OTKA PD-115637
2015.12.01 – 2018.11.30

Project title: **Climate change effects on ecosystem carbon efflux: combining field experiments and biogeophysical modelling**
Project type and project number: OTKA PD 115637
Supervisor: Lelleiné Kovács Eszter

Final report on the results of the research

The four research modules of the accomplished research work:

1. field measurements (instrumental measurements of soil respiration and ecosystem CO_2 exchange, investigation of micrometeorological variables) at the two climate change experimental sites in the Kiskunság;
2. empirical modelling of the responses of soil respiration and ecosystem gas exchange to the environmetal variables based on the measurements and elaboration of the data;
3. investigation of the impacts of the experimental treatments;
4. modelling of the carbon cycle using the Biome-BGCMuSo biogeophysical ecosystem model.

1. Field measurements (instrumental measurements of soil respiration and ecosystem CO_2 exchange, investigation of micrometeorological variables) at the two climate change experimental sites in the Kiskunság

The multi-year data series collected during the field works is suitable for the analyses, first, of the extreme and moderate drought effects and the effect of surplus water at the ExDRain climate-change experimental site, and second, the effect of the long-term summer drought at the INCREASE climate-change experimental site, on the soil carbon cycling. This data series makes furthermore possible the estimation of the responses of the two ecosystem types in the Kiskunság (ExDRain – open sand grassland, and INCREASE – sand grassland with polar sprouts) to the predicted climate change, and also makes possible the intercomparison of the changes in the carbon cycles of the two ecosystems responding to the climate manipulations.

2016

<u>INCREASE experimental site with 3 controls and 3 summer-drought affected parcels out of the nine</u>
From April to October of 2016 there were 5 measurement periods for measuring the net ecosystem exchange (NEE) and dark respiration (ER) (ADC Leaf Chamber Analyzer 4, ADC BioScientific, Hoddesdon, U.K. equipped with self-built ecosystem exchange chambers in closed system), at two

fixed measurement spots per plot, one between grasses and one under poplar sprouts. Parallel measurements of soil surface and chamber temperatures were occurred, with the sensors (PT100) built in the chambers, while the photosynthetically active radiation was measured with built-in PAR sensors (Quantum sensor, Apogee Instruments).

In March, June, and at the end of August, soil samples were taken by plots to determine the soil organic carbon content, soil pH, $CaCO_3$-, AL-K_2O, AL-P_2O_5, all-N, NH_4-N and NO_3-N content in the laboratory of the MTA ATK Institute for Soil Science and Agricultural Chemistry.

In March of 2016 the dry matter content of the roots in the soil samples was also measured, in the laboratory of the MTA ÖK Institute for Ecology and Botany, Vácrátót.

Between December of 2015 and November of 2016 there were a sum of 13 occasions of soil respiration measurements (ADC Leaf Chamber Analyzer 4 and PLC & 2250 Soil hood, ADC BioScientific, Hoddesdon, U.K.), at three fixed measurement spots per plot, together with the measurements of the soil temperature with the built-in temperature sensor of the soil chamber.

From May of 2016 I started the soil moisture measurements with the new IMKO TDR probe (Trime-FM, IMKO Mikromodultechnik, Ettlingen, Germany), directly on the soil respiration spots.

ExDrain experimental site with 48 parcels

From April to June of 2016 there were 3 measurement periods for measuring the net ecosystem exchange (NEE) and dark respiration (ER) (ADC Leaf Chamber Analyzer 4, ADC BioScientific, Hoddesdon, U.K. with a self-built ecosystem exchange chamber in closed system), at one fixed measurement spot per plot. Parallel measurements of soil surface and chamber temperatures were occurred, with the sensors (PT100) built in the chambers, while the photosynthetically active radiation was measured with built-in PAR sensors (Quantum sensor, Apogee Instruments).

In March, and June directly before, and at the end of August, directly after the drought and irrigation treatments, soil samples were taken by plots to determine the soil organic carbon content, soil pH, $CaCO_3$-, AL-K_2O, AL-P_2O_5, all-N, NH_4-N and NO_3-N content in the laboratory of the MTA ATK Institute for Soil Science and Agricultural Chemistry.

