Dryopteris carthusiana*, *Fritillaria meleagris*, *Leucojum vernum*), as most of them are characteristic to different habitats.

A significant change is the disappearance of species with the highest requirement for water. The rise of drought-tolerant species and the advance of heat-tolerant species is a less obvious phenomenon, while the number of species with better competitive ability are also increasing, taking the place of weaker competitors. Although these gradual changes have only a moderate effect on the overall natural value of the habitat, during this transformation we can lose species which have one of their last refuges here on a greater scale.

Acknowledgements

Supported by the ÚNKP-21-3 New National Excellence Program of the Ministry for Innovation and Technology from the source of the National Research, Development and Innovation Fund.

With the contribution of the LIFE Programme of the European Commission (LIFE17 IPE/HU/000018).

References

Bódis, J., Fülöp B., Lábadi V., Mészáros A., Pacsai B., Svajda P., Valkó O., Kelemen A. 2021. One year of conservation management is not sufficient for increasing the conservation value of abandoned fen meadows *Tuexenia*. **41**, pp. 381–394. https://doi.org/10.14471%2F2021.41.015

Borhidi, A. 1993. A magyar flóra szociális magatartás típusai, természetességi és relatív ökológiai értékszámai. JPTE Növénytani Tanszék, Pécs

Borhidi, A. 1995. Social behaviour types, the naturalness and relative ecological indicator values of the higher plants in the Hungarian Flora. *Acta Bot. Hung*. **39** (1–2): 97–181.

Burkett, V., Kusler, J. 2000. Climate change: potential impacts and interactions in wetlands of the United States. *Journal of the American Water Resource Association*. **36**, 313–320 https://doi.org/10.1111/j.1752-1688.2000.tb04270.x

Domonkosné Nagy, É. 1955. Vázlatok a türjei láprétek növényzetéről. *Annales historico-naturales Musei nationalis hungarici.* **47**, 181–188.

Ellenberg, H. 1950. Landwirtschaftliche Pflanzensoziologie I: Unkrautgemeinschaften als Zeiger für Klima und Boden. Ulmer, Stuttgart.

Fülöp, B., Király, G., Pacsai, B., Bódis, J. 2021. A Batyki-láprét védett és veszélyeztetett növényei: Protected and endangered plant species of the Batyk fen meadow In: Takács, Attila; Sonkoly, Judit (edits.); Advances in Research on the Flora and Vegetation of the Carpato-Pannonian Region" International Conference. Programme and Abstracts. Debrecen, Hungary. University of Debrecen, Faculty of Science and Technology, pp. 32–32.

Fülöp, B., Pacsai, B., Bódis, J. 2021. The role of haphazardly executed conservation treatments in the preservation of botanical values on the shore of Lake Balaton, *Gyepgazdálkoási Közlemények.* **19**, 21–23.

Fülöp B., Király G., Pacsai B., Bauer N., Bódis J. 2022. A Batyki-láprét botanikai értékei. *Botanikai Közlemények*. **109** (2) 231–256 https://doi.org/10.17716/BotKozlem.2022.109.2.231

IPCC (International Panel on Climate Change) 1998. The regional impacts of climate change: an assessment of vulnerability. In: Watson RT, Zinyowera MC, Moss RH (eds) A special report of IPCC working group II. Cambridge University Press, Cambridge

Lájer, K. 1999. Florisztikai adatok a Dunántúlról, valamint Vácrátót környékéről. *Kitaibelia.* **4** (2) 311–317.

Óvári, M. 2014. A Batyki láprét növényzetének változása in: Dénes, Schmidt D., Kovács M., Bartha D. (szerk.): Aktuális Flóra-és Vegetációkutatás a Kárpát-medencében, absztraktkötet.

Valkó, O., Venn, S., Zmihorski, M., Biurrun, I., Labadessa, R., Loos, J. 2018.: The challenge of abandonment for the sustainable management of Palaearctic natural and semi-natural grasslands. – *Hacquetia*. **17**, 5–16. https://doi.org/10.1515/hacq-2017-0018

Vikár, J. 2016. A Batyki-láprét florisztikai értékeinek változása 2015 és 2016 között. Szakdolgozat, Pannon Egyetem Georgikon Kar, Keszthely

Deforestation in Ghana

Erdőirtás Ghánában

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Abstract: This article seeks to highlight the increasing environmental problems in Africa with focus on deforestation in Ghana. The paper discusses how agricultural expansion, illegal mining and logging activities have become key driving factors of deforestation in the country due to increasing socioeconomic challenges and poor environmental protection policies. The devastating effects of deforestation in Ghana include biodiversity loss, land degradation and increase in water security issues. The dire situation posed by deforestation has become a national concern with strong public calls for immediate solution to the problem. Emphasis on the role stakeholders are to play in achieving environmental sustainability by promoting public awareness on deforestation, forest protection policy reforms, poverty alleviation, law enforcement and educational reforms are highlighted in this paper.

Keywords: *deforestation, illegal mining, illegal logging, environment, forest protection*

Összefoglalás: Ez a cikk az Afrikában egyre súlyosbodó környezeti problémákra kíván rávilágítani, különös tekintettel a ghánai erdőírtásra. A dokumentum tárgyalja, hogy a mezőgazdasági terjeszkedés, illegális bányászat és az illegális fakitermelés a fő hajtóereje az erdőírtásnak, elmélyítve a szociális-gazdasági kihívásokat és a gyenge környezetvédelmi politikát az országban. A Ghánában történő erdőírtás pusztító hatásai közé tartozik a biológiai sokféleség csökkenése, a földterület degradációja és a vízellátási problémák növekedése. Az erdőírtás okozta szörnyű helyzet nemzeti aggodalomra ad okot, és a nyilvánosság erőteljesen követeli a probléma azonnali megoldását. Ebben a cikkben hangsúlyt kap az érdekelt felek szerepe a környezeti fenntarthatóság elérésében az erdőírtással, az erdővédelmi politika reformjával, a szegénység enyhítésével, a bűnüldözéssel és az oktatási reformokkal kapcsolatos tudatosság növelésével.

Kulcsszavak: *erdőírtás, illegális bányászat, illegális fakitermelés, környezet, erdővédelem.*

1. Introduction

The environment we live in thrives on ecological balance. An ecosystem consisting of a complex mix of a myriad elements depending on one another for existence (Anjum, 2020)**.** Humans are a critical part of this ecosystem. As the human population increases, the greater the influence on the environment. United Nations (UN) report (2019) estimates that world population is expected to grow to 8.5 billion people in 2030 and 9.7 billion by the year 2050. The Anthropocene era is proving too expensive for the planet, the actions of mankind have become detrimental, threatening the stability needed for the survival of all aspects of the ecosystem. In some cases, these actions lead to irreversible consequences including extinction of species (Wodak, 2020). The quest for survival is fundamentally changing the biology and geology of the planet through acidifying coral reefs, mining of minerals and cutting down trees (Crutzen and Schwägerl, 2011).

The Food and Agriculture Organization (FAO) indicated in 2020 that forests form about 31% of the total land cover of the earth with an estimated area of 4.06 billion hectares providing habitat for most of the Earth's terrestrial biodiversity which consists of different animal and plant species. Forests provide homes to millions of indigenous people across the globe as well as serving as means livelihood providing jobs, food and fuel to millions across the globe report (FAO, 2020a; UN, 2015). Forests serve as carbon sinks, filtering out harmful gases from the atmosphere which are crucial to the greenhouse effect and climate change (Dean, 2019). Hence, there is no challenging the importance of forests to the different life forms that exist on the planet however, they are under serious threat around the globe due to deforestation. Deforestation is defined as the conversion of forests to other land use or the long-term reduction of tree canopy cover (FAO, 2007). Tropical forests spread across South and Central America, Central Africa and South East Asia. World Wide Fund for Nature (WWF) report (2022) indicates that tropical forests region which serves as home to a wide range of flora and fauna biodiversity and has unfortunately seen an alarming increase in deforestation in the past century. This is a very devastating situation, especially since tropical forests provide habitat to about two thirds of the world's total biodiversity (Mulatu et al., 2017). The Amazon forest in the past 50 years has lost close to 17% of its forest and in Brazil, deforestation in the year 2020 increased exponentially resulting in global concerns and demand for measures to halt the rise (Silva Junior et al, 2020; WWF, 2022). South America and Africa were reported as the regions with the largest carbon dioxide (CO_2) emissions in 2020 with emissions of 1 billion tonnes of CO_2 each. This article seeks to study deforestation in tropical forests with focus on Ghana, highlighting current situations and discussing possible measures of mitigation (FAO, 2020b).

2. Deforestation in Ghana

The Republic of Ghana in West Africa is characterized by a tropical climate. The country has a total land cover area of 238,535km^2 and a 550km long coastline. Annual mean temperatures range between 24°C and 36°C with relative mean humidity of about 81%. Annual rainfall ranges from 800mm to 2000mm depending on the ecological zone due to climate variability. The northern part of Ghana which is characterized by the savannah zone experiences little rainfall as compared to the southern part of the country with evergreen and forest areas (Owusu et al., 2021).

Ghana, like most developing countries with tropical forests is not immune to deforestation. Ghana has lost about 20% of its forest area from the year 1990 till date. The country had an estimated forest cover around 9,924,000ha in 1990 which has reduced to about 7,976,000ha today (Guuroh et al., 2021). Ghana is listed in a report by WWF as one of 24 deforestation fronts in the world (Pacheco et al., 2021). The report highlights these deforestation fronts as places noted with high concentration of deforestation zones where remaining forests are under serious threat. Deforestation in the country is ongoing also in some protected forests as shown Figure 1 resulting in increased national biodiversity losses. Currently in Ghana, the western chimpanzee is listed as an endangered species due habitat loss resulting from deforestation (Evans et al., 2021).

