DOCTORAL (PHD) THESIS

PINKE ZSOLT

Gödöllő

2018

SZENT ISTVÁN UNIVERSITY

ESTABLISHMENT OF A HORTOBÁGY-SÁRRÉT LANDSCAPE RESTORATION MODEL WITH NATIONAL ANALYSIS

Doctoral (PhD) Thesis

Zsolt Pinke

Gödöllő

2018

The Doctoral School

Name:	Doctoral School of Environmental Sciences
Discipline:	Environmental Sciences
Head of School:	Professor Csákiné Michéli Erika, DSc

Szent István University, Faculty of Agricultural and Environmental Sciences,

Institute of Environmental Sciences

Supervisor:	Professor Gyulai Ferenc, DSc

Szent István Egyetem, Mezőgazdaság- és Környezettudományi Kar,

Természetvédelmi és Tájgazdálkodási Intézet

....

Approval of the Head of School Approval of the Supervisor

1. PREMISES AND OBJECTIVES

The main part of Hungarian agro-production comes from the cereals barley, maize and wheat. This production structure evolved in the 19th century, and survives today by its low technological demand and the protectionism of the European Union. Grain production is dominant even in former wetlands with unfavourable agroecological conditions where land users face serious problems. The core challenges are: the gradual dismounting of the EU protectionist subsidy system (BUREAU et al 2014; SPILIOPOULOS 2014), and the changing climate (OLESEN & BINDI 2002; TRNKA et al. 2011; PINKE & LÖVEI 2017). These changes precipitate rapid conversion in areas with poor soil. The desire to manage threats and avoid this emerging land use crisis appears in the documents of environmental and rural development policy documents (EU Water Framework Directive (EWFD 2000); Hungarian River Basin Management Plan (VGT 2010, 2015); Hungarian Drought Strategy (NAS 2012); Hungarian Rural Development Strategic Plan 2012–2020 (NV 2012); National Climate Change Strategy 2014–2025 (NÉS2 2013); National Water Strategy (NVS 2015); Water Blueprint (2012). They state the necessity of water retention in low-lying areas, although the target areas for water retention have not been identified.

1.1. OBJECTIVES

1) In the first section of the dissertation that focuses on the hydroclimatic challenges of cereal production in Hungary my aim is to:

- analyse the relationship between mean monthly precipitation, monthly mean temperature and groundwater levels and the yields of barley, maize and wheat in Hungary at regional and country scales in the period1921–2010;

- compare the impact of current climate on crop yields to previous periods of similar time span, and
- investigate the regional patterns of climate vulnerability in the studied periods, as well as the regional patterns of groundwater-cereal yield relationship between 1981–2010.

2) Secondly, I aim to evaluate the additional costs of managing arable lands due to excess surface water and the value of the potential flood defence service of restored wetlands.

3) Finally, my goal is to propose a zonal land use system in a 9331 km^2 study area for retaining water in areas prone to excess surface water.

2. MATERIALS AND METHODS

In the first phase of the model I analysed the impacts of hydroclimatic challenges of grain production in a landscape context in Hungary between 1921–2010. Explanatory factors were mean monthly precipitation, monthly means of temperature and groundwater levels, while response variables were the annual county yields of barley, maize and wheat. My hypothesis was that the most climatically vulnerable landscape is the Great Hungarian Plain (GHP), and that the changing climate is one of the major stresses for the present land use system. As a key element of the mitigation of this challenge, areas prone to excess surface water were identified. Focusing on these areas, I made a suggestion for an integrative, ecologically and economically sustainable land use system. I estimated the most important additional costs of arable lands due to excess surface water and the value of the potential value of flood defence service of restored wetlands. As the output of the model, I identified the target areas of water retention. During this work phase, following the most important documents of environmental and rural development policy, I combined spatial categories of environmental vulnerability, nature protection, suitability for cropland farming and afforestation

2.1. Hypotheses

1) I assumed that the vulnerability of cereal yields to climate variability in Hungary will exceed global averages.
2) Relationships between climatic and crop yield variables will be different in the studied 30-year periods and
3) different regionally within the studied 30-year periods.
4) I hypothesized that groundwater levels and cereal yields will show a positive statistical relationship.

5) My expectation was that cereal yield vulnerability to hydroclimatic factors in Hungary will be the highest in the GHP.

6) My hypothesis was that through the conversion of arable lands in reclaimed floodplains and the restoration of former wetlands, very expensive flood protection investment can be avoided.

7) I assumed that via analysing spatial categories of agro-ecological potential, environmental vulnerability, land cover vast arable lands can be identified where land use conversion for retaining water can be recommended, to achieve the goal set in the strategic documents of environmental and rural development policy.

2.2. Analysis of the relationship between climatic factors, groundwater level and cereal yields at regional and country scale (1921–2010)

2.2.1. Data sources

To characterise climate in Hungary, I extracted data on mean monthly precipitation and temperature from 5 meteorological stations in Hungary: Budapest, Debrecen, Szeged, Pécs and Szombathely. Homogenized time series of Budapest, Pécs and Szombathely were extracted from the HISTALP dataset (AUER et al. 2007), those of Debrecen from the open access database of the Hungarian Meteorological Office (OMSZ) (http://www.met.hu/), while the homogenized time series of Szeged were obtained from the data support of the OMSZ. These five locations represent the topographic and climatic diversity of the country. For data on yields, I used the annual average yields (t/ha) of barley, maize and wheat at county and country level, collected and published by the Hungarian Central Statistical Office. Verified monthly means of groundwater level at county scale were provided by the Department of Sanitary and Environmental Engineering at the Budapest University of Technology and

Economics for 1961–2010 based on time series of 276 groundwater wells covering the entire country.

2.2.2. Descriptive analysis

Timeframe of data provide an opportunity to form 30-year data cohorts following the international meteorological protocol (SZALAI et al. 2005; SUGGITT et al. 2017). The period 1981–2010 is especially important because the 5th report of the IPCC (2014) devotes special attention to this period. This 90-year timeframe offers a rare opportunity to compare the impact of current climate change on crop yields to several longer periods of similar time span and analyse regional differences of the climate change impact. Since Shapiro-Wilk normality tests and QQ plot diagrams showed that the studied variables were normally distributed, the significance of changes in averages ($\alpha < 0.95$) were tested by using two-sample Welch tests in the R environment (R 3.2.4 Revised version). This method is equivalent to Fisher's F test (REICZIGEL et al. 2014), thus test results are informative in relation to the differences between variances as well. However, groundwater data for 1961–2010 have not provided an opportunity to compare changes in 30-year periods, thus I examined the changes between 25-year periods. In the next step, changes of 30-year means of climatic variables were interpreted in the modified Köppen-Geiger biophysical classification system (PEEL et al. 2007). This research was motivated by different aspects:

1) It seemed to be useful to illustrate the transformations of bioclimatic conditions by the widely used Köppen-Geiger method, as this has precedence in the Hungarian literature ((RÉTHLY 1933; SZELEPCSÉNYI et al. 2009; FÁBIÁN, MATYASOVSZKY 2010; ÁCS, BREUER 2012).

2) Earlier investigations for Hungary using Köppen’s method did not trace a century long transformation.

3) The widely used, updated Köppen-Geiger's map (PEEL et al. 2007) based on the modified Köppen-Geiger method (RUSSEL 1931) moving the threshold between D (continental/ microthermal) and C (temperate/mesothermal) climates from -3 °C to 0 °C was not previously used for analysing climatic changes in Hungary. This modification is important to clarify the differences between the Northern Mediterranean region and Central Europe.

In addition, to estimate the spatial validity of climatic data from the five meteorological stations, we correlated precipitation and temperature data with the CRU TS3.23 datasets (CRU) that are gridded to a 0.5x0.5 degree resolution (JONES 2015) using the KNMI Climate Explorer tool (TROUET, VAN OLDENBORGH 2013).

2.2.3. Data analysis

2.2.3.1. The relationship between climatic variables and yields

For grouping counties, I classified landscape characteristics of counties and stations and used hierarchical cluster analysis based on Ward and bootstrap resampling methods using the pvclust package (SUZUKI, SHIMODAIRA 2006). In certain regions, averages of data from different stations were used (Budapest-Debrecen, Budapest-Szombathely, Budapest-Szeged, Budapest-Debrecen-Szeged).

Although a linear regression is unable to interpret directions of causality, the assumption that changes in temperature and precipitation may have significant impact on cereal yields via plant physiology is justified (DOORENBOS et al., 1986; LUO 2011; KOLTAI 2003). Thus, I hypothesised that the variability of climatic and groundwater factors may drive yield fluctuations and the results of regression tests may be interpreted as the intensity of the relationship between the explanatory climatic variables and the response (yield) variables. As a result of professional discussions (JOLÁNKAI M., KOZMA ZS., LÖVEI L. G. personal communication), different vegetation periods of the studied cereals were selected for total precipitation (Prec) and for monthly means of temperature (Temp) as explanatory factors. They were: $Prec_{barley,\ wheat}$ = February–June (PEPÓ, SÁRVÁRI 2011); $Prec_{maize}$ = March–August (MENYHÉRT 1985); $Temp_{barley,\ wheat}$ = May–July; $Temp_{maize}$= May–August (LÁNG et al. 2006).

Groundwater-cereal yield relationships were analysed in the selected regions between 1981–2010. Contrary to the climatic factors there is no literature or case study to identify periods when groundwater has a significant impact on cereal yields. Preliminary tests for detecting relationships in the entire vegetation periods of the cereals showed no results either. Thus, following CEGLAR et al.'s (2017) approach, I investigated, if when does groundwater show a significant impact on cereal yields during the vegetation period? I calculated the linear relationship between barley and wheat yields and the monthly means of groundwater level in the period of October–July, and in the case of maize in the period of March–August. As a result of tests, I identified those periods in which groundwater-cereal relationship was analysed.