Between December of 2015 and November of 2016 there were a sum of 13 occasions of soil respiration measurements (ADC Leaf Chamber Analyzer 4 and PLC & 2250 Soil hood, ADC BioScientific, Hoddesdon, U.K.), at one fixed measurement spot per plot, together with the measurements of the soil temperature with the built-in temperature sensor of the soil chamber.

From May of 2016 I started the soil moisture measurements with the new IMKO TDR probe (Trime-FM, IMKO Mikromodultechnik, Ettlingen, Germany), directly on the soil respiration spots.

2017

In 2017, the field measurements could be only partly continued, as the ADC LCA-4 infrared gas analysator got out of order, and was sent back to the fabricant. However, the reparation was finished hardly, after many complaint and reconsignments. Parallelly, from the same factory, in the frame of another project, we bought a very new soil respiration instrument (ADC SRS-SD1000), which was set up in the late summer of 2017, with test measurements. After overcoming the technical difficulties and many claims, in October and November I conducted a calibration of the two SRS instruments in three measurement series. The detailed documentation of the calibration helps to make possible using the long-term (14 years) soil respiration data together with the new data measured with the new instrument.

For the reasons above, all the planned soil respiration and ecosystem respiration measurements together with the soil samplings all falled away in 2017. This loss, however, do not influence the publication possibilities, but that way, for the planned paper on the impacts of the climate change experiments (precipitation manipulations) on soil respiration I am using only data collected between 2013 and 2016, see the first planned paper under „**Publication**": *Resiliency of soil respiration against extreme and moderate drought in an open sand grassland).* The further measurement data are going to be used in the development of the empirical and ecosystem models, see the 4. planned paper: *Modelling soil respiration in a semiarid ecosystem: calibration and validation of the Biome-BGCMuSo model using data of a climate change experiment*.

<u>INCREASE experimental site with 3 controls and 3 summer-drought affected parcels out of the nine</u>

In October of 2017 I went on with the calibration measurements on soil respiration, parallel with the two infrared gas analysators (ADC Leaf Chamber Analyzer 4 with PLC & 2250 Soil hood; and ADC SRS-SD1000 with LCi Soil respiration hood V2; ADC BioScientific, Hoddesdon, U.K.), at three fixed measurement spots per plot, together with the measurements of the soil temperature with the built-in temperature sensors of the soil chambers.

In August and October of 2017, parallel to the soil respiration measurements, I conducted the soil moisture measurements with the new IMKO TDR probe (Trime-FM, IMKO Mikromodultechnik, Ettlingen, Germany), directly on the soil respiration spots.

<u>ExDrain experimental site with 48 parcels</u>

In October and November of 2017 I went on with the calibration measurements on soil respiration, parallel with the two infrared gas analysators (ADC Leaf Chamber Analyzer 4 with PLC & 2250 Soil hood; and ADC SRS-SD1000 with LCi Soil respiration hood V2; ADC BioScientific, Hoddesdon,

U.K.), at one fixed measurement spot per plot, together with the measurements of the soil temperature with the built-in temperature sensors of the soil chambers. (ADC Leaf Chamber Analyzer 4 with PLC & 2250 Soil hood; valamint ADC SRS-SD1000 with LCi Soil respiration hood V2; ADC BioScientific, Hoddesdon, U.K.), at 3-6 fix measurement spots per treatments, together with the measurements of the soil temperature with the built-in temperature sensors of the soil chambers.
Between August and November of 2017, parallel to the soil respiration measurements, I conducted the soil moisture measurements with the new IMKO TDR probe (Trime-FM, IMKO Mikromodultechnik, Ettlingen, Germany), directly on the soil respiration spots.
Evaluation of the data and determination of the relationships between measurement series is done.