Figure 1. *Essen Epam Forest Reserve, Ghana. March, 2022. Photos by Thomas Omari.*

3. Driving Factors of Deforestation in Ghana

3.1. Agricultural Land Expansion

Agricultural expansion is at the front of deforestation in Ghana. 45% of the country's over 31 million population are employed in the agricultural sector making it an integral part of Ghana's economy (Quacou, 2016). Cash crops such as cocoa, oil palm, coconut, rubber, mango, citrus and cashew which are mostly mono-cropped on large scale in the country, require the clearing of huge tracts of land usually forests for their production. The farmers often employ the shifting cultivation system where new tracts of land are cleared usually by slash and burn methods. This has resulted in the destruction of many forests in the country as illustrated in Figure 2 (FC 2021a).

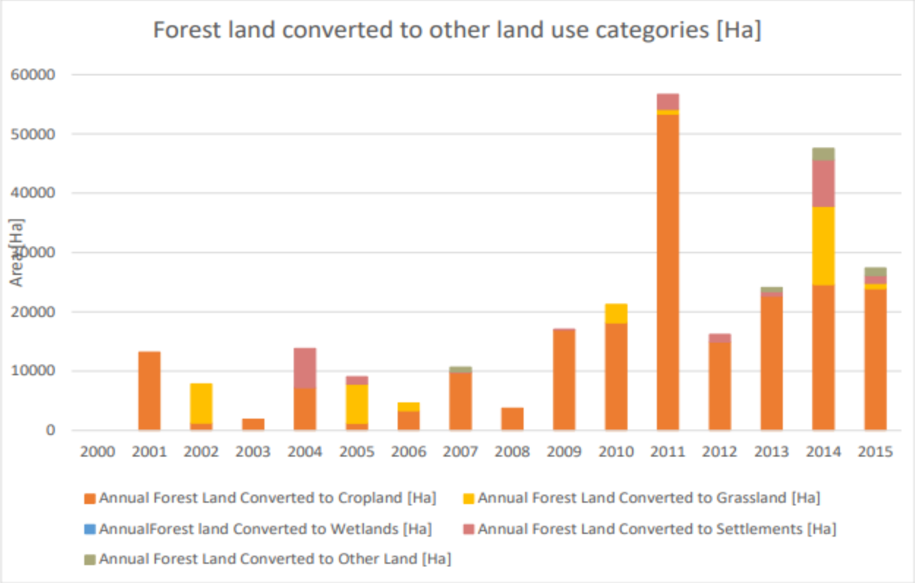

Figure 2. *Illustration affirming the conversion of most forest land to cropland in Ghana. (Sourced from Forestry Commission, Ghana's National Forest Reference Level, 2021)*

3.2. Illegal Tree Logging Activities

The rich wealth of natural resources of Ghana include its forest with different species of timber. Ghana secured a cumulative €113,522,746.51 from the export of 248,657.909m^3 timber products from January to October, 2021. The export products consisted of lumber, billet, briquettes, sliced veneer, rotary veneer and plywood from different tree species such as Teak (*Tectona grandis*), Wawa (*Triplochiton scleroxylon*), Ceiba (*Ceiba pentandra*), Essia (*Petersianthus macrocarpus*) and Denya (*Cylicodiscus gabunensis*) to about 40 countries including Belgium, India, Togo, Germany and United States of America (FC, 2021b).

Figure 3. *Logging activities in the Essen Epam & Esuboni Forest Reserve, Ghana. March, 2022. Photos by Thomas Omari.*

Unfortunately, not all logging activities are regulated and documented in the country. Illegal logging has become an undeniable factor in the increase in deforestation in Ghana and a serious threat to forests as shown in Figure 3 (FC, 2021b). Illegal logging involves harvesting trees in protected forests in violation of rules that govern which trees may be cut, where, when and in which quantities to cut (Hansen, 2010). Rosewood (*Pterocarpus erinaceus*) native to the forests of West Africa has become highly sought after in the illicit wood trade due to the exponential increase in demand on the international market especially in China resulting in rosewood becoming an endangered tree species in Ghana consequently resulting in series of national bans on harvesting and exporting of rosewood since 2012 as illustrated in Table 1 (Kansanga et al., 2021; Zhu, 2020).

Table 1. African Rosewood exports from Ghana 2007–2018. Bans imposed in 2012, 2014 and 2017. Compilations of Ghana Forestry Reports. (Adapted from Kansanga et al., 2021).

Year	Volume (M^3)	Value (€)
2018	23,211.96	17,017,811.66
2017	**57,383.38**	**39,370,242.41**
2016	96,357.03	63,594,584.62
2015	3,124.63	2,096,486.24
2014	**20,804.53**	**9,371,462.00**
2013	40,984.31	19,862,066.95
2012	**8,570.79**	**3,575,714.70**
2011	127.034	21,894.69
2010	1,569.95	533,021.94
2009	1,032.04	286,062.53
2008	331.91	76,842.07
2007	315.3	76,238.90

Wood collection by rural folks and charcoal burning business are also a contributing factors to the depletion of forests in Ghana. Unfortunately, a large number of households in Ghana still rely on charcoal as energy source for cooking (Asante, 2019). Charcoal producers harvest trees to produce charcoal to meet the demands of buyers without regards to the impact it causes to the environment. Deforestation due to wood fuel harvest is particularly widespread in the Savannah ecological zones of northern Ghana (Dumenu, 2019).

3.3. Illegal Mining Activities

Ghana for centuries was known as the “The Gold Coast” due to the discovery of large deposits of gold in the soil during the colonial times. According to the Ghana Chamber of Mines (2020), Ghana maintained its position as Africa’s leading producer of gold and the 6th gold producing country in the world. The report indicated gold accounted for 97.2% gross mineral revenue with bauxite, diamonds and manganese accounting for 0.54%, 0.01% and 2.25% respectively, establishing gold as an important part of the country’s mining industry.

Small-scale mining in Ghana dates back to pre-colonial times where simple alluvial mining methods were employed. In recent times, small scale-mining has become more sophisticated, intensified and destructive causing serious environmental problems and threatening the livelihoods of people (Bansah et al., 2016). Unlike commercial mining where legal concessions are legally given and controlled, small-scale mining locally called “Galamsey” is plagued with a lot of illegal mining activities. The methods employed by miners involved in illegal mining are often crude. Many lose their lives in the pursuit of gold due to landslides and mine cave-ins, those who do not suffer adverse effects of exposure to dangerous chemicals and heavy metals (Salifu et al., 2013). Mining activities together with the use of mercury have resulted in the pollution of important river bodies and the contamination of soils in mining areas. Previously forested lands have been stripped bare, land degradation and deforestation have increased exponentially. Currently there is intense public outcry and pressure on the government to clamp down as the devastating effects of the mining activities have become more visible with the pollution of more rivers across the country as shown in Figure 4 (Hilson et al., 2014).

The presence of weak legal and regulatory framework for the enforcement of environmental protection laws have resulted in the situation where there is no consistency and transparency when it comes to small-scale exploitation of natural resources in the country. Especially with regards to licensing and issuing of permits creating the perfect grounds for political leniency, hierarchical corruption, nepotism, non-compliance with standards and tax evasion (Abdulai, 2017). There have been cases where officials responsible for protecting national interest have been found to be involved in illicit forest resource exploitation (Gyamfi et al., 2021).

Figure 4. *Polluted Pra River as a result of illegal mining activities in Ghana (October, 2022). Photo by Richard Omari.*

3.4. Rapid Increase in Urbanization

In recent times, forest areas in the country have increasingly diminished mainly due to their conversion to agricultural lands and settlement areas as a result of rapid population growth, industrialization and urbanization (FC, 2021b). The population of Ghana has increased from 24.7 million people in 2010 to about 31 million in the past decade according to a report by the Ghana Statistical Service (GSS) in 2022. Rural communities around bigger cities like the capital, Accra, Kumasi and Takoradi are rapidly urbanizing leading to encroachment problems to forests in close proximity to urban sprawls and cities. The problem seems to compound each year with the increase in rural-urban migration due to poverty and low employment opportunities in certain parts of the country forcing the youth to seek greener pastures in other cities and towns (Cobbinah and Erdiaw - Kwasie, 2018).

3.5. Land Ownership Systems

In Ghana about 80% of the total land area is held under customary land tenure system. This places ownership of lands to heads of family and clans, The lands under the ownership of the government for public works form about 20% (Sarpong, 2006). Woefully, it is common to find some of the people engaging in the illicit activities of illegal mining and tree logging in the country with permission from some traditional heads who are supposed to be custodians of the land making it difficult for implementation of government policies against perpetrators of deforestation (Banchirigah, 2008).

3.6. Poor Knowledge on Forest Protection

The local people involved in illegal forest exploitation sometimes are unaware of the consequences their actions leave behind. Most of the areas suffering forest depletion in Ghana are close to rural settlements where formal education is low and unemployment is high. The local people often engage in these activities considering it as a genuine source of income without having any thoughts with regards to environmental protection since they believe the land belong to the indigenes of the land who should be allowed to benefit from the lands. They see the government's efforts of stopping their activities as a form of oppression (Tuokuu et al., 2020).