Besides precipitation and temperature as independent variables, I investigated the linear relationship between the common impact of climatic variables, as suggested by KRONMAL (1993). From among the different combinations of climatic indices, such as ‘Prec and Temp’, ‘Prec/Temp’ and ‘Prec*Temp’ and ‘$(\text{Prec and Temp})^2$’ it was ‘Prec/Temp’ (hereafter ‘combined climatic predictor’), whose variances showed the closest relationship to cereal yields (i.e. response variables) and the minor interactions in linear regression tests.

Out of the extreme environmental events with a potential impact on cereal growth, data were only available on droughts and the annual maximum extension of excess surface water. Time series on other extreme events (frost, storms, pests gradations, etc.) were not available. A preliminary analysis, however, indicated that despite the negative local impact of inundations on crop yield, years with inundations actually had higher crop yields at a national level than the years without floods. Consequently, this factor was excluded from further analysis and we only used the Palfai Drought Index (PAI) when defining years with 'potential yields' (PÁLFAI 2004, 2011). PAI values can have a theoretical minimum of 1 and increasing values are directly proportional to the intensity of drought. The maximum calculated value in Hungary between 1931 and 2010 was PAI=14. Between 1921 and 1930, I used PÁLFAI's (2009) five grade historical drought index, which I multiplied by 2.8 to make it comparable to the other calculated values.

Since the goal of the research was to examine statistical relationships between climatic, groundwater and cereal yield variables, to minimize the influence of agro-technological development during the study period, the first-difference method for annual crop yield and climatic variances was used (NICHOLLS 1997; PETERSON et al. 1998). The relationship between the variances of climatic parameters and crop yield was tested using the linear model in the *Rcmdr* package (FOX 2005). The uncertainty of the regression coefficients was estimated by bootstrap resampling over 5000 replicates using the *boot* package (DAVISON, HINKLEY 1997; LOBELL, FIELD 2007; CANTY, RIPLEY 2017).

2.2.3.2. Estimation of yield losses

Firstly, crop loss as a response parameter of the negative impact of precipitation or temperature fluctuation was calculated from the slope and direction of the regression equation expressed as an estimate of yield change accompanying a 1°C temperature or a 1 mm precipitation change (LIU et al., 2016). Besides the most widely used method for crop loss estimation, I calculated yield loss (NUTTER et al. 1993) as the difference between the actual yield of a given year and yield peaks (NEWMAN, 2016; OERKE & DEHNE 2004): first, we calculated the potential yield for a given decade as the mean of yields in the highest quartile in that decade. I calculated the differences from averages in decennial periods to reduce the bias due to changes caused by technological development. The difference between such potential mean values of the relevant decades and the yield of a given year within that decade was thus positive (yield gain) or negative (yield loss). Finally, the products of yield losses and the regression coefficients for 30-year periods were considered as the measure of climate driven crop yield losses.

2.3. Economic assessments for supporting integrative landscape planning

Using the replacement cost method (DE GROOT et al. 2002; BRANDER et al. 2006) I compared the investment costs/m^3 of storage capacity of two restored aquatic ecosystems with the storage capacity of the six completed reservoirs of the Vásárhelyi Development Plan (VDP). I also considered the maximum amount of sustainable water (DE GROOT et al. 2010) (5000 m^3/ha), and regional land prices (IFTEKHAR et al. 2016). Subsequently, I estimated the spatial average of the costs of protection against, and the damage caused by groundwater floods in the affected arable lands. Finally, as a step towards an integrative planning of sustainable land use, following SCHAUBROECK et al. (2016) and CABRAL et al.'s (2016) methods I set up an inventory of quantitative ecosystem services. My goal was to obtain results that can contribute to a landscape planning process, so I made estimations of monetary values per unit area.

2.4. Zonal land use system in areas prone to excess surface water: case study in the Trans-Tisza region

The 9331 km² sized study area lies in the centre of the Hungarian Plain, east of the Tisza River. Almost half of all the areas highly prone to groundwater flooding and one-third of the areas with the highest drought frequency and intensity in Hungary is concentrated here. This lowland region is one of the largest natural grasslands in Europe, and includes an UNESCO World Heritage site, the Hortobágy landscape, as well as extensive protected wetland reserves.

While preparing the water protection zone system, I considered aspects of environmental policy, nature protection, suitability for cropland farming and afforestation, vulnerability to drought, groundwater flooding and contamination by nitrates, and the additional costs of protection from groundwater floods. To tackle the problem caused by the different spatial scales of the studied databases, we adjusted the scale of output maps to the one with the crudest resolution of the input datasets (1:100 000). For suitability I used the 100 m x 100 m grids of the 'Ecotype-Based Land Use Analysis of Hungary' (ELUAH) (CENTERI et al. 2006) based on the measured physical, chemical and hydrological conditions of soils and on climatic conditions. There are four categories of the areas experiencing groundwater floods: those prone to serious and frequent floods (recurrence interval (RI) = 1–5 y), medium exposure (RI = 5–10 y), moderate exposure (RI = 10–20), and scarce exposure (RI >20). Environmentally Sensitive Areas (ESA), area belonging to the National Ecological Network and the Natura 2000 network were considered as the areas of nature protection. The three categories showed major overlap completing each other (BARNÁNÉ BELÉNYESI 2006).

2.4.1. Zonal classification

Areas belonging to Zone 0 were excluded from the analysis. These were artificial surfaces (settlements, roads, railroads, etc.), lakes and streams, as well as land classified of excellent agro-ecological potential in the ELUAH.

Zone 1 covered the areas exposed to serious or medium groundwater flood risk, and the intersection of areas under medium risk and either natural reserves or areas vulnerable to nitrification, identified by the RBMPH (2010, 2015) and the Hungarian Government Decree No. 221/2004 [VII. 21.]. Here the RBMPH recommends groundwater retention citing ecological and water protection reasons.

Zone 2 comprised areas prone to drought and groundwater flooding at a medium level but not under nature protection. These areas are suitable for excess surface water retention from the aspects of ecology, economy and water quality. The main environmental problems of crop farming here are diffuse water pollution from agriculture (RBMPH 2010, 2015), drought vulnerability, flood proneness (PÁLFAI 2004) and the low agro-ecological potential of soils formed under water effect (SISÁK et al. 2009) and a low level of biodiversity.

Zone 3 covered the intersection of areas falling into the three most suitable categories of afforestation in the ELUAH and Zones 1 and 2. These areas of water retention are suitable for afforestation.

3. RESULTS

3.1. The relationship between climatic variables, groundwater and cereal yield at regional and country scales (1921–2010)

3.1.1. Descriptive analysis

The 30-year averages of the coldest months permanently increased in every station during the studied 90 years. The mean temperature in January was 1.5 °C higher in 1981–2010 than in 1921–1950. The mean temperature in July decreased everywhere from 1921–1950 to 1951–1980, then -with the exception of Szeged- increased everywhere from 1951–1980 to 1981–2010. The mean temperature of the hottest month was significantly higher in four stations and at country level during the period of 1981–2010 than in 1921–1950. In Szeged, however, the mean July temperature was higher in 1921–1950 than in 1981–2010. The five meteorological stations almost homogeneously belonged to the Dfb category of warm summer continental climates in the modified Köppen-Geiger climate classification system (RUSSEL 1931; PEEL et al. 2007) between 1921–2010. Continental climate with warm summer (Dfa) occurred in Pécs and Szeged between 1921–1950 and in Budapest between 1981–2010.

Mean temperature in the periods of May–July and May–August decreased slightly in the majority of stations from 1921–1950 to 1951–1980, then significantly increased everywhere from 1951–1980 to 1981–2010. The mean temperature of vegetation periods in 1981–2010 was significantly higher than in the first 30-year period almost everywhere, but in Debrecen and Szeged in terms of May–July period.

Precipitation means during the relevant vegetation periods showed a trend-like decrease in three stations during the studied 90 years. Contrary to this, precipitation in Budapest had a trend-like increase over the entire study period. In summary, precipitation means did not show statistically significant change during the studied 90 years.

The country scale average of the drought index (PAI) decreased slightly, then increased significantly from 1951–1980 to 1981–2010. The mean temperature during the relevant vegetation periods in 1981–2010 was significantly higher than in the first 30-year period almost everywhere.

Table 1 The counties of the GHP and the six bioclimatic regions of Hungary selected by the landscape characteristic of the counties, the position of the meteorological stations and the results of cluster analysis of annual county grain yield

Region	County
1	Vas, Zala
2	Fejér, Győr- Moson-Sopron, Komárom-Esztergom, Pest, Veszprém
3	Borsod-Abaúj-Zemplén, Heves, Nógrád
4	Hajdú-Bihar, Szabolcs-Szatmár-Bereg
5	Bács-Kiskun, Békés, Csongrád, Jász-Nagykun-Szolnok
6	Baranya, Somogy, Tolna
7	Bács-Kiskun, Békés, Csongrád, Hajdú-Bihar, Jász-Nagykun-Szolnok, Szabolcs-Szatmár-Bereg

The "Green Revolution" spectacularly improved yields of barley, maize and wheat between the 1950s and 1980s. The same yields showed a gradual, slight increase before this big technological exchange and a trend-like stagnation after the 1980s. Due to agrochemicals, motorization and plant breeding, mean barley yields between 1980–2010 were 2.74 times higher than during 1921-1950, maize yields increased 3.21 times and wheat 3.29 times during the same period. Yield increases, however, showed serious regional differences. The gap between the lowest and the highest production by county increased by 11% to 154% for barley, by 15% to 171% for maize, but decreased by 6% to 135% for wheat. While in the top three quartiles of yield rank were nearly always counties in Transdanubia, the most markedly in the last 30 years, the lowest positions on the yield rank lists was occupied by hilly counties and counties of the GHP.