2018

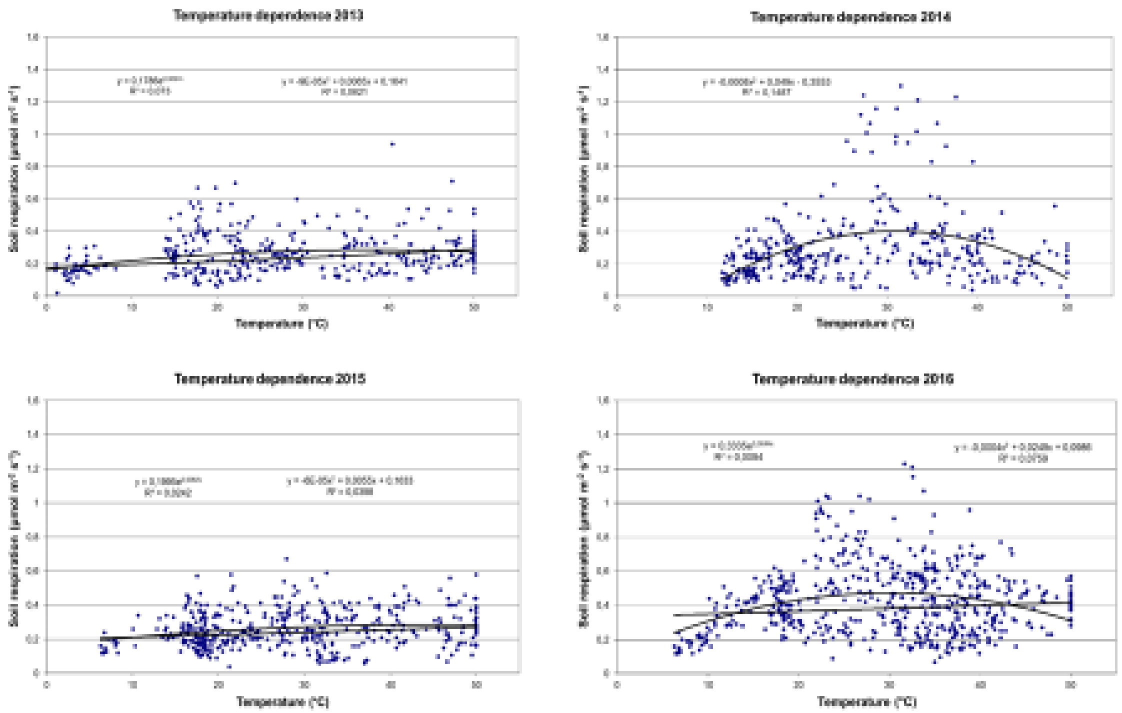
From December of 2017 I continued the soil respiration measurements with the new ADC SRS SD1000 infrared gas analyser, and parallelly, with the repaired ADC LCA-4 infrared gas analyser. In 2018 I measured only on the ExDRain experimental site, as on the INCREASE experimental site some technical problems have arisen, preventing both conducting treatments (damages of the roofs, faltering of the electric supply of the engines, insenescence of the batteries), and continuously gathering micrometeorological data. (Solving these problems points far beyond the financial potential of my OTKA PD project.)
This year the measurements of the ecosystem gas exchange falled away, because of the failure of the NEE chamber. The chamber was repaired.

<u>ExDrain experimental site with 48 parcels</u>
In December of 2017, and also in 2018 between April and November, altogether seven times, I continued the soil respiration measurements, parallel with the two devices (ADC Leaf Chamber Analyzer 4 with PLC & 2250 Soil hood; and ADC SRS-SD1000 with LCi Soil respiration hood V2; ADC BioScientific, Hoddesdon, U.K.), at one fixed measurement spot per plot, together with the measurements of the soil temperature with the built-in temperature sensor of the soil chamber.
Parallel to the soil respiration measurements, I conducted the soil moisture measurements with the new IMKO TDR probe (Trime-FM, IMKO Mikromodultechnik, Ettlingen, Germany), directly on the soil respiration spots.
On 6th of September, directly after the drought and irrigation treatments, soil samples were taken by plots to determine the soil organic carbon content, soil pH, $CaCO_3$-, AL-K_2O, AL-P_2O_5, all-N, NH_4-N and NO_3-N content in the laboratory of the MTA ATK Institute for Soil Science and Agricultural Chemistry. The soil assaying was prepared and finished in December 2018.

2. Empirical modelling of the soil respiration and the ecosystem gas exchange responses to the environmental factors, based on the elaborated measurement data

The elaboration of the collected soil respiration data is finished (see the details of the manuscript under preparation below, at point ***3.***), while the analyses of the ecosystem exchange data and the publication of their results are planned in the middle of 2019, in a methodological paper: *Lellei-Kovács E. et al.: Closed chamber method for measurement of ecosystem carbon exchange in a climate manipulation experiment*.