4. Mitigating Deforestation in Ghana

Institutional strengthening and policy reform is needed in the forestry management sector in the country. This is necessary to reduce and check corruption in the natural resource exploitation sector. Legal framework that will hold members in position accountable and ensure high commitment to the elimination of malpractices in the forest sector. These policy reforms should dictate proper punitive measures to perpetrators irrespective of social connections and ranks to deter others from partaking. Policy reforms should also give forestry officials the independence to do their duties diligently and freely without external influences as well as provide conducive working conditions to serve as motivation against bribery and corruption. "Operation Vanguard" a joint military-police intervention recently launched by the President of Ghana in 2017 in the Ashanti, Western and Eastern Regions of Ghana to clamp down on illegal mining, saw a number of mining sites being shut down. This intervention resulted from general public outrage on the increase in production cost by the Ghana Water Company for treating water sourced from water bodies polluted by illegal mining. The operation saw to the seizure and destruction of mining machines and equipment at various mining sites (Abdulai, 2017). Another intervention by the Government of Ghana is the "Green Ghana Day" an annual day purposed for planting millions of trees nationwide which was started in June, 2021. The program saw to the successful planting of over 5 million trees 2021. The next year saw to the planting of about 20 million trees in 2022 (FC, 2022). Sustaining such policies is vital to the preservation of forests in the country.

Also, ensuring environmental sustainability and forest management in Ghana requires the active participation of every citizen of the country. Multi-stakeholder consultation and participation is necessary in solving deforestation problems. The traditional heads, governmental heads, local people, forestry officials, law enforcement officers and ultimately all Ghanaians should be made aware of the extent of damage and the need for long-term, sustainable ways of protecting the forests. More education and awareness on deforestation issues is needed especially communities where the problem is prevalent as most people engaging in illegal activities have been found to be mostly unemployed with little or no formal education (Azumah et al., 2019).

Governmental policies should be directed at improving the socioeconomic status of the rural communities in Ghana. Interventions should be aimed at making productive use of the active population in the mining communities by creating employment opportunities in areas of forest management to give the people a means to provide for the families without engaging in illicit activities detrimental to the environment.

5. Conclusions

The clarion call for the address of deforestation in Ghana can no longer be ignored. The physical evidence of the damage being caused in the country are too overwhelming. The rivers are muddied and polluted such that accessibility to drinking water is under threat, biodiversity is diminishing, farm lands are degraded, and forests are being lost at alarming rates. There is the need for active participation of all stakeholders, government leaders, traditional rulers and officials and to ensure environmental safety and sustainability.

Institutions in authority should ensure proper monitoring of forest and proper investments put into safeguarding forest reserves in Ghana. As the country strives to restore depleted forest and reclaim degraded lands by planting more trees, it is important to protect the ones that are still left and limit further destruction.

References

Abdulai, A.-G. 2017. The Galamsey Menace in Ghana: A Political Problem Requiring Political Solutions? University of Ghana Business School. Policy Brief No.5.

Anjum, R. 2020. The Concept of Ecological Balance and Environmental Conservation: An Islamic Perspective. https://doi.org/10.13140/RG.2.2.13164.80003

Asante, J. 2019. Estimating National Charcoal Production in Ghana.

Azumah, F. D., Baah, E. and Nachinaab, J. O. (2019): Causes and Effects of Illegal Gold Mining (Galamsey) Activities on School Dropout and Residents at the Tutuka Central Circuit in Obuasi Municipality in Ashanti Region. Ghana. *Journal of Education*. **201** (3) 1–12. https://doi.org/10.1177/0022057420905109

Bansah, K., Yalley, A. B. and Dumakor-Dupey, N. 2016. The Hazardous Nature of Small Scale Underground Mining in Ghana. *Journal of Sustainable Mining*. **15** (1) 8–25. https://doi.org/10.1016/j.jsm.2016.04.004

Banchirigah, S. M. 2008. Challenges with Eradicating Illegal Mining in Ghana: A Perspective from the Grassroots. *Resources Policy*. **3** (1) 29–38. https://doi.org/10.1016/j.resourpol.2007.11.001

Cobbinah, P. and Erdiaw - Kwasie, M. 2018. Urbanization in Ghana: Insights and Implication for Urban Governance. https://doi.org/10.4018.978-1-5225-5646-6.ch012

Crutzen, P. J. and Schwägerl C. 2011. Living in the Anthropocene: Toward a New Global Ethos. Yale E360.

Dean, A. 2019. “Deforestation and Climate Change” Climate Council. https://www.climatecouncil.org.au/deforestation/ Assessed on 8th March, 2022.

Dumenu, W. K. 2019. Assessing the Impact of Felling/Export Ban and CITES Designation on Exploitation of African Rosewood (Pterocarpus erinaceus). *Biological Conservation.* **236** 124–133. https://doi.org/10.1016/j.biocon.2019.05.044

Evans, T., Wingard, J. and Humle, T. 2021. The Mitigation Hierarchy in Environmental Impact Assessment and Related Legislation as a Tool for Species Conservation: A Case Study of Western Chimpanzees and Mining Development. *Biological Conservation*. **261** 109237. https://doi.org/10.1016/j.biocon.2021.109237

FAO and the United Nations Environment Programme (UNEP) 2020.: The State of the World's Forests 2020. Forests, biodiversity and people, Rome. https://doi.org/10.4060/ca8642en

FAO 2020. Forest Land Emissions and Removals. Global, Regional and Country Tends. 1990-2020. FAOSTAT Analytical Brief 12. Rome.

FAO 2007. Definitional Issues Related to Reducing Emissions from Deforestation in Developing Countries. Forests and Climate Working Paper 5. Rome.

Forestry Commission 2021. Ghana Forest Reference Level (FRL) / Forest Reference Emissions Level (FREL) 2001 - 2015 (Revised). Submissions on Proposed Reference Level. https://redd.unfccc.int/submissions.html?country=GH. Accessed on 18th March, 2022.

Forestry Commission 2021. Population, Status, Trade and Sustainable Management of African Rosewood Pterocarpus erinaceus in Ghana. https://cites.org/sites/default/files/ndf/Rosewood_NDF_Ghana_Final_0.pdf. Accessed on 28th March, 2022.

Forestry Commission 2022. President Launches Green Ghana Day 2022 Edition. News & Events. https://fcghana.org Accessed on 28th March, 2022.

Ghana Chamber of Mines 2020. Mining Industry Statistics and Data.

Ghana Statistical Service 2022. Ghana 2021 Population and Housing Census. General Report. Volume 3N.

Guuroh, R. T., Foli, E. G., Addo-Danso, S. D., Stanturf J. A., Kleine, M. and Burn, J. 2021. Restoration of degraded forest reserves in Ghana. *Reforesta.* **12** 35–55. https://doi.org/10.21750/REFOR.12.05.97

Gyamfi, E., Derkyi, M. A. A. and Brobbey, L. K. 2021. Insights, Motives, And Means Of Overcoming Forest Offenses In Ghana's Forestry Sector: The Case of the Bibiani Forest District. *Scientific African* **13** e00962. https://doi.org/10.1016/j.sciaf.2021.e00962

Hansen, C. P. 2010. Assessing Illegal Logging in Ghana. *International Forestry Review*. **10**. 573–590. https://doi.org/10.1505/ifor.10.4.573

Hilson, G., Hilson, A. and Adu-Darko, E. 2014. Chinese Participation in Ghana's Informal Gold Mining Economy: Drivers, Implications and Clarification. *J. Rural Stud*., **34** 292–303. https://doi.org/10.1016/j.jrurstud.2014.03.001.

Kansanga, M. M., Dinko, D. H., Nyantakyi-Frimpong, H., Arku G. and Luginaah, I. 2021. Scalar Politics and Black Markets: The Political Ecology of Illegal Rosewood Logging in Ghana. *Geoforum.* **119** 83–93. https://doi.org/10.1016/j.geoforum.2020.12.020

Mulatu, K. A., Mora B., Kooistra, L. and Herold, M. 2017. Biodiversity Monitoring in Changing Tropical Forests: A Review of Approaches and New Opportunities. *Remote Sensing*. **9** (10) 1059. https://doi.org/10.3390/rs9101059

Owusu, V., Ma W., Emuah, D. and Renwick, A. 2021. Perceptions and Vulnerability of Farming Households to Climate Change in Three Agro-Ecological Zones of Ghana. *Journal of Cleaner Production.* **293** 126154. https://doi.org/10.1016/j.jclepro.2021.126154

Pacheco, P., Mo, K., Dudley, N., Shapiro, A., Aguilar-Amuchastegui, N., Ling, P.Y., Anderson, C. and Marx, A. 2021. Deforestation fronts: Drivers and responses in a changing world. WWF, Gland, Switzerland.

Quacou, E. I. 2016. Unsustainable Management of Forests in Ghana from 1900-2010. *International Journal of Environmental Monitoring and Analysis*. **4** **(**6) 160–166. https://doi.org/10.11648/j.ijema.20160406.14

Salifu, O., Oladejo, N. K. and Adetunde, I. A. 2013. Gold Production and the Ghanaian Economic Performance.

Sarpong, G. A. 2006. Improving Tenure Security for the Rural Poor. Ghana-Country Case Study. Food and Agriculture Organization of the United Nations. Support to the Legal Empowerment of the Poor (LEP). https://www.fao.org/3/k0783e/k0783e.pdf. Accessed on 23rd March, 2022.

Silva Junior, C. H. L., Pessôa, A. C. M. and Carvalho, N.S. 2021. The Brazilian Amazon Deforestation Rate in 2020 is the Greatest of the Decade. *Nat Ecol Evol.* **5** 144–145. https://doi.org/10.1038/s41559-020-01368-x

Tuokuu, F. X. D, Idemudia, U., Bawelle, E. B. G and Sumani, J. B. B 2020. Criminalization of "Galamsey" and Livelihoods in Ghana: Limits and Consequences. *Natural Resources Forum. United Nations Sustainable Development Journal*. **44** (1) 52–65 https://doi.org/10.1111/1477-8947.12189

United Nations 2019. World Population Prospects 2019.