Table 2 Twenty-five-year annual averages of groundwater level at county, regional and country scale, and their differences (1961-2010)

Spatial level	$\gamma Gw_{1961-1985}$. m	$\gamma Gw_{1986-2010}$. m	ΔGw. m
Bács-Kiskun	-2.18	-2.51	-0.33*
Baranya	-2.23	-1.99	0.24*
Békés	-3.02	-3.08	-0.06
Borsod-Abaúj-Zemplén	-2.78	-3.24	-0.46*
Csongrád	-1.59	-2.09	-0.50*
Fejér	-3.40	-3.43	-0.02
Győr-Moson-Sopron	-2.58	-3.32	-0.74*
Hajdú-Bihar	-2.67	-2.98	-0.31*
Heves	-1.49	-1.74	-0.26*
Jász-Nagykun-Szolnok	-3.22	-3.29	-0.06
Komárom-Esztergom	-2.25	-2.83	-0.58*
Nógrád	-5.18	-4.92	0.26
Pest	-2.37	-3.17	-0.80*
Somogy	-3.39	-3.27	0.11
Szabolcs-Szatmár-Bereg	-2.84	-3.37	-0.53*
Tolna	-3.08	-3.51	-0.43*
Vas	-1.61	-1.56	0.05
Veszprém	-1.55	-1.61	-0.06
Zala	-3.07	-3.47	-0.39*
Region 1	-2.58	-2.91	-0.33
Region 2	-2.47	-3.11	-0.64*
Region 3	-3.07	-3.49	-0.42*
Region 4	-2.72	-3.10	-0.38*
Region 5	-2.44	-2.69	-0.25*
Region 6	-2.93	-3.23	-0.30*
The Great Hungarian Plain	-2.55	-2.85	-0.30*
Country	-2.59	-2.98	-0.38*

* = significant difference between the average of the periods of 1961–1985 and 1986–2010 (Welch-test; $p < 0,05$); γGw = average of groundwater level; Δgw = differences between the average of groundwater level ($\gamma Gw_{1986-2010} - \gamma Gw_{1961-1985}$).

The average of groundwater level decreased significantly from 1961–1985 to 1986–2010 in five regions and in eleven counties. The annual average decrease was 1.52 cm/y at country scale and 1.2 cm/y on the GHP from 1961–1985 to 1986–2010 (Table 2).

3.1.2. The relationship between groundwater and average yields at county and regional scales (1981–2010)

The relationship between the monthly averages of groundwater level and annual yields were everywhere negative for barley and wheat between October–April and for maize between March–May. The negative impact was the most visible in the case of barley, while it was very rare in the case of maize and wheat. Contrary to this, the relationship during the period of May–October was positive in every county. The impact of this positive statistical relationship was basically negligible for barley and wheat almost in every county, except Bács-Kiskun, Fejér, Győr-Moson-Sopron and Veszprém. By contrast the relationship between the July–October averages of groundwater level fluctuation and maize yields proved significantly positive in half of the counties and in the vast majority of regions (Table 1). The value of regression coefficients was multiple of the negative ones during the first half vegetation periods. Another remarkable spatial characteristic is that the negative impact of groundwater level fluctuation in the early phase of vegetation period was almost imperceptible in the important grain producer areas, except Somogy. The positive relationship, however, appeared only in the important agricultural regions, e.g. Southern GHP.

3.1.3. The relationship between climatic, groundwater and cereal yield variables at regional and country scale (1921–2010)

During the studied period, temperature variance proved to be the strongest climatic driver of yield fluctuations in barley and wheat. For maize, precipitation variance was the most influential factor. While temperature change had a negative linear relationship with crop yields in every period, precipitation had a usually positive impact on cereal yields in all three periods (Figure 1), except barley and wheat in the period of 1921–1950, when precipitation had a nonsignificant negative linear relationship with the yields of these two cereals.

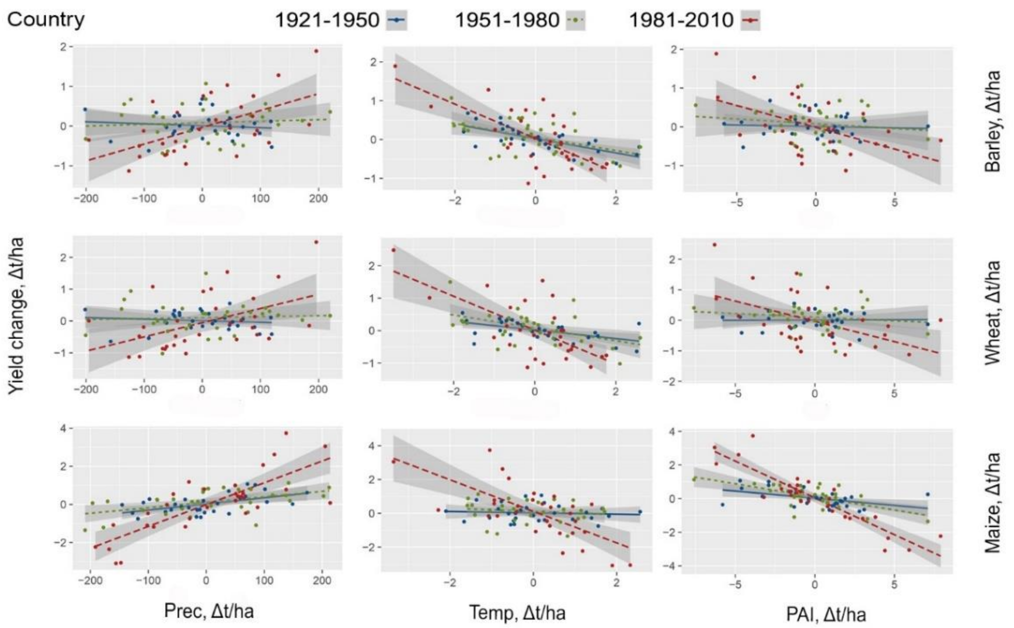

Figure 1 Scatterplots for the first-differences of three climatic and four crop yield variables by 30-year-long periods (1921–2010); dark grey shading indicates the 95% confidence intervals of the regressions (1921–2010). Prec = precipitation sums in vegetation periods, Temp = mean temperature in vegetation periods; PAI = annual Pálfai drought index.

There was nonsignificant relationship between precipitation and barley and wheat yields, and between temperature and maize yield during the first two periods. The deterministic relationship between climatic factors and cereal yields was much stronger in 1981–2010 than earlier. During this period, the combined climatic factor (Temp/Prec) explained ca. 50% of barley and wheat yield variances and almost two-third of maize ones. The relationship between groundwater and barley and wheat yields was non-significant at country and regional scales, except in the hilly counties of Northern Hungary. By contrast, the positive relationships were characterized by relatively high coefficients. Combined temperature and groundwater variables as combined climatic factors showed close relationship with cereal yields.

Table 3 Twenty-five-year averages of groundwater level between August – October at regional and country scale, and their differences (1961-2010).

Spatial level	$\gamma Gw_{1961\text{-}1985}$. m	$\gamma Gw_{1986\text{-}2010}$. m	ΔGw. m
Region 1	-2.91	-3.18	-0.28*
Region 2	-2.59	-3.19	-0.60*
Region 3	-3.25	-3.65	-0.40*
Region 4	-2.90	-3.27	-0.37*
Region 5	-2.66	-2.87	-0.21*
Region 6	3.20	3.47	0.27*
The Great Hungarian Plain	-2.75	-3.02	-0.28*
Country	-2.25	-3.12	-0.87*

* = significant difference between the average of the periods of 1961–1985 and 1986–2010 (Welch-test; $p < 0,05$); γGw = average of groundwater level; Δgw = differences between the average of groundwater level ($\gamma Gw_{1986\text{-}2010} - \gamma Gw_{1961\text{-}1985}$).

The regional investigation discovered temporarily changing and diverse spatial relationships between climatic and cereal yield variables. While temperature showed the strongest relationship with barley and wheat yields in the county groups of Transdanubian region, this relation was hardly visible on the GHP between 1921–1950. During 1981–2010, however, the strongest temperature-barley yield, and temperature-wheat yield connections appeared in the Southern GHP. The strongest temperature-maize yield relationship was found in the Southern GHP region during this period. Based on the equation of this statistical relationship in the GHP ($R^2 = 0.34$; $p < 0.01$; $y = 0.0023x + 0.0154$), 100 mm groundwater level increase in the August–October period at a landscape scale would have caused 0.25 t/ha maize yield increase. Using this equation, my estimation is that groundwater decrease (Table 3) caused 0.70 t/ha/y crop loss during 1981–2010. By comparison, a 1 °C mean temperature increase during the studied vegetation period ($R^2 = 0.49$; $p < 0.01$; $y = -0.9561x + 0.044$) led to 0.91 t/ha maize yield loss during 1981–2010.

3.1.4. Yield loss estimation

The estimated yield loss based on the highest quartiles ranged between 3–6% for barley and wheat and between 4–9% for maize during 1981–2010. Barley in Region 2 saw the biggest yield loss (6.00%) in the period, while maize and wheat suffered the highest losses (5.94% and 9.26%) on the Southern GHP. Due to the lack of significant relationship for barley, crop loss could not be estimated in the northern GHP region. In Southern Transdanubia maize and wheat growers faced the lowest yield losses in the last 30 years. Yield losses calculated from the regression equations of temperature-cereal yield relationship proved the highest in the Southern GHP region for three crops, while the Southern Transdanubian region saw the lowest yield losses for and maize and the hilly counties in the northern region for wheat during 1981–2010. The four counties of the Southern GHP showed very high vulnerability from many aspects. My estimation at country scale was that 1 °C mean temperature increase of the studied vegetation period cut back barley yields by 10.91%, maize by 12.17% and wheat by 16.46% during 1981–2010 (barley: $R^2 = 0.48$; $p < 0.01$; $y = -0,4146x + 0,0236$; maize: R^2

= 0.50; $p < 0.01$; y = -0,994x + 0,0589; wheat: R^2 = 0.42; $p < 0.01$; y= -0,5284x + 0,0104).

3.1.5. Territorial validity

Precipitation showed statistically significant correlations with the gridded CRU data ($r > 0.48$; $p = 0.10$) essentially in the whole Carpathian Basin. In the temporal pattern of this spatial relationship, however, we found large differences with a decreasing trend. In contrast to the relatively narrow regional validity of precipitation data, temperature variables proved valid in almost half of the continent demonstrating an ever broadening spatial correlation. Notably, this widening spatial correlation in Europe coincided with the significant growth of temperature in the last three decades.