Preliminary results: We investigated the temperature and moisture dependences of soil respiration in the open sand grassland ecosystem comparing the fit of exponential, Lloyd-Taylor and Gaussian equations combined with additiv or interactive soil moisture effect. We tested the following hypothesis: the Gaussian temperature model including interactive soil moisture impact fits better than the exponential model and without including soil moisture. The model selection was conducted through the intercomparison of the Akaike Information Criteria (AIC) of the models. Further analyses are conducting on yearly separated datasets, to reveal the impacts of the short-term extreme drought, the longer term moderated drought treatments and their combinations on the dependencies of soil respiration in this open sand grassland ecosystem. We are also calculating annual soil respiration based on the relationships between soil respiration and soil temperature and soil moisture.



Temperature dependence of soil respiration 2013-2016, including all plots.

3. Investigation of the impacts of the experimental treatments

Soil respiration data collected on the ExDRain experimental site were elaborated, the evaluation of the results is finished, and now the manuscript is under preparation: based on these investigations an empirical paper will be produced, which is studying the treatment effects and the different aspects of climate change. This is going to be submitted in March of 2019.

Working title of the manuscript:

Extreme drought and following rain or drought effects on soil respiration in a semiarid grassland

Hypotheses to be tested:

a) By quantifying soil respiration, its amount depends both on the treatments and the amount of precipitation of the given year. Supposedly, drought treatments decrease, while irrigation increases both actual and annual soil respiration related to the control. The reducing effect of extreme drought treatment on soil respiration is bound to be tangible also in the next years.

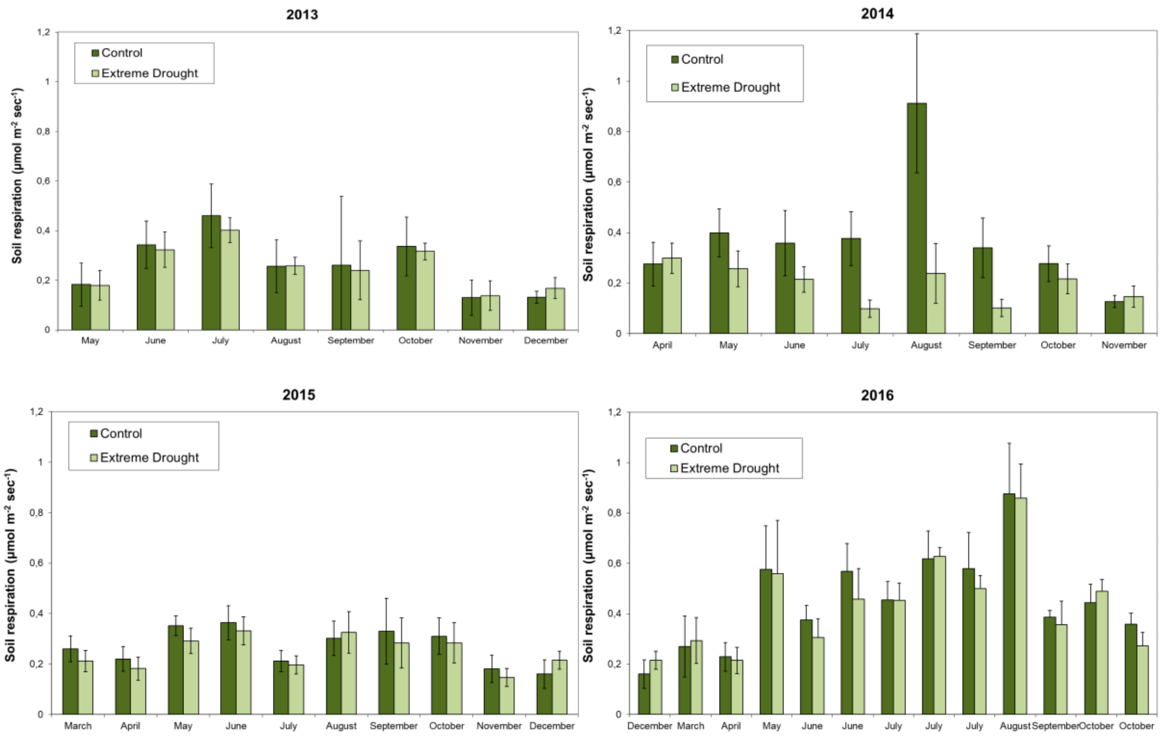
b) The seasonal and annual course of the soil respiration is related to the course of the associated soil temperature and soil moisture.