United Nations 2015. What role do indigenous people and forests have in a sustainable future?

Wodak, J. 2020. (Human-Inflected) Evolution in an Age of (Human-Induced) Extinction: Synthetic Biology Meets the Anthropocene. *Humanities.* **9** (4) 126. https://doi.org/10.3390/h9040126

World Wide Fund for Nature 2022. Deforestation and Forest Degradation.

Zhu, A. L. 2020. China's Rosewood Boom: A Cultural Fix to Capital Over accumulation, *Annals of the American Association of Geographers.* **110** (1) 277–296. https://doi.org/10.1080/24694452.2019.1613955

3D printing in agriculture - review

3D nyomtatás a mezőgazdaságban - áttekintés

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Abstract: Additive Manufacturing techniques are more and more popular in the word. The most popular name of it is 3D printing. This solution is used in many different areas and applications. This work is a review that concentrate the applications of 3Dprinting in agriculture. The paper discusses the different tools and devices used in agricultural producing, sensors that can be used for process monitoring. In both fields There are many types of raw material that use in this technology, but the most popular at the PLA and the ABS. The popularity of these come from the low prise and the easy and many side usability. An interesting area of printable materials is the usage of agricultural wastes such as nut and crab shells, etc. An interesting usage of 3D printing when we are printing food. This should be helps for sick person who has swallowing problems or unique look at can be created with it for example for a restaurant.

***Keywords**: 3D printing; agriculture; food processing*

Összefoglalás: A 3D nyomtatást - hivatalos nevén additív gyártás - számos különböző alkalmazásban használják már sikeresen a világon. Ez a cikk a 3D nyomtatás mezőgazdasági, élelmiszer-feldolgozási és felügyeleti felhasználási eseteinek áttekintését mutatja be. A munka bemutatja a mezőgazdasági termelésben használt különböző eszközöket és berendezéseket, valamint olyan érzékelőket, amelyeket ennek a technológiának a segítségével lettek hatékonyabbak/olcsóbbak/jobbak. Bár számos nyomtatási alapanyagot ismerünk a műanyagtól a fémig, mégis a PLA és az ABS hőre lágyuló műanyagok a legelterjedtebbek, mivel a többihez képest olcsóak és könnyen nyomtathatóak. Az alapanyagok közül érdekes terület a mezőgazdasági hulladékok, melyekre kiváló például a dió- és rákhéjak felhasználása. Egy másik fontos alkalmazás az élelmiszerek közvetlen extrudálása, amely segítséget tudnak nyújtani a nyelési nehézségekkel küzdő embereknek, hogy könnyebben és jobb minőségben tudjanak táplálkozni. További előnye ennek az eljárásnak, hogy speciális étrendek alakíthatóak ki, amely testre szabható és változatos étrendet eredményez. A 3D nyomtatás alkalmazási területei várhatóan bővülni fognak és egyre újabb és újabb területek fog megjelenni.

***Kulcsszavak**: 3D nyomtatás; mezőgazdaság; élelmiszer feldolgozás*

1. Introduction

In various industries, there is a growing focus on 3D printing in the field of manufacturing. Due to its widespread adoption, it offers a sustainable and efficient method for creating various objects layer by layer (Dizon et al., 2018). This technology significantly reduces waste and production time compared to traditional manufacturing, which often involves subtractive processes, where a portion of the material is removed from a larger whole to create the desired product. An undeniable advantage of 3D printing over traditional manufacturing is its ability to create complex shapes, some of which may be unachievable with current technologies. The burden of high costs associated with traditional manufacturing is also greatly reduced through additive manufacturing (Dizon et al., 2020).

Additive manufacturing is widely used in various fields, including the construction industry, electronics, automotive manufacturing, personal protective equipment, space exploration, the study of various marine life forms, defence, and more (Carolo and Haines, 2020, Espera et al., 2019, Advincula et al., 2020, Al-Dulimi et al., 2021, Wong, 2016, J. Mohammed, 2016, Peels, 2017). Furthermore, 3D printing is becoming increasingly prevalent in industrial applications where time is a critical factor, such as rapid prototyping, rapid tooling, and fast production (Dizon et al., 2018, Diego et al., 2021, Dizon et al., 2021, Valino et al., 2019, Dizon et al., 2019, Dong et al., 2015). Additive manufacturing is also finding broader applications in the medical field (Advincula et al., 2020), water purification and desalination (Dong et al., 2015, Tijing et al., 2021). In agriculture, 3D printing is primarily used for the production of agricultural tools (Pearce, 2015) and components (Podchasov, 2021a). The food industry primarily uses 3D printing to accelerate personalized nutrition (Derossi et al., 2018) and to assist individuals with swallowing difficulties in increasing their food intake (Pant et al., 2021). Regarding environmental protection, relevant applications of additive manufacturing include the use of recycled filaments (M. I. Mohammed et al., 2019) and components for devices used in air quality monitoring (Salamone et al., 2015) and wastewater treatment facilities (Martín de Vidales et al., 2019).

There are numerous 3D printing technologies, each of which uses various materials. One of the most popular technologies is fused deposition modelling (FDM) because it offers consumer-grade materials (filaments) such as acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) (Dizon et al., 2018). Additionally, it can be used to directly 3D print food using the printer head. It can build food layer by layer or pour it into a mold (for example, 3D-printed puree (C. Liu et al., 2018)), which can also be created using 3D printing technology.

The application of 3D printing represents the future of manufacturing across various industries and sectors (Jan Lloyd at al., 2021). It is a revolutionary technology where efficiency and sustainability go hand in hand, offering significant improvements in the way we design and manufacture products. This overview article provides insights into the applications of 3D printing in agriculture, food production, and monitoring, as well as the applied technologies and materials used in these fields.

2. Overview of Additive Manufacturing

Manufacturing can be divided into groups according to many aspects. One such breakdown defines two broad groups. One is the additive - and the other is subtractive manufacturing. Subtractive manufacturing is the process of removing parts from a solid material to create the desired tool. One of the best known of these techniques is CNC machining. While additive production builds it layer by layer. Both technologies have advantages and disadvantages. We will make an overview only from the latter now. 3D printing usually goes through a 5-step process. First, a 3D model is created using computer-aided design (CAD) software. Then this model is converted into a Standard Tessellation Language (.STL) file. The 3D printer can read the geometry of the surface with the help of STL file. The model is then sliced into several layers so that printing instructions can be sent to the 3D printer. The model is then materialised in the additive manufacturing system (3D printer) where the object is extruded layer by layer. Finally, post-processing takes place to improve the print quality of the 3D printed object (Dizon et al., 2018).

We know many different 3D printing technologies. In addition to fused deposition modelling (FDM) based on extrusion, stereolithography (SLA) is a common 3D printing technology, often using light-curing resin as a material. Digital light processing (DLP) uses a projected digital image instead of a laser, which allows the printing process to proceed much faster, compared to SLA. You can see schematic figure from the operating principles in the Figure 1. Another solution the selective laser sintering (SLS) that uses a laser as a heating source that selectively sinters a powdered polymer such as resin or metal to create a 3D printed model. Next to the previous techniques there are other 3D printing for example the electron beam melting (EBM), the multijet fusion (MJF), laminated object manufacturing (LOM) and direct metal laser sintering (DMLS).

PLA and ABS are widely used materials for 3D printing. Both of them are associated with consumer FDM printing technology. There are many kinds of colour variation of these filaments. These are very popular because of their strength, rigidity, printability, cost-effectiveness, and other favourable properties (Markforged, 2021). Resins belong to other materials include, which exhibit high-quality prints with transparent and smooth surfaces. Polyamide nylon-based powders are also popular because of highly detailed and flexible printed items (Company, 2017). Jewellery industry can use precious metals such as gold, silver and brass with this solution (i.materialise, 2021).

3. 3D printing in agriculture

Indeed, 3D printing can play a significant role in agriculture. This encompasses the creation of tools and equipment to support production, optimization of production conditions, and even the customization of end products. Additionally, it offers opportunities for recycling and reusing waste generated in the food industry.

3.1. Printing tools and devices

3D printing indeed enables the rapid and flexible production of custom agricultural tools and equipment. For instance, machine components (Garuda3D, 2023, Podchasov, 2021a), spray nozzles (ProximityDesigns, 2023), fertilizer spreaders, hose splitters for irrigation (Pearce, 2015), seed planting tools (Halterman, 2023), or even garden implements can be easily and cost-effectively produced using 3D printing. The most commonly employed technology for this purpose is Fused Deposition Modeling (FDM), while thermoplastic materials like PLA and ABS are frequently used for the printing process.