3.2. Economic assessments for supporting integrative landscape planning and the concept of a water protection zone system

3.2.1. Inventory for economic assessments for supporting integrative landscape planning

Data for net profitability of land use forms and the value of carbon sequestration benefits of floodplain forests came from external research (KISS et al. 2013; PINKE et al. 2018). As for the value of the flood protection service of areas exposed to groundwater floods, the reservoir capacity cost per m^3 of the two restored wetlands (0.05 €/m^3) was ca. 10 times cheaper than that of the VDP reservoirs which means that the reservoir capacity of restored wetlands with an ecologically optimal 0.5 m water depth (5000 m^3/ha x 0.05 €/m^3) could replace 2200 €/ha flood protection investment cost (Table 4). The estimated operational and maintenance costs at country level (SOMLYÓDY 2011) in areas with groundwater risk runs to 10.6 €/hay, respectively, between 1999 and 2005.

Table 4 Inventory: Estimation of monetary value of various activities of current and planned land use and their spatial validity.

Issue	Type	Value, €/ha/y	Spatial validity	Source, method
Net profitability of different agricultural sectors				
Profitability of arable lands	Food production, provisioning services	54.5	Local, national, EU	(KISS et al. 2013) market price method
Profitability of forests	Timber, provisioning service	116.2	Local, national, EU	(KISS et al. 2013) market price method
Profitability of grasslands	Provisioning service	18.2	Local, national, EU	(KISS et al. 2013) market price method
Profitability of orchards	Food production, provisioning service	163.4	Local, national, EU	(KISS et al. 2013) market price method
Profitability of wetlands	Fish production, provisioning service	370.4	Local, national, EU	(KISS et al. 2013) market price method
Monetary values of				
CO2 sequestration in floodplain forests	Mitigating global warming	5-24	Global	(PINKE et al. 2018) monetary evaluation of model outputs, damage cost method
Flood defence service#	Replacing investments	2200#	National, EU	Replacement method
Benefits from avoiding costs related to floods				
Costs of flood defence	Avoiding protection costs	20.8–51.7*	Local, national, EU	Data from descriptive analysis
Costs of flood damage on arable land	Avoiding damage costs	1010.1	Local, national, EU	Data collection and descriptive analysis

* = in areas with serious and medium groundwater risk; # = onetime benefit

Based on PÁLFAI’s (2006) damage assessment of excess surface water inundations for 1951–2010, the estimated groundwater flood damage to arable lands between 1999 and 2005 amounted to 1010.1 €/ha/y. This, nonetheless, is not the average of the damage in areas with serious or medium groundwater risk, but the average on the actually inundated areas.

3.2.2. Water protection land use zone system: case study in the Trans-Tisza region

Although only 28.1% of the study area was classified as belonging to excellent or good agro-ecological suitability categories, almost 66% of the landscape is currently used for monocultural cropland farming. Currently, woody vegetation that comprises forest (2.9%) and shrub categories of the Corine covers less than 4% of the study area. (Table 5).

Table 5 Land use structure of target areas to retain excess surface water

	Ratio in study area, km^2 (%)	Occupancy of current land use forms, km^2 (%)		
		Arable lands	Meadows	Woods
Study area total	9331 (100)	6232 (66.8)	905 (9.7)	341 (3.7)
Zone 1	3978 (42.6)	1826 (45.9)	1482 (37.3)	289 (7.3)
Zone 2	890 (9.5)	794 (89.4)	49 (5.5)	29 (3.2)
Zone 3	847 (9.1)	738 (87.2)	61 (7.2)	26 (3.0)

The implementation of the RBMPH (2010, 2015) requires water retention in Zone 1 where land use conversion on flood-prone arable lands under environmental protection extends to 19.6% of the study area. The results of the zonal analysis indicated that 28.1% of the study area should be converted from arable land to wet meadows, forests or marshlands. The percentage of arable lands is also outstandingly high in Zone 2 where land use change is ecologically and economically justified. In summary, water retention was recommended or justified almost on 52.6% of the study area and 53.8% of these target areas are currently arable lands. While 26.5% of area is suitable for economically reasonable afforestation, most of these, especially in loess ridges, overlap with areas of good or excellent agro-ecological suitability. This conflict zone was excluded from the analysis. Almost a third of areas suitable for afforestation is exposed to inundations covering Zone 3, which hardly shows overlap with current forest coverage.

3.3. New scientific results

1) Mean temperature in the periods of May–July and May–August decreased slightly in the majority of stations from 1921–1950 to 1951–1980, then significantly increased everywhere from 1951–1980 to 1981–2010. Precipitation means of the studied 30-year periods did not change during the studied 90 years and 1981–2010 was the hottest and most drought affected period.
2) The average of groundwater level decreased significantly from 1961–1985 to 1986–2010 in five regions and eleven counties. The average decrease at country scale (0.38 m) and in the Great Hungarian Plain (0.30 m) were significant.
3) Combined factors of temperature/precipitation and temperature/groundwater explained almost 50% of barley and wheat yield variances and almost two-third of maize ones.
4) While temperature change had a negative linear relationship with crop yields in every period, precipitation had a usually positive impact on cereal yields in all three periods, except barley and wheat in the period of 1921–1950, when precipitation had a nonsignificant negative linear relationship with the yields of these two cereals.
5) While above cited research demonstrated that climate variability explained one-third of maize and wheat yield variances globally, the regression coefficient of the statistical relationship between the combined climatic factor and wheat yield was $R^2 > 0.46$ in Hungary.
6) Temperature driven crop losses were estimated in two ways. Using regression equations, 1 °C mean temperature increase of the studied vegetation period cut back barley yields by an estimated 10.91%, maize by 16.46% and wheat by 12.17% during 1981–2010, which is almost double the global average of temperature driven crop loss (4.1–6.4%). When I

calculated it from the highest quartiles, temperature driven crop loss ranged between 3,56–5,94% matching to the global average.

7) The regional investigation discovered temporarily changing and diverse spatial relationships between climatic and cereal yield variables. While temperature showed the strongest relationship with barley and wheat yields in the Transdanubian region, this relationship was hardly visible in the Great Hungarian Plain between 1921–1950. During 1981–2010, however, the strongest temperature-barley yield and temperature-wheat yield connections appeared in that region. The strongest temperature-maize yield relationship was also reconstructed in the Southern Great Hungarian Plain region during this period.

8) Monthly averages of groundwater level and annual yields showed different directions during the period of 1981–2010. While the relationships for barley and wheat yields between October–April and in case of maize yields between March–May were negative everywhere, the relationships of the period of May–October were positive in every county. Contrary to the usually non-significant negative relationship, groundwater level-maize yield relationships proved significantly positive in half of the counties and in the majority of regions.

9) Based on the equation of this statistical relationship in the Great Hungarian Plain, 100 mm groundwater level increase in the August–October period at a landscape scale would have caused 0.25 t/ha maize yield increase. Using this equation, my estimation is that groundwater decrease caused 0.70 t/hay crop loss during 1981–2010.

10) The estimated investment costs (considering the cost m^3 of stored floodwater) of the current flood defense megaproject on the Hungarian Plain (the Vásárhelyi Development Plan) are almost 10 times higher than the establishment costs of the two wetland restoration programs implemented in the same region.

11) The estimated value of ecosystem services in areas with groundwater hazard provide ‘win-win’ solutions for land users interested in profitability providing services for the community and for institutional actors interested in flood prevention and environmental protection.
12) Via combination of areas with weak or medium agroecological potential, areas prone to excess surface water and areas suitable for afforestation a zone was selected, where the extremely low forest coverage of the landscape (<4%) could significantly increase by retaining water and properly allocated subsidies for public afforestation.

4. CONLUSIONS AND RECOMMENDATIONS

The central, southern and western regions of Hungary, where mean temperature of coldest and hottest months was near the upper threshold of Dfb category of the modified Köppen-Geiger classification system (PEEL et al. 2007) were not the typical areas of the continental zone, but they belonged to its transitional zone. Regarding regional climate predictions (PIECZKA et al. 2011) and the dynamics of reconstructed changes, I can conclude that the vast majority of the country will be shortly classified among northern Mediterranean regions in the Cfa zone (PEEL et al. 2007).

The negative relationships between groundwater and cereals between November and April temporarily overlapped with the crest of the annual groundwater level oscillation. Increasing groundwater due to melting, frozen soil, precipitation maximum or low intensity of evaporation could damage cereals during this period. This half year and mainly the January–March period was the main period of groundwater floods. This negative impact was identified in the dissertation at county and regional scale. This result also illuminates that the negative effect of groundwater floods were just local phenomena and their negative impact on cereal yields at landscape scale are negligible. Contrary to this, the positive relationships between groundwater and cereal yields appeared in the declining section of groundwater. In this period and especially between July and September the evapotranspiration-water demand balance of maize is mainly negative (LÁNG et al. 2006) and groundwater probably has a key role in counterbalancing this climatic water shortage. Positive impact of groundwater on maize yields was not only local, but also regional, and this valid relationship can be identified by statistical tools.

Since the combined climatic factor of mean temperature and precipitation sum is relatively easily available or replaceable by using proxies (KERN et al. 2016; DEMÉNY et al. 2017), and it showed close relationship with cereal yields, using this explanatory factor in bioclimatic studies could be effective when only weak data are available (RUDGERS et al. 2018). This research resulted additional support for our knowledge on the climate change impacts on cereal production at regional and country scale, highlighting that grain production vulnerability to warming increased the most during the studied 90 years on the Great Hungarian Plain. My conclusion is that the high vulnerability of cereal production is symptomatic in the continental plains of the Northern Hemisphere (RAMANKUTTY, FOLEY 1999; RAY et al. 2012). This discussion should be widened to include the consideration of climatic effects: due to the relatively great amplitude of temperature variability, Hungary and the surrounding regions are among grain producers most vulnerable to climate change that is a strong warning signal for the future. The 30-year averages of estimated yield losses, however, conceal the fact that in terms of certain crops, the highest annual losses may have reached 40% of the potential cereal yield in Hungary. Every large yield loss was accompanied by a high PAI index value (PINKE 2012).