The analyses would be conducted by Repated Measures ANOVA, where the repeated-measure factor is the measurement date (seasonal changes), and independent variables are the treatments and the plant cover type.

c) Investigating the temperature and moisture dependences of soil respiration, the Gaussian temperature model including interactive soil moisture impact fits better than the exponential model and without including soil moisture.

d) Soil properties as organic matter content and nutrients change with both extreme and moderate but annually repeated drought treatments, such as with annually repeated irrigation.

<u>Preliminary results:</u> Soil respiration of the open sand grassland ecosystem was measured for four years between 2013 and 2016. We found a low volume of soil respiration comparing to other grassland ecosystems, with a pronounced seasonal and annual course. We also found a significant effect of the extreme drought treatment on soil respiration, as well as significant effects of the moderate drought treatments and irrigation on soil respiration. However, these effects proved to be temporary and short term, and seemed to disappear during the next vegetation period.



Monthly course of soil respiration 2013-2016, in the control and the extreme drought affected plots.

4. Modelling of the carbon cycle using the Biome-BGCMuSo biogeophysical ecosystem model

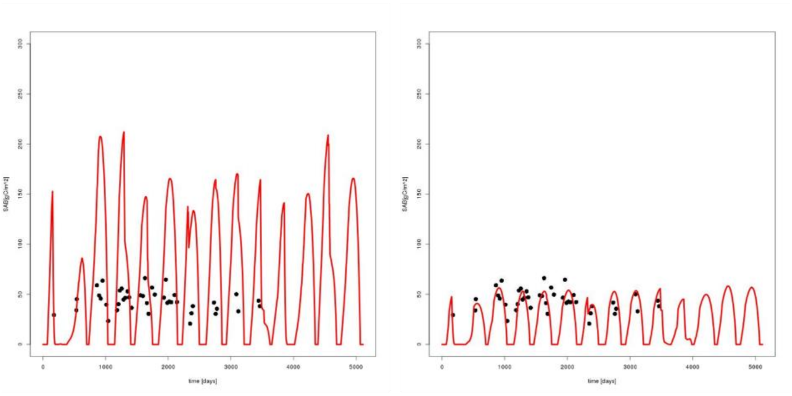
Modelling works were started in 2017, and during this time the modell development works, iterative amendments were going on resulted in more new versions of the model. Present time we have for using two parallel, also structurally different version. With the 4.1 version of the Biome-BGCMuSo model I modelled the carbon cycling, mostly the aboveground biomass of five grassland ecosystems of different water status in the Kiskunság, which work was (oral) presented in 2017 in two international conferences. Now I am going to publish the results in a scientific paper, submitting a manuscript in the middle of 2019.

Working title of the manuscript: *Prediction of primary production along an environmental gradient for different climate and management scenarios.*

<u>Preliminary results:</u> Biogeochemical cycles of grassland ecosystems are highly sensitive to changes in water availability caused by land use and climate change. Simulation of the biogeochemical cycles of managed grasslands may help in identifying and quantifying the main processes, contributing to changes in their productivity. In our work we used the 4.1 version of Biome-BGCMuSo model, the modified version of the widely used biogeochemical Biome-BGC model, with structural improvements to simulate herbaceouos ecosystem carbon and water cycles more faithfully. Our

sampling areas were in five different grassland types in the Kiskunság, Hungary, as open and closed sand grasslands, mesic meadow, wet meadow and marshland. Different soil texture and changing water table level, consequently highly different water conditions are characteristic in these ecosystems, influencing the developement and productivity of vegetation, and also the potential for animal husbandry. Hence, for the meadows and the marshland ecosystems we included mowing management in the simulations. For the comparison of the ecosystems and studying the performances of the model under different conditions and parameterizations we simulated and calibrated the model to standing aboveground biomass measured 1 to 9 times per year per ecosystem. We compared the results by years and by ecosystems. We found that ecosystems of higher water availability were more sensitive to changes in water conditions, and their productivity was more variable between years.