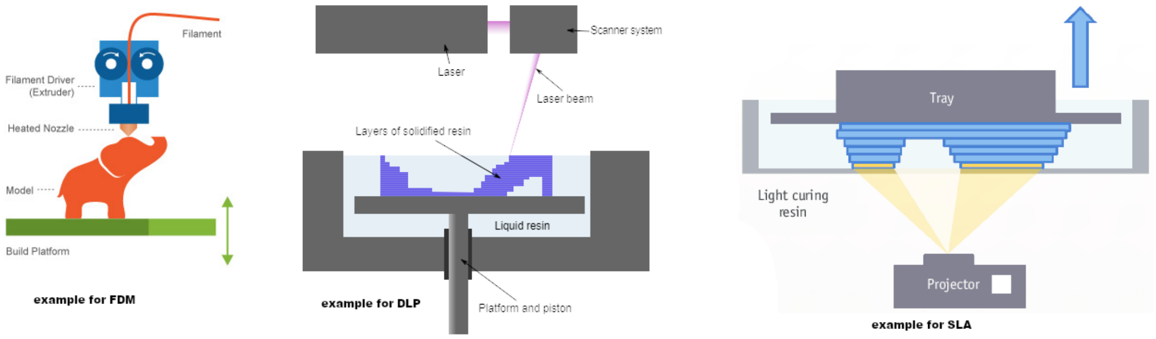

Figure 1. *Example for 3d printing technologies.*

The technology also offers significant potential for manufacturing personalized tools that cater to the unique needs of farmers and are often not commercially available. One example is the fruit tree picker and shovel, where 3D-printed parts of the tools can be combined with traditionally manufactured components like wooden handles, springs, and screws (Pearce, 2015). The advantage of the fruit picker shown in Figure 2 is that it allows for the retrieval of high-hanging fruits without the need for a ladder, making the work faster, safer, and less physically demanding.

It's important to note that while the PLA materials used here may vary slightly in their properties, such as rigidity and heat resistance, they are still the most commonly used thermoplastic filaments due to their low cost and ease of use in 3D printing. Another significant advantage is that the 3D printing process avoids the generation of unnecessary waste associated with traditional manufacturing. Additionally, since PLA is biodegradable and recyclable, its use promotes sustainability. Table 1 summarizes the applications of tools, materials, and 3D printing techniques used in agriculture (ProximityDesigns, 2023, Pearce, 2015, Halterman, 2023, Garuda3D, 2023).

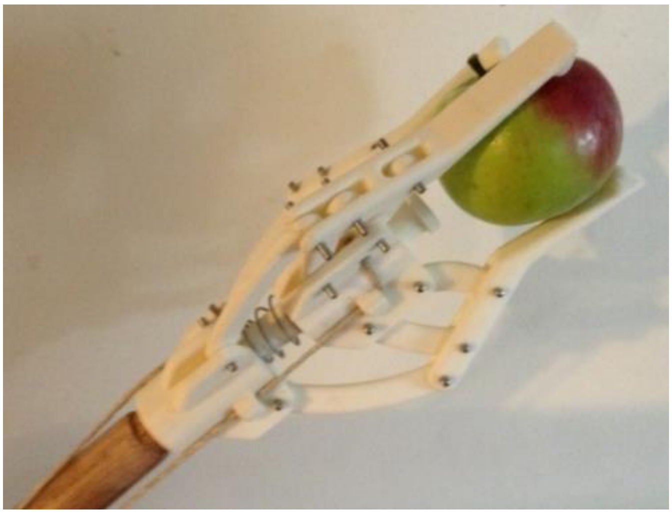

Figure 2. *Fruit picker from 3D printed material and wood.*

Table 1. Applications examples on 3D printing in agriculture (Jan Lloyd at al., 2021).

Printed part	Application	Printing technique	Material
Tube distributor	Irrigation	FDM	PLA
Sprinkler	Irrigation	FDM	ABS
Paddle and handle	Urban farming	FDM	PLA
Picker	Urban farming	FDM	PLA
Packing bottom	Testing equipment	FDM	ABS
Spigot	Water management	FDM	PLA
Corn auger	Spare part	FDM	PLA

3D printing opens up the possibility of creating various cultivation systems and accessories. This can include containers, supports, frames, or even plant containers needed for hydroponic or aeroponic systems (3Dponics, 2023). Another opportunity is the manufacture of irrigation and water treatment equipment through 3D printing. An example of this is the fruit picker that you can see in Figure 2. (Pearce, 2015), which demonstrates how you can modify an accessory to allow for multi-directional water flow from a garden hose. Thermoplastic materials are also used here to produce the components, which can greatly assist in replacing costly original parts in farm water distribution systems.

Figure 3 show an example for spigot that was printed with the help of 3D printing technique (Pearce, 2015), (Jan Lloyd at al., 2021). PLA was the raw material in this exact example and of course the applied technology was FDM (Fused Deposition Modelling). Unique size and scaling are needed many times in the practice. The Additive Manufacturing can give solution for this challenge in easy way. We can do personalisation our ideas with the help of 3d planning solutions. Today, this technology provides efficient and cost-effective solutions to the challenges mentioned above.

Figure 3. *A 3D printed spigot.*

3.2. Sensors and data logging

Absolutely, in modern agriculture, the use of various sensors and data collection solutions has become essential across many areas, whether it's crop cultivation or animal farming. Each field has its own unique characteristics and requirements. With 3D printing, it's possible to create customized tools and enclosures that, when combined with traditional sensors, can effectively support agricultural applications. This allows for tailored solutions that can enhance efficiency and precision in farming practices.

Monitoring air quality can be crucial in many places. The "nEMos" is such a device produced with 3D technology (from PLA material), which, due to its ease of portability, can be applied in various contexts and even over large geographical areas. (Salamone et al., 2015). In the case of various wastewater treatment solutions, flexible materials that can be used to build specialized filters can be particularly useful. Nylon, as a 3D printing material, combined with sensors and alternative automated adjustable water pathways, can create an efficient water pre-filter (Podchasov, 2021b). The further treatment of this process can be aided by the application or combination of ceramic (Natives, 2019) and/or membrane-based (Tijing et al., 2020) 3D-printed water filters in the aforementioned solution.

It's essential to recognize that 3D printing opens up new possibilities for the location-specific deployment and application of traditional sensor solutions. In practice, this can involve housing or integrating sensors with specialized, otherwise difficult-to-assemble solutions that can enhance the efficiency of the intended application. Collecting and transmitting sensor data to a central database is a crucial part of this process, and there are several methods to achieve this.

In the simplest case, the deployed data collector (equipped with sensors and/or actuators) locally stores the data (e.g., on an SD card) and, from time to time, a person collects this data and inputs it into the central database. In more advanced scenarios, this process can be fully automated, with data flow occurring through a communication channel. It's important to prepare these systems for potential disruptions, such as intermittent server connectivity.

In this context, 3D printing plays a significant role in creating specialized enclosures and housings that are ideal for the specific operating environment. This can encompass everything from meeting specific attachment and spatial requirements to resistance against various environmental factors, including exposure to organic materials.

3.3. 3D Printing Applications in Food

At first glance, it may seem strange that 3D printing can be used in the food industry, but there are many useful applications. Of course, we work with completely different materials than classic 3D printing technology. In this sector again, extrusion-based 3D printing (FDM), is the most widely used printing technology. In this case, the raw material is mostly edible. In a significant number of cases, classic materials have to be reworked, made denser or softer, i.e. printable. In practice, this means mixing 3D-printed purees with a certain number of thickening additives. It should be for example include meat slices mixed with gelatin and the use of pectin in fruit-based snacks (Derossi et al., 2018), (C. Liu et al., 2018). Another example is Mashed potatoes are made from potato flakes containing gelatinised starch, which is known to be an ideal raw material for the production of finished products due to its low post-processing requirements (Z. Liu et al., 2018). Important to know there are many vegetables such as corn, carrots, peas and turnips that can also be 3D printed, as they are relatively easy to produce and inexpensive food colours.

Figure 4. *Example for 3D Printing Applications in Food.*

Next to the raw materials the usage is also important. There are many areas where this technology is more accurate, faster, more predictable and more standardizable than the traditional way. In the case of confectionery, for example, using a cake decorating robot, we can make the layer-by-layer production of a cake (Wolf, 2019). We can repeat this process again and again as often as we want. Other uses may include direct preparation of desserts, pasta and pizzas (Z. Liu et al., 2017).

In certain diseases and special cases, this technology can be particularly useful. One example is the people who live with dysphagia and the other is when a person needs special diet. Dysphagia is a disease where the patient has difficulty in swallowing and therefore unable to swallow solid food. In this case, only pulp food is an option. In the disease mentioned earlier, not only can you get pulp and free-formed food, but this technology also helps you to formulate a diet. This can be achieved by manipulating (even automating) the exact nutritional ingredients before printing. Vegetables are an important part of a balanced diet and, as we have read before, many vegetables can easily be used as a raw material. We can enhance the visual appeal of the dish by shaping and colouring the food so that the dining experience is not or only minimally compromised (Pant et al., 2021).

Of course, there are also disadvantages of the technology, which are important to mention, such as the large space requirements, the need for cleaning and maintenance of equipment. All in all, there have been useful developments in this area and there are also advances in the field of operation, so we can expect this technology to become widespread in the near future.

3.4. Printing from agricultural waste

Printing in 3D from agricultural waste is indeed an exciting and emerging area of research. While these materials are originally unsuitable for technical use due to their properties and perishability, food and agricultural products generate a significant amount of waste globally. Food wastage is a serious issue, and from a recycling and waste reduction perspective, agricultural waste represents a potential resource (Yu and Wong, 2023).

3D printing allows the transformation of these wastes into useful and recyclable products, such as agricultural tools, packaging materials, or even construction materials. This way, recycling food waste can contribute to sustainable development and environmental protection while creating economic value. Furthermore, such technologies can aid in more efficient resource utilization and waste reduction in agriculture.

Drying and grinding have provided a solution to the problem of poor condition and perishability. After mixing with known plastics such as PLA, these processes result in composites that can be used in 3D printing. Numerous experiments have been conducted using various plant waste materials. The most commonly used composite materials from plant sources include rice husks, coffee grounds, sugarcane bagasse, walnut shells, eggshells, and fruit peels.