The mid-20th century Green Revolution improved yields 'at the mercy of the weather' (SEWELL et al. 1968), when the impact of increasing fertilization and mechanization coincided with a period of favorable climatic conditions (CHLOUPEK et al. 2004). It is not accidental that agricultural productivity could improve dramatically in a period (1951–1980) when annual temperature means—and consequently PAI values—did not fluctuate wildly. Temperature and yield loss means were lower than in the previous and subsequent 30-year periods. Our country scale examination confirms that stagnation in the production of the most important cereals in temperate zone since the early 1980s is partly attributable to significantly rising temperatures during the vegetation periods (LOBELL, FIELD

2007). The mainstream agro-economic discourse of the unfolding crisis of cropland farming in postcommunist countries between the early 1980s and the 2000s (HARCSA et al. 1998; MARTIN-RETORTILLO, PINILLA 2015; SARRIS et al. 1999) concentrated on the socio-economic drivers. Regarding the results of climate-cereal research in case of vulnerability (TRNKA et al. 2011; OLESEN, BINDI 2002), spatial pattern of yield stagnation (RAY et al. 2015) and results of this study his discussion should be widened to include the consideration of climatic effects.

Eastern European crop farming must face the challenge that climate change (SUTTON et al. 2013) will have cumulative negative impacts on its most important crops, since the transformation of climatic regime is predicted to produce rapidly increasing temperatures (KROMP-POLB et al. 2014), more droughts and other hydro-climatic extremities (IPCC 2014; TRNKA et al. 2011). OLESEN & BINDI's (2002) assessment on the consequences of climate change for European agricultural productivity, land use and policy suggests that the relevant response to recent and future hydro-climatic shifts in Southeastern Europe is the extensification of agriculture. The results of this paper underline the importance of this suggestion. In Hungary, where former floodplains cover one-third of arable lands, of which 40%–45% are situated in a highly drought-prone zone, transformation of the vulnerable anthropogenic landscape together with the restoration of the mitigation functions of the landscape is highly recommended (DE GROOT 2006; Hungarian Climate Change Strategy 2013; Hungarian Drought Strategy 2012; Hungarian Water Strategy 2015; River Basin Management Plan of Hungary 2015).

The estimated value of ecosystem services of areas with high groundwater hazard provide 'win-win' solutions for land users interested in profitability, providing services for the community and for institutional actors interested in flood prevention and environmental protection (EEA 2017). The discovered positive groundwater level-maize yield relationships provide a new reason for the land use conversion and water retention in areas prone to access surface water inundations. Results of the study above suggest that by raising groundwater level through wetland restoration, maize yields will increase in areas with good and excellent agroecological potential.

Land users could use their land to gain tangible benefits both to themselves and the community instead of continuing to produce commodities financed by subsidies. Some benefit transfers are financed by the EU or governmental agri-environmental measures, but ecosystem services which land users transfer to the community, especially in the case of wetlands, are generally underfunded (SWEENEY et al. 2004; CLARE et al. 2011; PENDLETON et al., 2016). If land users relieve the community (e.g. by flood or drought protection) from expenses tied to maintaining the current land use pattern and abandon their former attitude of seeking maximized yield gains (HARDIN 1968), they would be entitled to benefit from the value of the transferred services.

Natural reserves, and especially the remains of the highly endangered forest-steppe lying in areas prone to groundwater floods are generally water-dependent habitats (MOLNÁR et al. 2012). Draining them caused landscape-wide water shortage, which grossly degraded these habitats, and their restoration is indispensable (RBMPH 2010). Furthermore, patches of retained inland water is to be linked to the creation of a self-sustaining habitat network that provides paths for energy and material fluxes and for the migration of species (CLAIRE et al. 2010). Thus, restoration of the early Holocene and Pleistocene river beds (GÁBRIS et al. 2012; LÓCZY et al. 2016) and corridors of the National Ecological Network are important elements of the outlined zonal water protection system.

The targeted integrated landscape restoration would mostly result in large areas of marshlands, wet meadows and floodplain forests with mixed vegetation potential. Establishing Zone 3 that covers flood-prone areas suitable for afforestation could facilitate the increase of recent forest coverage (<4%). The success of completed afforestation programs in the Hungarian Plain in the past decades (Agricultural Operation Office 2009) suggests that most of the conflicts between water retention and arable farming can be resolved by properly allocated subsidies for public afforestation in this zone. The valuable carbon capture, flood reservoir and water purification capacity of wetland forests (SZILÁGYI 2005) would make even significantly increased subsidies for wetland reforestation reasonable (JENKINS et al. 2010; MAES et al. 2012).

Climatic conditions of the study area do not allow forests to form a closed canopy, which is reflected in the current categorization of afforestation suitability. Still, intrazonal effects of water coverage may make forestation possible even in areas under adverse climatic conditions (PÁLYI 2004; PINKE, SZABÓ 2012). Consequently, the mitigation function of wetlands will become even more important at the landscape scale. Historical examples confirm that shallow water coverage and high groundwater levels would support the evolution of biodiverse sylvi- and pomiculture in currently drought-prone areas (GYULAI 2010).

5. THE CANDIDATE'S PUBLICATIONS RELATED TO THE TOPIC OF THE THESIS

5.1. Peer-reviewed journal articles

PINKE ZS. (2014): Modernization and decline: an eco-historical perspective on regulation of the Tisza Valley, Hungary. *Journal of Historical Geography,* 45 92–105. p.

PINKE ZS., FERENCZI L., F. ROMHÁNYI B., GYULAI F., LASZLOVSZKY J, MRAVCSIK Z., PÓSA P., GÁBRIS G. (2017). Zonal assessment of environmental driven settlement abandonment in the medieval Trans-Tisza region, Central Europe. *Quaternary Science Review,* 157 98–113. p.

PINKE ZS., FERENCZI L., F. ROMHÁNYI B., LASZLOVSZKY J., POW S. (2017): Climate of doubt: a re-evaluation of Büntgen and Di Cosmo's environmental hypothesis for the Mongol withdrawal from Hungary, 1242 CE. *Scientific Reports,* 7 12695. doi:10.1038/s41598-017-12128-6

PINKE ZS., KISS M., LÖVEI L. G. (2018): Developing an integrated land use planning system on reclaimed wetlands of the Hungarian Plain using economic valuation of ecosystem. *Ecosystem Services,* (in print). doi: 10.1016/j.ecoser.2017.09.007

PINKE ZS., LÖVEI L. G. (2017): Increasing temperature cuts back crop yields in Hungary over the last 90 years. *Global Change Biology,* 12 5426–5435. p.

5.2. Peer-reviewed book chapter in English

FERENCZI L., LASZLOVSZKY J., PINKE ZS., SZABÓ P., VADAS A. (2018): Environmental conditions in medieval Hungary with special regard to its impact on the agricultural possibilities. In: NAGY B., LASZLOVSZKY J., SZABÓ P. (Szerk.): *Farming and Economy in Medieval Hungary (East Central and Eastern Europe in the Middle Ages, 450–1450)*. Brill, Leiden–Boston. (in print)

5.3. Peer-reviewed articles in Hungarian

PINKE ZS. (2012): A költség alapú értékelés és a szabályozó ökoszisztéma szolgáltatások szerepe a belvizes területek vizes élőhellyé alakításában. *Természetvédelmi Közlemények,* 18 425–434. p.

PINKE ZS. (2012). Aszály-, belvízkárok és az árvízvédelmi ökoszisztéma szolgáltatás értékelésének szerepe a belvizes területek vizes élőhellyé alakításában. *Tájökológiai Lapok,* 10 271–286. p.

PINKE ZS., SZABÓ B. (2012): Fásszárú növényzettel borított területek változásai a Hortobágy–Sárréten az elmúlt ezer évben. *Helynévtörténeti tanulmányok,* 8 141–150. p.

5.4. Conference proceedings papers in English

Pinke Zs. (2010): The Role of Floodplain Rehabilitation in the Danube Strategy In: BÁLINT G., DOMONKOS M. (Szerk.): „Development and tradition in water sciences”. XXVth Conference of the Danubian Countries on the Hydrological Forecasting and Hydrological Bases of Water Management. Budapest, Magyarország, 2011.06.16-2011.06.17. CD/Paper 5_06. VITUKI, Budapest. ISBN:978-963-511-151-0

PINKE ZS. (2010): Chapter on the Preparation of the Area Planning Program Titled Floodplain Rehabilitation Model in Hortobágy-Sárrét. 1 207–224. p. In: BUDAY-SÁNTHA A., GUNSZT K., HORVÁTH M., MILOVECZ Á., PÁGER B., TÓTH Z. (Szerk.): *„Félidőben” c. konferencia, közép-európai* *terület-, település-, vidék- és környezetfejlesztéssel foglalkozó doktori iskolák találkozója 1–3.* Pécsi Tudományegytem Közgazdasági Kar, Pécs.

5.5. Conference proceedings papers in Hungarian

BENŐ D., PINKE ZS. (2011): Ártér rehabilitáció célterületeinek leválogatása fuzzy módszerrel a Hortobágy-Sárréten. 271–278. p. In: LÓKI, J. (Szerk.): *Az elmélet és a gyakorlat találkozása a térinformatikában: II. Térinformatikai Konferencia és Szakkiállítás.* Debreceni Egyetem, Debrecen.

PINKE ZS. (2010): Tájtörténet-tájrehabilitáció, kutatás-tervezés. 1 172–190. p. In: BUDAY-SÁNTHA A., GUNSZT K., HORVÁTH M., MILOVECZ Á., PÁGER B., TÓTH Z. (Szerk.): *„Félidőben” c. konferencia, közép-európai terület-, település-, vidék- és környezetfejlesztéssel foglalkozó doktori iskolák találkozója 1–3.* Pécsi Tudományegytem Közgazdasági Kar, Pécs.

PINKE ZS. (2012): Ökoszisztéma szolgáltatások és természeti tőke értékelésének szerepe a területi tervezésben. 169–182. p. In: REISINGER A. (Szerk.): *Szent István Egyetem Regionális- és Gazdaságtudományi Doktori Iskola Évkönyve.* Szent István Egyetem, Győr.