Open sand grassland



Standing aboveground biomass (gC m^{-2})

An example for uncalibrated and calibrated model run of the BiomeBGCMuSo model using aboveground biomass measurement data as plotted by full black circles on the figure.

Based on the experiences of this modelling work, and using the micrometeorological, soil respiration and NEE data originated from the climate change experiments I plan to prepare the next publication on the modelling of the soil respiration in open sand grasslands and white poplar shrublands. To this work I am going to use the 5.x version of the Biome-BGCMuSo model.

Working title of the manuscript:

Modelling soil respiration in a semiarid ecosystem: calibration and validation of the Biome-BGCMuSo model using data of a climate change experiment

Following, now a long-term plan is the modelling of the total carbon cycle of the open sand grasslands and white poplar shrublands (see in the *Working plan* the publication planned in the 3. year: *Lellei-Kovács E. et al.: Ecosystem carbon exchange and its components in climate manipulation experiments of semiarid ecosystems*), to that I am applying the ecosystem respiration and dark respiration data measured in the previous years. Hence, it is getting possible the intercomparison of the total carbon cycle of the two ecosystems.

Publication

A. Published papers
Papers in the research area, which contain direct reference to the project OTKA PD-115637 ; 4 international peer reviewed papers, whereout 1 is first author (see publication list below).

B. Planned publications
Further four scientific papers are under preparation, in which I am the first author, and planned to be published in 2019, based on the field and modelling work done in the frame of the present project. I plan to submit them in March 2019 and in the second half of the year:

1. paper - title: Resiliency of soil respiration against extreme and moderate drought in an open sand grassland.
authors: Lellei-Kovács Eszter, Kröel-Dulay György, Ónodi Gábor
aimed journal: Global Change Biology
readiness: field work and data processing and statistical analyses are done, description of methodology is ready, paper is under preparation
planned date of submission: March of 2019

2. paper - title: Closed chamber method for measurement of ecosystem carbon exchange in a climate manipulation experiment
authors: Lellei-Kovács Eszter et al.
readiness: field work and data processing are done, statistical analyses and writing paper are under preparation
planned date of submission: June of 2019

3. paper - title: Prediction of primary production along an environmental gradient for different climate and management scenarios.
authors: Lellei-Kovács Eszter, Barcza Zoltán, Hidy Dóra, Hollós Roland, Ónodi Gábor és Kertész Miklós
aimed journal: Community Ecology
readiness: Data processing, modelling work is needed
planned date of submission: second half of 2019

4. paper - title: Modelling soil respiration in a semiarid ecosystem: calibration and validation of the Biome-BGCMuSo model using data of a climate change experiment.
authors: Lellei-Kovács Eszter…
aimed journal: Global Change Biology
readiness: Data processing, modelling work is needed
planned date of submission: end of 2019

Publications published during the project (MTMT id.: 10016383)
(after papers referring the project by its identification number, please, the OTKA i.d.):

PUBLICATIONS

Isabel Nogues, Mauro Medori, Alessio Fortunati, Eszter Lellei-Kovács, György Kröel-Dulay, Carlo Calfapietra (2018): Leaf gas exchange and isoprene emission in poplar in response to long-term experimental night-time warming and summer drought in a forest-steppe ecosystem. Environmental and Experimental Botany 152, 60–67. ***SCI 4.369***

OTKA PD115637

Gábor Ónodi, Zoltán Botta-Dukát, György Kröel-Dulay, Eszter Lellei-Kovács, Miklós Kertész (2018): Reduction in primary production followed by rapid recovery of plant biomass in response to repeated mid-season droughts in a semiarid shrubland. Plant Ecology 219(5), 517–526 ***SCI 1.615***