Other intriguing experiments have involved PLA combined with buckwheat husks or even PLA reinforced with shrimp shells. In most cases, the aim is to enhance the static properties of traditional plastics. However, the combination of powdered banana peels and guar gum, for example, could be an excellent choice for packaging materials (Shepherd and McKay, 2021).

It's essential to examine how the finished composite is processed because it significantly impacts the strength of the final product. For instance, Fused Deposition Modelling (FDM) has been shown to create the strongest and most durable structures when working with these composites (Yu and Wong, 2023).

4. Conclusion

3D printing is now a widespread technology with many applications. This review article looks mainly at the agricultural applications of this technology. Due to the technological capabilities, a wide range of parts/devices with specific dimensions and solutions can be produced with this solution. As a result of it, time and money can be saved. In addition to the efficient application options, the sustainability options are also an important advantage of this technology. One example is the use of agricultural waste as raw material. Another advantage is that it improves the possibilities for maintenance, repair and further development. The article clearly shows that 3D printing is already being used successfully in a number of areas in the context of agriculture and is expected to become more widespread in the future.

Acknowledgemant

This work has been implemented by the TKP2021-NKTA-21 project with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the 2021 Thematic Excellence Programme funding scheme.

We acknowledge funding by the National Multidisciplinary Laboratory for Climate Change, RRF-2.3.1-21-2022-00014 project.

References

3Dponics. 2023. 3d printing + hydroponics. Retrieved October 10, 2023, from https://www.3dponics.com/

Jan Lloyd B. Crisostomo1, John Ryan C. Dizon. 2021. 3D Printing Applications in Agriculture, Food Processing, and Environmental Protection and Monitoring. *Advance Sustainable Science, Engineering and Technology (ASSET).* **3** (2) 0210201-01–0210201-10. https://doi.org/10.26877/asset.v3i2.9627

Advincula, R. C., Dizon, J. R. C., Chen, Q., Niu, I., Chung, J., Kilpatrick, L., & Newman, R. 2020. Additive manufacturing for covid-19: Devices, materials, prospects, and challenges. *MRS Communications.* **10** 413–427. https://doi.org/10.1557/mrc.2020.57

Al-Dulimi, Z., Wallis, M., Tan, D. K., Maniruzzaman, M., & Nokhodchi, A. 2021. 3D printing technology as innovative solutions for biomedical applications. *Drug Discovery Today.* **26** (2) 360–383. https://doi.org/10.1016/j.drudis.2020.11.013

Carolo, L., & Haines, J. 2020. All3dp: 3d printed house: 20 most important projects. Retrieved June 26, 2023, from https://all3dp.com/2/3d-printed-house-3d-printed-building/

Company, S. P. (2017). What materials are used for 3d printing? Retrieved October 3, 2023, from https://www.sharrettsplating.com/blog/materials-used-3dprinting/

Derossi, A., Caporizzi, R., Azzollini, D., & Severini, C. 2018. Application of 3d printing for customized food. a case on the development of a fruit-based snack for children. *Journal of Food Engineering*. **220** 65–75. https://doi.org/10.1016/j.jfoodeng.2017.05.015

Diego, J. R. R., Martinez, D. W. C., Robles, G. S., & Dizon, J. R. C. 2021. Development of smartphone-controlled hand and arm exoskeleton for persons with one-arm disability (schax). *Open Engineering*. **11** (1) 161–170. https://doi.org/10.1515/eng-2021-0016

Dizon, J. R. C., Gache, C. C. L., Cascolan, H. M. S., Cancino, L. T., & Advincula, R. C. 2021. Post-processing of 3d-printed polymers. *Technologies*. **9** (3) 61. https://doi.org/10.3390/technologies9030061

Dizon, J. R. C., Valino, A. D., Souza, L. R., Espera, A. H., Chen, Q., & Advincula, R. C. 2019. 3d-printed molds and materials for injection molding and rapid tooling applications. *MRS Communications Prospectives Journal*. **9** 1267–1283. https://doi.org/10.1557/mrc.2019.147

Dizon, J. R. C., Espera Jr, A. H., Chen, Q., & Advincula, R. C. 2018. Mechanical characterization of 3d-printed polymers. *Additive manufacturing*. **20** 44–67. https://doi.org/10.1016/j.addma.2017.12.002

Dizon, J. R. C., Valino, A. D., Souza, L. R., H, E. A., Chen, Q., & Advincula, R. C. 2020. 3d printed injection molds using various 3d printing technologies. *Materials Science Forum*. **1005**, 150–156. https://doi.org/10.4028/www.scientific.net/MSF.1005.150

Dong, Y., Fan, S. Q., Shen, Y., Yang, J. X., Yan, P., Chen, Y. P., Li, J., Guo, J. S., Duan, X. M., Fang, F., & Liu, s. Y. 2015. A novel bio-carrier fabricated using 3d printing technique for wastewater treatment. *Scientific Reports*. **5** 12400. https://doi.org/10.1038/srep12400

Espera, A. H., Dizon, J. R. C., Chen, Q., & Advincula, R. C. 2019. 3d-printing and advanced manufacturing for electronics. *Progress in Additive Manufacturing*. **4** 245–267. https://doi.org/10.1007/s40964-019-00077-7

Garuda3D. 2023. 3d printing in agriculture. Retrieved October 10, 2023, from https://garuda3d.com/3d-printing-in-agriculture

Halterman, T. E. 2023. 3d printing helpds test crop seeding system. Retrieved October 10, 2023, from https://3dprint.com/48469/3d-printing-groundbreaking/

i.materialise. 2021. Metals 3d printing. Retrieved October 3, 2023, from https://i.materialise.com/en/3d-printing-materials/metals#preciousMetals

Liu, C., Ho, C., & Wang, J. 2018. The development of 3d food printer for printing fibrous meat materials. *IOP Conference Series: Materials Science and Engineering*. **284** 012019. https://doi.org/10.1088/1757-899X/284/1/012019

Liu, Z., Bhandari, B., Prakash, S., & Zhang, M. 2018. Creation of internal structure of mashed potato construct by 3d printing and its textural properties. *Food Research International*. **111** 534–543. https://doi.org/10.1016/j.foodres.2018.05.075

Liu, Z., Zhang, M., Bhandari, B., & Wang, Y. (2017). 3d printing: Printing precision and application in food sector. *Trends in Food Science & Technology*. **69** 83–94. https://doi.org/10.1016/j.tifs.2017.08.018

Markforged. 2021. Pla vs abs vs nylon. Retrieved October 3, 2023, from https://markforged.com/resources/blog/pla-abs-nylon

Martín de Vidales, M. J., Nieto-Márquez, A., Morcuende, D., Atanes, E., Blaya, F., Soriano, E., & Fernández-Martínez, F. 2019. 3d printed floating photocatalysts for wastewater treatment. *Catalysis Today*. **328** 157–163. https://doi.org/10.1016/j.cattod.2019.01.074

Mohammed, J. 2016. Applications of 3d printing technologies in oceanography. *Methods in Oceanography*. **17** 97–117. https://doi.org/10.1016/j.mio.2016.08.001

Mohammed, M. I., Wilson, D., Gomez-Kervin, E., Rosson, L., & Long, J. 2019. Ecoprinting: Investigation of solar powered plastic recycling and additive manufacturing for enhanced waste management and sustainable manufacturing. 2018 IEEE Conference on Technologies for Sustainability, SusTech, 1–6. https://doi.org/10.1109/SusTech.2018.8671370

Natives, 3. 2019. The 12 initiatives that combine 3d printing and sustainability. Retrieved October 3, 2023, from https://www.3dnatives.com/en/3d-printing-sustainability-220420194/

Pant, A., Lee, A. Y., Karyappa, R., Lee, C. P., An, J., Hashimoto, M., Tan, U.- X., Wong, G., Chua, C. K., & Zhang, Y. 2021. 3d food printing of fresh vegetables using food hydrocolloids for dysphagic patients. *Food Hydrocolloids.* **114** 106546. https://doi.org/10.1016/j.foodhyd.2020.106546

Pearce, J. M. 2015. Applications of open source 3-d printing on small farms. *Organic Farming.* **1** 19–35. https://doi.org/10.12924/of2015.01010019

Peels, J. 2017. 3d print: 3d printing in the military. Retrieved February 23, 2017, from https://3dprint.com/165561/3d-printing-in-the-military/

Podchasov, E. O. 2021a. Design and technological features of 3d-printing usage in agricultural machines gearings repair. International *Journal of Mechanical Engineering and Robotics Research*. **10** 32–37. https://doi.org/10.18178/ijmerr.10.1.32-37

Podchasov, E. O. 2021b. Design and technological features of 3d-printing. work, 5, 9.

ProximityDesigns. 2023. Retrieved October 10, 2023, from https://proximitydesigns.org/service/farm-tech/

P.s, A. 2022. The top applications in food 3d printing. Retrieved October 3, 2023, from https://www.3dnatives.com/en/food-3d-printing220520184/

Salamone, F., Belussi, L., Danza, L., Ghellere, M., & Meroni, I. 2015. Design and development of nemos, an all-in-one, low-cost, web-connected and 3d-printed device for environmental analysis. *Sensors.* **15** (6), 13012–13027. https://doi.org/10.3390/s150613012

Shepherd, J., & McKay, R. 2021. Alternative possibilities on some issues of mass transportation systems. *International Journal of Science and Technology.* **11** 558–563.