PINKE ZS., F., ROMHÁNYI B., GRÓNÁS V., MRAVCSIK Z., PÓSA P., GYULAI F. (2017): A hajdúsági várostérség agroökológiai adottságai. 105–144. p. In: KENYERES I. (Szerk.): *Urbs Várostörténeti Évkönyv X–XI.* Fővárosi Levéltár, Budapest.

5.6. Conference abstracts in English

PINKE ZS., F. ROMHÁNYI B., GÁBRIS GY., GYULAI F., MRAVCSIK Z., PÓSA P., FERENCZI L. (2016): Adaptation and rise: Little Ice Age challenges and social responses on the Trans-Tisza Region (Hungary). In:

Geophysical Research Abstracts, 18, Paper EGU2016-1028-1. EGU General Assembly 2016. Bécs, Ausztria: 2016.04.17–2016.04.22.

PINKE ZS. (2015): Land use response to the climate change in the Great Hungarian Plain? 283–284. p. In: *Our common future under climate change: International scientific conference. Párizs, Franciaország, 2015.07.07–2015.07.10. Abstract book.* UNESCO, Párizs.

PINKE ZS. (2015): Climate-Driven Change of Arable Lands in the Great Hungarian Plain over the Last Century. *ESEH's 8th biennial conference, Versailles, 2015.06.30–2015.07.03.*

PINKE ZS. (2015): Hypothesis on the relation between the late humid period of the Little Ice Age and the culmination of the Hungarian arable lands. 101. p. In: *Climate variability and human impacts in Central and Eastern Europe during the last two millennia. Gdansk, Lengyelország, 2015.06.17-19. Abstracts book.*

PINKE ZS. (2013): Water protection zone system concept: implementation of the Hungarian River Basin Plan measures in areas exposed to excess surface water. 62. p. In: ZIMMERMANN Z., SZABÓ G. (Szerk.): *VIII. Kárpát-medencei Biológiai Szimpózium - I. Fenntartható fejlődés a Kárpát-medencében nemzetközi konferencia. Budapest, Magyarország, 2013.11.21-23. Absztraktkötet*, Szent István Egyetem, Gödöllő.

PINKE ZS. (2011): The Role of Floodplain Rehabilitation in the Danube Strategy. 291. p. In: HABERSACK H., SCHOBER B., WALLING D. (Szerk.): *International Conference on the Status and Future of the World's Large Rivers: WLR Abstract Book.* Bécs, Ausztria, 2011.04.11–2011.04.14. BOKU, Bécs.

PINKE ZS. (2011): Floodplain Rehabilitation Model in Hortobágy-Sárrét. 38. p. In: RHODRI P. T. (Szerk.): *Proceedings of the Global Forum on Salinization and Climate Change (GFSCC2010). Valencia, Spanyolország,* *2010.10.25-2010.10.29.* Food and Agriculture Organization of the United Nations (FAO), RÓMA.

5.7. Conference abstracts in Hungarian

PINKE ZS. (2014): Vízvédelmi zónarendszer koncepció: Az Országos Vízgyűjtő-gazdálkodási Terv belvizes területeken végrehajtandó intézkedéseinek megvalósítása. 103. p. In: LENGYEL SZ. (Szerk.): *IX. Magyar Természetvédelmi Biológiai Konferencia: "Tudományoktól a döntéshozatalig". Szeged, 2014.11.20-23. Absztraktkötet.* Magyar Biológiai Társaság, Szegedi Tudományegyetem Ökológiai Tanszék, MTA Ökológiai Kutatóközpont, Budapest.

TÖRÖK K., HALASSY M., CSECSERITS A., SZITÁR K., DIMITRIEVITS D., DEZSÉNYI P., SOMODI I., KÖVENDI-JAKÓ A., PINKE ZS. (2014): Pusztai tölgyes – gyepmozaik rekonstrukció iparterületen: a nyíregyházi LEGO projekt. 131. p. In: LENGYEL SZ. (Szerk.): *IX. Magyar Természetvédelmi Biológiai Konferencia: "Tudományoktól a döntéshozatalig". Szeged, 2014.11.20-23. Absztraktkötet.* Magyar Biológiai Társaság, Szegedi Tudományegyetem Ökológiai Tanszék, MTA Ökológiai Kutatóközpont, Budapest.

PINKE ZS. (2012): Az elmúlt 100 esztendő aszály- és belvízkárainak statisztikai értékelése. *„A mindennapi élet változásai és ennek politikai és gazdasági aspektusai a 19-20. században" c. konferencia. ELTE BTK, Budapest, 2012. november 22*

PINKE ZS. (2012): Az elmúlt évszázad aszály- és belvízkárainak statisztikai értékelése. 181. p. In: NYÁRI D. (Szerk.): *Kockázat – Konfliktus – Kihívás: A VI. Magyar Földrajzi Konferencia, a MERIEXWA nyitókonferencia és a Geográfus Doktoranduszok Országos Konferenciája., 2012.09.05-07.*

Absztrakt kötet. SZTE TTIK Természeti Földrajzi és Geoinformatikai Tanszék, Szeged.

PINKE ZS. (2012): Tájrehabilitáció lehetőségeinek vizsgálata a Rákos-patak vízgyűjtőjén. In: *9. Magyar Ökológus Kongresszus, Hotel Helikon, Keszthely - 2012. szeptember 5-7.*

Erdőtörténet az erdősítés szolgálatában a Hortobágy-Sárréten. *KITAIBELIA,* 17, (Aktuális Flóra- és Vegetációkutatás a Kárpát-medencében IX. Nemzetközi konferencia. Gödöllő, Magyarország: 2012.02.24 -2012.02.26. Abstract Book) 137. p.

PINKE ZS. (2012): Isaszegi örökségi tanösvény. *KITAIBELIA,* 17, (Aktuális Flóra- és Vegetációkutatás a Kárpát-medencében IX. Nemzetközi konferencia. Gödöllő, Magyarország: 2012.02.24 -2012.02.26. Abstract Book) 138. p.

LITERATURE CITED

AUER I., BÖHM R., JURKOVIC A., LIPA W., ORLIK A., POTZMANN R., SCHÖNER W., UNGERSBÖCK M., MATULLA C., BRIFFA K., JONES P., EFTHYMIADIS D., BRUNETTI M., NANNI T., MAUGERI M., MERCALLI L., MESTRE O., MOISSELIN J.-M., BEGERT M., MÜLLER-WESTERMEIER G., KVETON V., BOCHNICEK O., STASTNY P., LAPIN M., SZALAI S., SZENTIMREY T., CEGNAR T., DOLINAR M., GAJIC-CAPKA M., ZANINOVIC K., MAJSTOROVIC Z., NIEPLOVA E. (2007): HISTALP – historical instrumental climatological surface time series of the Greater Alpine Region. *International Journal of Climatology*, 27 17–46. p. DOI: 10.1002/joc.1377

ÁCS F., BREUER H. (2012): Biofizikai éghajlat-osztályozási módszerek. ELTE TTK, Budapest, 244 p.

BARNÁNÉ BELÉNYESI M. (2006): Magas Természeti Értékű Mezőgazdasági Területek Lehatárolása Térinformatikai Módszerekkel. Ph.D. dissertation. Szent István Egyetem.

BIRÓ SZ. 2009. A földjelzálog–hitelezés intézményrendszere és alkalmazási lehetőségei a magyar mezőgazdaságban. Ph.D dissertation. Szent István Egyetem, Gödöllő, 181 p.

BRANDER L. M., FLORAX R. J. G. M., VERMAAT J. E. (2006): The Empirics of Wetland Valuation: A Comprehensive Summary and a Meta-Analysis of the Literature. *Environmental and Resource Economics,* 33 223–250. p.

BUREAU J.-C. DISDIER A-C., EMLINGER C., FOURÉ J., FELBERMAYR G., FONTAGNÉ L., JEAN S. (2014): Risks and opportunities for the EU agri-food sector in a possible EU-US trade agreement. Structural and Cohesion Studies. European Parliament, Policy Department B, Brussels, 154 p.

CABRAL P. FEGER C., LEVREL H., CHAMBOLLE M., BASQUE D. (2016): Assessing the impact of land-cover changes on ecosystem services: A first step toward integrative planning in Bordeaux, France. *Ecosystem Services,* 22 318–327. p.

CANTY A., RIPLEY B. (2017): boot: Bootstrap R (S-Plus) functions. R package version 1.3-19. (https://cran.r-project.org/web/packages/boot/boot.pdf) Lekérdezés időpontja: 2016.04.10.

CEGLAR A., TORETI A., LECERF R., VAN DER VELDE M., DENTENER F. (2017): Impact of meteorological drivers on regional inter-annual crop yield variability in France. *Agricultural and Forest Meteorology,* 216 58–67. p. doi.org/10.1016/j.agrformet.2015.10.004

CENTERI CS., BELÉNYESI M., HALÁSZ T., KRISTÓF D., MAGYARI J., NEIDERT D., PATAKI R., PODMANICZKY L., SCHNELLER K. (2006): Magyarország ökotípusos földhasználati vizsgálata: Agráralkalmassági-környezetérzékenységi elemzés Magyarország területére. Környezet- és Tájgazdálkodási Tervező Iroda, Gödöllő, 34 p.

CHLOUPEK O., HRSTKOVAA P., SCHWEIGERT P. (2004): Yield and its stability, crop diversity, adaptability and response to climate change, weather and fertilisation over 75 years in the Czech Republic in comparison to some European countries. *Field Crops Researc,* 85 167–190. p. doi:10.1016/S0378-4290(03)00162-X

CLAIRE S., VAN DER HOEK D. C. J., VONK M. (2010): Spatial planning of a climate adaptation zone for wetland ecosystems. *Landscape Ecology,* 25 1465–1477. p. DOI 10.1007/s10980-010-9535-5

CLARE S., KROGMAN N., FOOTE L., LEMPHERS N. (2011): Where is the avoidance in the implementation of wetland law and policy? *Wetlands Ecology and Management,* 19 165–182. p.