Jan Dick, Francis Turkelboom, Helen Woods, Irene Iniesta-Arandia, Eeva Primmer, Sanna-Riikka Saarela, Peter Bezák, Peter Mederly, Michael Leone, Wim Verheyden, Eszter Kelemen, Jennifer Hauck, Chris Andrews, Paula Antunes, Réka Aszalós, Francesc Baró, David N. Barton, Pam Berry, Rob Bugter, Laurence Carvalho, Bálint Czúcz, Rob Dunford, Gemma Garcia Blanco, Nicoleta Geamănă, Relu Giucă, Bruna Grizzetti, Zita Izakovičová, Miklós Kertész, Leena Kopperoinen, Johannes Langemeyer, David Montenegro Lapola, Camino Liquete, Sandra Luque, Guillermo Martínez Pastur, Berta Martin-Lopez, Raktima Mukhopadhyay, Jari Niemela, David Odee, Pablo Luis Peri, Patricia Pinho, Gleiciani Bürger Patrício-Roberto, Elena Preda, Joerg Priess, Christine Röckmann, Rui Santos, Diana Silaghi, Ron Smith, Angheluţă Vădineanu, Jan Tjalling van der Wal, Ildikó Arany, Ovidiu Badea, Györgyi Bela, Emil Boros, Magdalena Bucur, Stefan Blumentrath, Marta Calvache, Esther Carmen, Pedro Clemente, João Fernandes, Diogo Ferraz, Claudia Fongar, Marina García-Llorente, Erik Gómez-Baggethun, Vegard Gundersen, Oscar Haavardsholm, Ágnes Kalóczkai, Thalma Khalalwe, Gabriella Kiss, Berit Köhler, Orsolya Lazányi, Eszter Lellei-Kovács, Rael Lichungu, Henrik Lindhjem, Charles Magare, Jyri Mustajoki, Charles Ndege, Megan Nowell, Sergi Nuss Girona, John Ochieng, Anders Often, Ignacio Palomo, György Pataki, Rasmus Reinvang, Graciela Rusch, Heli Saarikoski, Alison Smith, Emma Soy Massoni, Erik Stange, Nora Vågnes Traaholt, Ágnes Vári, Peter Verweij, Suvi Vikström, Vesa Yli-Pelkonen, Grazia Zulian (2018): Stakeholders' perspectives on the operationalisation of the ecosystem service concept: Results from 27 case studies. Ecosystem Services 29, 552-565. ***SCI 4.072***

Giovanbattista de Dato, Alessandra Lagomarsino, Eszter Lellei-Kovacs, Dario Liberati, Renée Abou Jaoudé, Rosita Marabottini, Silvia Rita Stazi, Gabriele Guidolotti, Edit Kovacs-Lang, György Kroel-Dulay, Paolo De Angelis (2017): The Response of Soil CO_2 Efflux to Water Limitation Is Not Merely a Climatic Issue: The Role of Substrate Availability. Forests 8, 241. ***SCI 1.951***

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OTKA PD115637

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OTKA PD115637

Marc Estiarte, Sara Vicca, Josep Peñuelas, Michael Bahn, Claus Beier, Bridget A. Emmett, Philip A. Fay, Paul J. Hanson, Roland Hasibeder, Jaime Kigel, György Kröel-Dulay, Klaus Steenberg Larsen, Eszter Lellei-Kovács, Jean-Marc Limousin, Romà Ogaya, Jean-Marc Ourcival, Sabine Reinsch, Osvaldo E. Sala, Inger Kappel Schmidt, Marcelo Sternberg, Katja Tielbörger, Albert Tietema, Ivan A. Janssens: (2016): Few multiyear precipitation–reduction experiments find a shift in the productivity–precipitation relationship. Global Change Biology 22, 2570–2581. ***SCI 8.444***

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Eszter Lellei-Kovács, Zoltán Barcza, Dóra Hidy, Ferenc Horváth, Roland Hollós, Gábor Ónodi, Miklós Kertész (2017): Carbon and water cycle in grassland ecosystems of diverse water availability – Modelling with Biome-BGCMuSo. ComEc2017 September 28–29, 2017, Budapest, Hungary. 1st International Conference of Community Ecology: Book of Abstracts. Budapest: Akadémiai Kiadó, 2017 p. 87.

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Lelleiné Kovács E. (2017): Ökoszisztéma szolgáltatások és természetvédelmi politika – Lehet-e hatni a klímaadaptációra? Ökoszisztéma-szolgáltatások és klímaadaptáció multidiszciplináris megközelítésben; MTA KRTK Workshop, 2017 február 15., Kecskemét.

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