Tijing, L. D., Dizon, J. R. C., & Cruz, G. G. 2021. 3d-printed absorbers for solar-driven interfacial water evaporation: A mini-review. *Advance Sustainable Science, Engineering, and Technology*. **3** (1) 0210103-1–0210103-9. https://doi.org/10.26877/asset.v3i1.8367

Tijing, L. D., Dizon, J. R. C., Ibrahim, I., Nisay, A. R. N., Shon, H. K., & Advincula, R. C. 2020. 3d printing for membrane separation, desalination and water treatment. *Applied Materials Today.* **18** 100486. https://doi.org/10.1016/j.apmt.2019.100486

Valino, A. D., Dizon, J. R. C., Espera, A. H., Chen, Q., Messman, J., & Advincula, R. C. 2019. Advances in 3d printing of thermoplastic polymer composites and nanocomposites. *Progress in Polymer Science.* **98** 101162. https://doi.org/10.1016/j.progpolymsci.2019.101162

Wolf, M. 2019. 3d food printing startup beehex debuts a cake decorating robot. Retrieved October 3, 2023, from https://thespoon.tech/beehex-ships-hi-volume-cookie-cakedecorating-robot/

Wong, J. Y. 2016. 3d printing applications for space missions. *Aerospace Medicine and Human Performance.* **87** 580–582. https://doi.org/10.3357/AMHP.4633.2016

Yu, I. K. M., & Wong, K. -H. 2023. Food waste-derived 3d printable materials: A carbon neutral solution to global foodloss. *Trends in Food Science and Technology*. **137** 156–166. https://doi.org/10.1016/j.tifs.2023.05.014

Evolution of decomposition coefficients for different leaf litters

A bomlási együtthatók alakulása különböző avarfélék esetében

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Abstract: Temperature is one of the main abiotic drivers of decomposition processes in water. In the international literature, the values measured under different environmental conditions can be compared with the value of the traditional exponential decay coefficient (k, day-1). However, this indicator does not take temperature into account, it only calculates the remaining mass and the elapsed time. The water temperature-based daily mean breakdown rate is suitable for taking water temperature into account (ktemp, day-1). During the research, 3 types of litter (willow, Salix sp.; poplar, Populus sp.; reed, Phragmites australis) and their mixture were examined using the litterbag method. The experiment was set up between June 10 and September 2, 2022. Based on our results, it can be said that ktemp values are higher than k values. The differences between the varieties and their mixtures became more visible in the case of ktemp than in the case of k. With the exception of reed, the litter mixtures showed a higher deviation than the litter samples containing only one type of leaf litter when comparing the values of k and ktemp.

Keywords: *willow, poplar, reed, litter mixture, decomposition coefficient*

Összefoglalás: A vízben történő avarlebontási folyamatok egyik fő abiotikus mozgatórugója a hőmérséklet. A nemzetközi szakirodalomban a hagyományos exponenciális bomlási együttható (k, nap-1) értékével tehetjük összehasonlíthatóvá a különböző környezeti feltételek közt mért értékeket. Ezen mutató azonban nem veszi figyelembe a hőmérsékletet, csupán a visszamaradt tömeggel és az eltelt idővel számol. A vízhőmérséklet figyelembevételére a vízhőmérséklettel kompenzált bomlási együttható alkalmas (ktemp, nap-1). A kutatás során egy mikrokozmosz kísérletben (hagyományos A kádban) 3 avar-típus (fűz avar, Salix sp.; nyár avar, Populus sp.; nád, Phragmites australis), valamint ezek keverékét vizsgáltuk avarzsákos módszerrel 2022. június 10 és szeptember 2. között. Eredményeink alapján elmondható, hogy ktemp értékei magasabbak a k értékeknél, valamint az avarféleségek és keverékeik közti különbségek is a ktemp esetében jobban láthatóvá váltak. A nádat leszámítva az avarkeverékek magasabb eltérést mutattak, mint az egyféle avart tartalmazó avarmintáknál k és ktemp értékeit összehasonlítva.

Kulcsszavak: *5 fűz, nyár, nád, avarkeverék, bomlási együttható*

1. Introduction

Leaf fall means approximately 1000 to 7000 kg/ha dry matter annually (Mátyás, 1997: 45-65). Allochtonous input from riparian vegetation provides a significant amount of organic matter to the energy cycle of water bodies (Nakajima et al., 2006). After entering the water, CPOM (coarse particulate organic matter) turns into FPOM (fine particulate organic matter) and DOM (dissolved organic matter) due to dissolution, physical fragmentation and the decomposing activity of micro- and macroorganisms (Wallace et al., 1995; Dobson & Frid, 1998; Abelho, 2001).

Leaf litter decomposition is limited by a number of factors. Meentemeyer (1978) mentions temperature as the main influencing factor of leaf litter decomposition. It affects both the speed of chemical and biological reactions (Brown et al., 2004). The rise of temperature accelerates the mass loss of leaf litter, directly by leaching, and indirectly by increasing the energy consumption of invertebrate detrivores and microbial organisms (Chergui, 1990; Ferreira & Chauvet, 2011). In general, it can be stated, that an increase in water temperature stimulates the metabolic rate, but only up to a certain limit (Sokolova & Lanning, 2008). It is expected that leaf litter decomposition processes will also respond sensitively to global climate change (Boyero et al., 2011).

To examine the speed of decomposition, the negative exponential decay model is most commonly used, where exponential decay coefficient (k) expresses the rate of decomposition (Petersen & Cummins, 1974; Webster & Benfield, 1986). In knowledge of the „k” value, decomposition rates of the given samples can be categorized into slow ($k < 0.005$), medium ($k = 0.005$-0.01) and fast ($k > 0.01$) categories (Bärlocher et al. 2005, Petersen and Cummins, 1974), furthermore, using the formula of Bärlocher et al. (2005) the halving times can also be expressed. The model, on the other hand, is not wholly accurate, as it omits the temperature factor, which is – as previously described - a key factor in decomposition processes. It assumes that the litter mass loss at any given point in time is proportional to the litter mass present, regardless of temperature (Bärlocher et al., 2020). The exponential decay model can be expanded, assuming a linear temperature dependency of the overall decay rate (Bärlocher et al. 2020). This is called temperature-normalized decay rate coefficient (k_{temp}). The expanded model is more accurate, because it takes the temperature factor also into account. Determination and comparison of the different leaf litter decomposition rates can help to better understand the importance of temperature factor by the examination of cycle processes of aquatic ecosystems.

The aim of the research was to compare the extent to which the decomposition rates calculated with the two different methods differed. The two equations used differ in that one of them also takes water temperature into account, because temperature plays a prominent role in the decomposition processes.

2. Materials and Methods

The experiment was set up at the university's Agrometeorological Research Station (latitude: 46°440’ N, longitude: 17°140’ E, elevation: 124 m a.s.l.) in a class A evaporation pan. This class A pan filled with water was 1.21 m in diameter and 0.25 m in height located on an elevated (~0.15 m) wooden grid. The class A pan was covered on the bottom with sediment to a thickness of 0.003 m. Water temperature was collected with a Delta Ohm HD-226-1 data logger. In this class A pan, we examined the rate of decomposition of the following 3 type leaf litter and their mixture using the litterbag technique (Bärlocher et al., 2005), under water conditions: willow (*Salix* sp.), poplar (*Populus* sp.), reed (*Phragmites australis*).

The litter was collected in the fall of 2021 and dried to a constant mass. After reaching a constant mass, the litters were filled into litterbags, which are made of plastic material. We put 10 grams of each type of litter into the litterbags (with 3 repetitions), in the case of bags containing mixed litter, we measured 5 grams from one litter and 5 grams from the other litter.

In the case of a mixture of the 3 types of litter, the litterbag contained equal leaf litter of willow, aspen and reed. Based on these, we set up the following treatments:

- willow
- poplar
- reed
- willow – poplar
- willow – reed
- poplar – reed
- willow – poplar – reed

The experiment was set up between June 10, 2022 and September 2, 2022. A total of 6 sampling happened on the 14th, 28th, 42nd, 56th, 70th and 84th days after the placement. After the sampling, the litters were cleaned and then dried again until the weight was constant. After that, we remeasured their weight, so the weight loss can be determined.

In the literature, decomposition coefficients are used for better comparability of changes during litter decomposition. One way to do this is to use the most used exponential model (Bärlocher et al., 2005):

$$\frac{dm}{dt} = -k \times m$$

where m (g) is the mass loss as a proportion of initial mass, t the time in days after the initial exposure, and k (day^{-1}) is the decomposition constant.

Using another formula, the temperature can also be considered when calculating the decomposition rate:

$$\frac{dm}{dt} = -k_{temp} \times \frac{T_w}{T_R} \times m$$

where T_w is the water temperature, k_{temp} (day^{-1}) is the temperature-normalized decomposition rate coefficient. Set TR=10 °C as Bärlocher et al. (2020) suggested, for ease of comparison with other temperaturebased models (Anda et al., 2023).

3. Results and Discussion

Figure 1 shows the values of the exponential decay coefficient (k). Similar k values can be observed in the case of willow and reed (k= 0.0047 and 0.0041), in the case of poplar the k value is higher (k=0.0068). The litter mixtures show similar values (k=0.0046 – 0.0059). Based on the results of the t-test (at a significance level of 0.05) a significant difference can be observed between the k values of willow and poplar, poplar and reed, poplar and reed-poplar, poplar and reed-willow, poplar and willow-poplar-reed, reed and willow-poplar, willow-poplar and reed-willow litters ($p<0.05$ – $p=0.03$). Comparing the results of our experiment with data of other similar researches, even significantly different k values can be observed in the case of the examined plant parts. The main reason for the differences may be the timing and the location of the experiment (Asaeda & Nam, 2002), furthermore, decomposition rates are also influenced by biotic (saprotrophic organisms present, leaf litter quality) and abiotic factors (water parameters, like chemical compound, temperature and movement) (Chen et al., 2019).