DAVISON A. C., HINKLEY D. V. (1997): Bootstrap Methods and Their Applications. Cambridge University Press.

DE GROOT R. S., WILSON M. A., BOUMANS R. M. J. (2002): A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41, 393–408. p.

DE GROOT R. S., ALKEMADE R., BRAAT L., HEIN L., WILLEMEN L. (2010): Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity,* 7 260–272. p.

DEMÉNY A. KERN Z., CZUPPON GY., NÉMETH A., SCHÖLL-BARNA G., SIKLÓSY Z., LEÉL-OSSY SZ., COOK G., SERLEGI G., BAJNÓCZI B., SÜMEGI P., KIRÁLY Á., KISS V., KULCSÁR G., BONDÁR M. (2017): Middle Bronze Age humidity and temperature variations, and societal changes in East-Central Europe. *Quaternary International* (in press) DOI10.1016/j.quaint.2017.11.023

DOORENBOS J., KASSAM A. H., BENTVELSEN C. L. M. (1986): Yield response to water. FAO, Róma, 193 p.

EEA (European Environment Agency). [2017]: Green infrastructure and flood management: Promoting cost-efficient flood risk reduction via green infrastructure solutions. Luxemburg, 156. p.

FÁBIÁN Á. P., MATYASOVSZKY I. (2010): Analysis of climate change in Hungary according to an extended Köppen classification system, 1971–2060. *Időjárás,* 114 251–261. p.

FOX J. (2005): The R Commander: A Basic-Statistics Graphical User Interface to R. *The Journal of Statistical Software,* 14 1–42. p. DOI:10.18637/jss.v014.i09

Földművelésügyi Minisztérium [2012]: Nemzeti Aszálystratégia. Budapest.

GÁBRIS GY., HORVÁTH E., NOVOTHNY A., RUSZKICZAY-RUDIGER ZS. (2012): Fluvial and Aeolian landscape evolution in Hungary e results of the last 20 years research. *Netherlands Journal of Geosciences,* 91 111e128. Doi: 10.1017/S0016774600001530.

GYULAI F. (2010): Archaeobotany in Hungary: Seed, Fruit and Beverage Remains in the Carpathian Basin from the Neolithic to the Late Middle Ages. Archaeolingua, Budapest, 478 p.

HARCSA I., KOVÁCH I., SZELÉNYI I. (1998): The Hungarian agriculture 'miracle' and the limits of socialist reforms. 21–42. p. In: SZELÉNYI I. (Szerk.): *Privatizing the Land: Rural Political Economy in Post-Communist Societies.* Routledge, London, New York.

HARDIN G. (1968): The Tragedy of the Commons. *Science*, 162 1243–1248. p. DOI: 10.1126/science.162.3859.1243

IFTEKHAR M. S., POLYAKOV M., ANSELL D., GIBSON F., KAY G. H. (2016): How economics can further the success of ecological restoration. *Conservation Biology*, 31 261–268. p.

IPCC (2014): Annex II: glossary. 117–130. p. In: MACH K. J., PLANTON S., VON STECHOW C. (Szerk.): *Climate change 2014: synthesis report.* IPCC, Geneva.

ILONCZAI ZS. (2014): Klaszter-analízis és alkalmazásai. MSc dissertation. Eötvös Lóránd Tudományegyetem, Budapest, 76 p.

IVÁNYI A. (2005): Informatikai algoritmusok 2. ELTE Eötvös Kiadó, Budapest. p. 767.

JONES, P. D. (2015): CRU TS3.23: Climatic Research Unit (CRU) Time-Series (TS) Version 3.23 of High Resolution Gridded Data of Month-by-month Variation in Climate (Jan. 1901- Dec. 2014): Leeds, UK: Centre for Environmental Data Analysis. doi:10.5285/4c7fdfa6-f176-4c58-acee-683d5e9d2ed5. Lekérdezés időpontja: 2016.11.12.

KERN Z., NÉMETH A., HOROSZNÉ GULYÁS M., POPA I., LEVANIČ T., HATVANI I. G. (2016): Natural proxy records of temperature- and hydroclimate variability with annual resolution from the Northern Balkan–Carpathian region for the past millennium – Review, recalibration. *Quaternary International,* 415 109–125. p. DOI10.1016/j.quaint.2016.01.012

KOHLHEB N., PODMANICZKY L., SKUTAI J. (2009): Magyarország felszínborítottságának lehetőségei az éghajlatvédelemben. Ökológiai Intézet a Fenntartható Fejlődésért Alapítvány, Miskolc. 75 p.

KOLTAI G. (2003): A talajvíz és talajnedvesség, valamint a tápanyagellátás hatása a növénytermesztési hozamokra a Szigetközben. Ph.D dissertation. Veszprémi Egyetem, Mosonmagyaróvár, 208 p.

KROMP-POLB H., NAKICENOVIC N., STEININGER K., GOBIET A., KÖPPL A., PRETTENTHALER F., STÖTTER J., SCHNEIDER J., FORMAYER H. (Szerk.): (2014): Austrian Assessment Report Climate Change 2014 (AAR14) Summary for Policymakers and Synthesis: Austrian Panel on Climate Change (APCC) Austrian Assessment Report 2014 (AAR14). Austrian Academy of Sciences Press, Bécs, 1096 p.

KRONMAL R. A. (1993): Spurious Correlation and the Fallacy of the Ratio Standard Revisited. *Journal of the Royal Statistical Society. Series A (Statistics in Society,)* 156 379–392. p. DOI: 10.2307/2983064

LÁNG I., CSETE L., JOLÁNKAI M. (2006): A globális változás: hazai hatások és válaszok – VAHAVA zárójelentés. Környezetvédelmi és Vízügyi Minisztérium, Magyar Tudományos Akadémia, Budapest.

LIU B. SENTHOLD ASSENG, CHRISTOPH MÜLLER, FRANK EWERT, JOSHUA ELLIOTT, DAVID B. LOBELL, PIERRE MARTRE, ALEX C. RUANE, DANIEL WALLACH, JAMES W. JONES, CYNTHIA ROSENZWEIG, PRAMOD K. AGGARWAL, PHILLIP D. ALDERMAN, JAKARAT ANOTHAI, BRUNO BASSO, CHRISTIAN BIERNATH, DAVIDE CAMMARANO, ANDY CHALLINOR, DELPHINE DERYNG, GIACOMO DE SANCTIS, JORDI DOLTRA, ELIAS FERERES, CHRISTIAN FOLBERTH, MARGARITA GARCIA-VILA, SEBASTIAN GAYLER, GERRIT HOOGENBOOM, LESLIE. A. HUNT, IZAURRALDE R. C., JABLOUN M., JONESBB C. D., KERSEBAUM K. C., KIMBALL B. A., KOEHLERS A-K., KUMAR S. N., NENDEL C., O'LEARY G., OLESEN J. E., OTTMAN M. J., PALOSUO T., VARA PRASAD P.V., PRIESACK E., PUGHLL T. A. M., REYNOLDS M., REZAEID E. E., RÖTTER R. P., SCHMID E., SEMENOV M. A., SHCHERBAK I., STEHFEST E., CLAUDIO O. STÖCKLE C. O., STRATONOVITCH P., STRECK T., SUPIT I., TAORR F., THORBURN P., WAHA K., WALL G. W., WANG E., WHITE J. W., WOLF J., ZHAO Z., ZHU Y. (2016): Similar estimates of temperature impacts on global wheat yield by three independent methods. *Nature Climate Change,* 6 1130–1136. p. doi:10.1038/nclimate3115

LOBELL D., FIELD C. (2007): Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters,* 2 014002. doi:10.1088/1748-9326/2/1/014002

LÓCZY D., DEZSŐ J., RONCZYK L. (2016): Floodplain rehabilitation projects in Hungary: Case studies from the Danube, Tisza, Körös and Drava rivers. *Bulletin of the Serbian Geographical Society,* 96 1–10. p.

LUO Q. (2011): Temperature thresholds and crop production: a review. *Climatic Change,* 109 583–598. p. DOI 10.1007/s10584-011-0028-6

MARTÍN-RETORTILLO M., PINILLA V. (2015): On the causes of economic growth in Europe: Why did agricultural labour productivity not converge between 1950 and 2005? *Cliometrica,* 9 359–396. p. DOI 10.1007/s1 1698-014-0119-5

MENYHÉRT Z. (1985): A kukorica termesztés kézikönyve. Mezőgazdasági Kiadó, Budapest, 560 p.

MGSZH KÖZPONT ERDÉSZETI IGAZGATÓSÁG REGIONÁLIS ÉS ZÖLDÖVEZETI TERVEZŐ OSZTÁLY. (2009): Országos erdőtelepítési terv felülvizsgálata. Balatonfüred.

MOLNÁR ZS., BIRÓ M., BARTHA S., FEKETE G. (2012): Past Trends, Present State and Future Prospects of Hungarian Forest-Steppes. 209–252. p. In: WERGER M. J. A., VAN STAALDUINEN M. A. (Szerk.): *Eurasian Steppes. Ecological Problems and Livelihoods in a Changing World.* Springer, Dordrecht, New York.

Nemzeti Fejlesztési Minisztérium Nemzeti Alkalmazkodási Központ Főosztály [2013]: Nemzeti Éghajlatváltozási Stratégia 2014–2025. Budapest.

NEWMAN J. (2016, March 29): USDA Expected to Project Growing Crop Stockpiles. *Wall Street Journal.*

NICHOLLS N. (1997): Increased Australian wheat yield due to recent climate trends. *Nature,* 387 484–485. p. DOI: 10.1038/387484a0

OERKE E. C., DEHNE H. W. (2004): Safeguarding production—losses in major crops and the role of crop protection. *Crop Protection,* 23 275–285. p. doi:10.1016/j.cropro.2003.10.001

OLESEN J. E., BINDI M. (2002): Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy,* 16 239–262. p.

PÁLFAI I. (2004): Belvizek és Aszályok Magyarországon – Hidrológiai tanulmányok. VITUKI, Budapest.

PÁLFAI I. (2006): Belvízgyakoriság és belvízkárok Magyarországon. *Hidrológiai Közlöny,* 86 25–26. p.