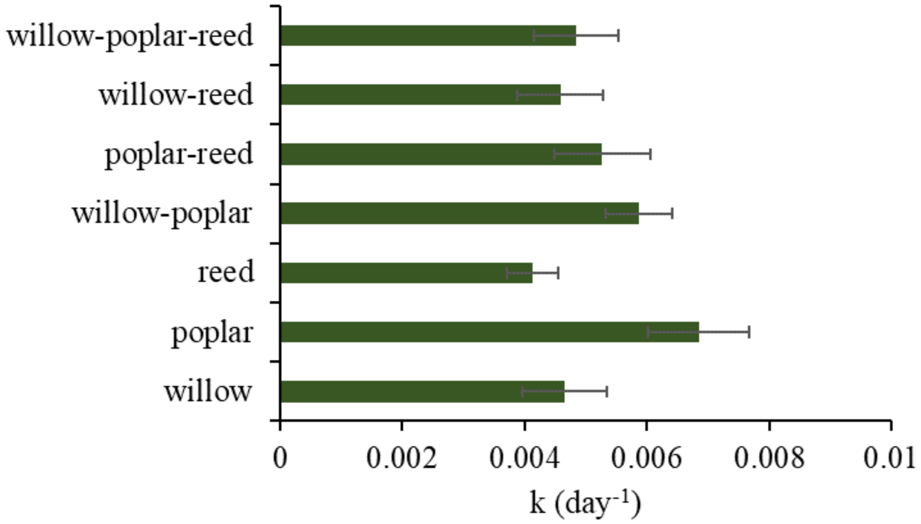

Figure 1. *Exponential decomposition rates, k (day^{-1}) of three plant species (willow, Salix sp.; poplar, Populus sp.; reed, Phragmites australis) and their mixtures*

The Water temperature-based decay coefficient (k_{temp}) values are shown in Figure 2. Compared to the k values, in the case of k_{temp}, we can already see several differences in the values of the decomposition coefficients. All this is due to the fact that the method used also takes the effect of temperature into account. In the case of k_{temp}, reed (k= 0.0445) shows the highest value compared to poplar and willow (k=0.0078 and 0.0085). In the case of k_{temp}, the litter mixtures did not develop similarly: willow-reed and poplar-reed show higher values (k= 0.0258 and 0.0254), while willow-poplar (k=0.0078) and willow-poplar-reed (k= 0.0131) show lower values.

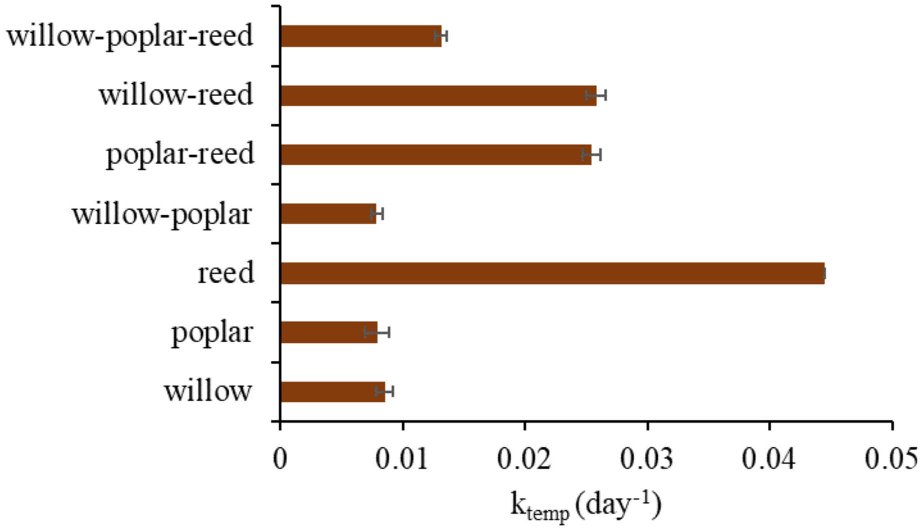

Figure 2. *Water temperature-based daily mean breakdown rates, k_{temp} (day^{-1}) of three plant species (willow, Salix sp.; poplar, Populus sp.; reed, Phragmites australis) and their mixtures*

Comparing k and k_{temp} values, 13.3-79.3% higher values were observed for ktemp compared to k values. These differences between k and k_{temp} values were significant ($p<0.05$ – $p= 0.0021$). Based on this, it seems that k_{temp} better shows the difference between different litters and their mixtures for decomposition processes under water surface. Furthermore, it seems that, with the exception of reed, the mixture treatments are more sensitive to the value of the decomposition coefficient, which also takes into the temperature into account, compared to the traditional k coefficient.

Acknowledgements

Supported by the ÚNKP-22-3-I New National Excellence Program of the Ministry for Culture and Innovation from the Source of the National Research, Development and Innovation Fund.

References

Abelho, M. 2001. From litterfall to breakdown in streams: a review. *The Scientific World Journal.* **1** 656–680. https://doi.org/10.1100/tsw.2001.103

Anda, A., Simon, Sz., Simon-Gáspár, B. 2023. Impacts of wintertime meteorological variables on decomposition of Phragmites australis and Solidago canadensis in the Balaton System. *Theoretical and Applied Climatology*. **151** 1963–1979. https://doi.org/10.1007/s00704-023-04370-y

Asaeda, T., Nam, L.H. 2002. Effects of rhizome age on the decomposition rate of Phragmites australis rhizomes. *Hydrobiologia*. **485** 205–208. https://doi.org/10.1023/A:1021314203532

Bärlocher, F. 2005. Leaf Mass Loss Estimated by Litter Bag Technique. In: Graça M.A.S., Bärlocher F., Gessner M.O., Eds., Methods to Study Litter Decomposition, a Practical Guide, Springer, Dordrecht, pp. 37–42. https://doi.org/10.1007/1-4020-3466-0_6

Bärlocher, F; Gessner, M.O.; Graca, M. A. S. 2020. Leaf mass loss estimated by the litter bag technique. Methods to study litter decomposition. A Practical Guide (2nd ed.) SpringerNature Switzerland AG., Part 1., pp. 43–51. https://doi.org/10.1007/978-3-030-30515-4_6

Boyero, L.; Pearson, R. G.; Gessner, M. O.; Barmuta, L. A. 2011. A global experiment suggests climate warming will not accelerate litter decomposition in streams but might reduce carbon sequestration. *Ecology Letters*. **14** (3) 289–94. https://doi.org/10.1111/j.1461-0248.2010.01578.x

Brown, J. H.; Gillooly, J. F.; Allen, A. P. 2004. Toward a metabolic theory of ecology. *Ecology*. **85** (7) 1771–1789. https://doi.org/10.1890/03-9000

Chen, Y., Ma, S., Jiang, H., Yangzom, D., Cheng, G., Lu, X. 2019. Decomposition time, chemical traits and climatic factors determine litter-mixing effects of decomposition in an alpine steppe ecosystem in Northern Tibet. *Plant Soil*. **459** 23–35. https://doi.org/10.1007/s11104-019-04131-9

Chergui, H.; Pattee, E. 1990. The influence of season on the breakdown of submerged leaves. *Arch. Hydrobiol*. **120** (1) 1–12. https://doi.org/10.1127/archiv-hydrobiol/120/1990/1

Dobson, M.; Frid, C. 1998. Ecology of Aquatic Systems. Longman, Essex

Ferreira, V.; Chauvet E. 2011. Synergistic effects of water temperature and dissolved nutrients on litter decomposition and associated fungi. *Global Change Biol*. **17** (1) 551–564. https://doi.org/10.1111/j.1365-2486.2010.02185.x

Mátyás, Cs. 1997. Erdészeti ökológia. Mezőgazda Kiadó, Budapest.

Meentemeyer, V. 1978. Macroclimate and lignin control of litter decomposition rates. *Ecology*. **59** (3) 465–472. https://doi.org/10.2307/1936576

Nakajima, T.; Asaeda, T.; Fujino, T.; Nanda, A. 2006. Leaf Litter Decomposition in Aquatic and Terrestrial Realms of a Second-Order Forested Stream System. *Journal of Freshwater Ecology*. **21** (2) 259–263. http://dx.doi.org/10.1080/02705060.2006.9664994

Petersen, R. C.; Cummins, K. W. 1974. Leaf processing in a woodland stream. *Freshwater Biology.* **4** (4) 343–368. https://doi.org/10.1111/j.1365-2427.1974.tb00103.x

Sokolova, I. M.; Lannig, G. 2008. Interactive effects of metal pollution and temperature on metabolism in aquatic ectotherms: implications of global climate change. *Climate Research.* **37** 181–201. http://dx.doi.org/10.3354/cr00764

Wallace, J. B.; Whiles, M. R.; Eggert, S.; Cuffney, T. F.; Lugthart, G. J.; Chung, K. 1995. Long-term dynamics of coarse particulate organic matter in three Appalachian Mountain Streams. *Journal of the North American Benthological Society*. **14** (2) 217–232. http://dx.doi.org/10.2307/1467775

Webster, J. R.; Benfield, E. F. 1986. Vascular plant breakdown in freshwater systems. *Annual Review of Ecology and Systematics*. **17** 567–594. http://dx.doi.org/10.1146/annurev.es.17.110186.003031

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Volume 27 2023 Number 2

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