PÁLFAI, I. (2009): Aszályos évek a Kárpát-medencében a 18-20. században. *„Klíma-21" Füzetek: Klímaváltozás – Hatások – Válaszok,* 57 107–112. p.

PÁLFAI I. (2011): Aszályos évek az Alföldön 1931–2010 között. 87–96. p. In: RAKONCZAI J. (Szerk.): *Környezeti változások és az Alföld.* Nagyalföld Alapítvány, Békéscsaba.

PÁLYI Z. (2004): Szatmár éghajlati adottságai a terület erdősítése szempontjából. *Erdő és Klíma,* 4 921–928. p.

PEEL M. C., FINLAYSON B. L., MCMAHON T. A. (2007): Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences*, 11 1633–1644. p.

PENDLETON, L. H. THÉBAUD O., MONGRUEL R. C., LEVREL H. (2016): Has the value of global marine and coastal ecosystem services changed? *Marine Policy*, 64 156–158. p.

PEPÓ P., SÁRVÁRI M. (2011): Gabonanövények termesztése. Debreceni Egyetem, Debrecen, 143 p.

PETERSON T. C. KARL T. R., JAMASON P. F., KNIGHT R., EASTERLING DAVID R. (1998): First difference method: Maximizing station density for the calculation of long-term global temperature change. *Journal of Geophysical Research,* 103 25967–25974. p.

PIECZKA I., PONGRÁCZ R., BARTHOLY J. (2011): Expected trends of regional climate change for the Carpathian Basin for the 21st century. *International Journal of Environment and Pollution,* 46 6–17. p.

PINKE ZS. (2012): Aszály-, belvízkárok és az árvízvédelmi ökoszisztéma-szolgáltatás értékelésének szerepe a belvizes területek vizes élőhellyé alakításában. *Tájökológiai Lapok,* 10 271–286. p.

PINKE ZS., KISS M., LÖVEI L. G. (2018): Developing an integrated land use planning system on reclaimed wetlands of the Hungarian Plain using economic valuation of ecosystem. *Ecosystem Services,* (in print). doi: 10.1016/j.ecoser.2017.09.007

PINKE ZS., LÖVEI L. G. (2017): Increasing temperature cuts back crop yields in Hungary over the last 90 years. *Global Change Biology,* 12 5426–5435. p. DOI: 10.1111/gcb.13808

PINKE ZS., SZABÓ B. (2012): Fásszárú növényzettel borított területekváltozásai a Hortobágy–Sárréten az elmúlt ezer évben. *Helynévtörténeti Tanulmányok,* 8 141–150. p.

RAMANKUTTY N., FOLEY J. A. (1999): Estimating historical changes in global land cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles,* 13 997–1027. p. DOI: 10.1029/1999GB900046

RAY K. D., GERBER J. S., MACDONALD G. K., WEST P. C. (2015): Climate variation explains a third of global crop yield variability. *Nature Communications,* 6 5989. DOI: 10.1038/ncomms6989

RAY K. D., RAMANKUTTY N., MUELLER N. D., WEST P. C., FOLEY J. A. (2012): Recent patterns of crop yield growth and stagnation. *Nature Communications,* 3 1293. doi:10.1038/ncomms2296

REICZIGEL, J., HARNOS, A., SOLYMOSI, N. (2014) Biostatistika nem statitsztikusoknak. Pars, Nagykovácsi, 463 p.

RÉTHLY A. (1933): Kisérlet Magyarország klímatérképének szerkesztésére a Köppen-féle klímabeosztás értelmében. *Időjárás,* 9 105–115. p.

RUDGERS J. A., CHUNG, MAURER G. E., MOORE D. I., MULDAVIN E. H., LITVAK M. E., COLLINS S. L. (2018): Climate sensitivity functions and net primary production: A framework for incorporating climate mean and variability. *Ecology*, (in print). DOI: 10.1002/ecy.2136

RUSSELL R. J. (1931): Dry climates of the United States: I climatic map. *Johnson Reprint Corp*, 5 1–41. p.

SARRIS A. H., DOUCHA T., MATHIJS E. (1999): Agricultural restructuring in central and eastern Europe: implications for competitiveness and rural development. *European Review of Agricultural Economics*, 26 305–329. p. doi: 10.1093/erae/26.3.305

SCHAUBROECK T., DECKMYN G., GIOT O., CAMPIOLI M., VANPOUCKE C., VERHEYEN K., RUGANI B., ACHTEN W., VERBEECK H., DEWULF J., MUYS B. (2016): Environmental impact assessment and monetary ecosystem service valuation of an ecosystem under different future environmental change and management scenarios; a case study of a Scots pine forest. *Journal of Environmental Management*, 173 79–94. p. doi.org/10.1016/j.jenvman.2016.03.005

SEWELL W. R., KATES R., PHILLIP L. E. (1968): Human response to weather and climate: geographical contribution. *Geographical Review*, 58 262–280. p. DOI: 10.2307/212438

SOMLYÓDY L. 2011. Quo vadis hazai vízgazdálkodás? Stratégiai összegzés. 9−84. p. In: SOMLYÓDY L. (Szerk.): *Magyarország vízgazdálkodása: helyzetkép és stratégiai feladatok. MTA Köztestületi stratégiai feladatok.* MTA, Budapest.

SPILIOPOULOS O. (2017): The EU-Ukraine Association Agreement As A Framework Of Integration Between The Two Parties. *Procedia Economics and Finance*, 9 256–263. p. doi: 10.1016/S2212-5671(14)00027-6

SUGGITT A. J., PLATTS I. J., BARATA I. M., BENNIE J. J., BURGESS M. D., BYSTRIAKOVA N., DUFFIELD S., EWING S. R., GILLINGHAM P. K., HARPER A. B., HARTLEY A. J., HEMMING D. L., MACLEAN I. M. D., MALTBY K., MARSHALL H.ARRY H., MORECROFT M. D.,

PEARCE-HIGGINS J. W., PEARCE-KELLY P., PHILLIMORE A. B., PRICE J. T., PYKE A., STEWART J. E., WARREN R., HILL J. K. (2017): Conducting robust ecological analyses with climate data. *Oikos,* 126 1533–1541. p. doi: 10.1111/oik.04203

SUTTON W. R., SRIVASTAVA J. P., NEUMANN J. E., STRZEZPEK, K. M., BOEHLERT B. B (2013): Reducing the Vulnerability of the Former Yugoslav Republic of Macedonia's Agricultural Systems to Climate Change. Impact Assessment and Adaptation Options. The World Bank, Washington, DC.

SUZUKI R., SHIMODAIRA H. (2006): Pvclust: an R package for assessing the uncertainty in hierarchical clustering. *Bioinformatics,* 22 1540–1542. p. DOI: 10.1093/bioinformatics/btl117

SWEENEY B. W. BOTT T. L., JACKSON J. K., KAPLAN L. A., NEWBOLD J. D., STANDLEY L. J., HESSION W. C., HORWITZ R. J. (2004): Riparian deforestation, stream narrowing, and loss of stream ecosystem services. *PNAS*, 101 14132–14137. p. doi: 10.1073/pnas.0405895101

SZALAI S., KONKOLYNÉ BIHARI Z., LAKATOS M., SZENTIMREY T. (2005): Magyarország éghajlatának néhány jellemzője 1901-től napjainkig. Országos Meteorológiai Szolgálat, Budapest.

SZELEPCSÉNYI Z. BREUER H., ÁCS F., KOZMA I. (2009): Biofizikai klímaklasszifikációk (2. rész: magyarországi alkalmazások). *Légkör,* 54 18–22. p.

SZILÁGYI F. (2005): Mérnökökológia. Egyetemi jegyzet. Műszaki és Gazdaságtudományi Egyetem Építőmérnöki Kar Vízi Közmű és Környezetmérnöki Tanszék, Budapest.

TRNKA M., OLESEN J. E., KERSEBAUM K. C., SKJELVÅG A. O., EITZINGER J., SEGUIN B., PELTONEN-SAINIO P., RÖTTER R., IGLESIAS A., ORLANDINI S., DUBROVSKÝ M., HLAVINKA P., BALEK J., ECKERSTEN H., CLOPPET E., CALANCA P., GOBIN A.,

VUČETIĆ V., NEJEDLIK P., KUMAR S., LALIC B., MESTRE A., F. ROSSI, KOZYRA J., ALEXANDROV V., SEMERÁDOVÁ D., ŽALUD Z. (2011): Agroclimatic conditions in Europe under climate change. *Global Change Biology,* 17 2298–2318. p. doi: 10.1111/j.1365-2486.2011.02396.x

TRNKA M., OLESEN J. E., KERSEBAUM K. C., RÖTTER R. P., BRÁZDIL R., EITZINGER J., JANSEN S., SKJELVÅG A. O., PELTONEN-SAINIO P., HLAVINKA P., BALEK J., ECKERSTEN H., GOBIN A., VUČETIĆ V., DALLA MARTA A., ORLANDINI S., ALEXANDROV V., SEMERÁDOVÁ D., ŠTEĚPÁNEK P., SVOBODOVÁ E., RAJDL K. (2017): Changing regional weather−crop yield relationships across Europe between 1901 and 2012. *Climate Research,* 70 195–214. p. doi: 10.3354/cr01426

TROUET V., VAN OLDENBORGH G. J. (2013): KNMI Climate Explorer: a web-based research tool for high-resolution paleoclimatology. *Tree Ring Research,* 69 3–13. p. doi: 10.3959/1536-1098-69.1.3

Vidékfejlesztési Minisztérium [2012]: Nemzeti Vidékstratégia 2012–2020. Budapest.

Vidékfejlesztési Minisztérium [2013]: Nemzeti Vízügyi Stratégia. Budapest.

VINOGRADOV S. (2009): Szántóföldek komplex közgazdasági értékelése Magyarországon. Ph.D dissertation. Szent István Egyetem, Gödöllő, 151 p.

Vízügyi és Környezetvédelmi Központi Igazgatóság [2010]: Magyarország Vízgyűjtő-gazdálkodási Terve. Budapest.