QUO VADITIS AGRICULTURE, FORESTRY AND SOCIETY UNDER GLOBAL CHANGE?

Conference Proceedings

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PREFACE

The 5th annual "Global Change: A Complex Challenge" conference, entitled "Quo vaditis agriculture, forestry and society under global change?", was held in Velké Karlovice, Czech Republic during 2–4 October 2017. The conference was organized by the Global Change Research Institute, Czech Academy of Sciences, with financial support from the Ministry of Education, Youth and Sports of the Czech Republic within the National Sustainability Program I (NPU I), grant number LO1415 and by CzeCOS ProCES project no. CZ .02.1.01/0.0/0.0/16_013/0001609.

The conference programme was structured in three sections: Global Change and Agriculture, Global Change and Forestry, and Human Dimensions of Global Change Impacts. Each section began with invited lectures by leading scientists (Christian Körner, University of Basel, Switzerland; Reinhart Ceulemans, University of Antwerp, Belgium; Mauro Masiero, University of Padova, Italy; Tomáš Václavík, Helmholtz Centre for Environmental Research, Germany; Douglas Godbold, BOKU Wien, Austria; Kai Schwärzel, United Nations University, Germany; and Jan Urban, Masaryk University in Brno, Czech Republic). Accordingly, these sessions reflected new progress in atmospheric, ecosystem, and socio-economic sciences at diverse hierarchical levels (ranging from molecular to regional scales). Thirty-two reports selected from the submitted abstracts covered the full range of conference topics and presented the latest research results in all aspects of global change impacts and adaptation. Early-stage researchers and PhD students presented their best ongoing research at a poster session as well as in the form of 2-minute flash talks (48 in total).

In the section Global Change and Agriculture, lectures focused not only upon impacts of global change on the production and nonproduction functions of agriculture but also included lectures on adaptation measures, and particularly on issues of improving water management and carbon sequestration. The section started with the keynote lecture by Dr. T. Václavík (Helmholtz Centre for Environmental Research, Germany) focusing on possible trade-offs between agricultural expansion, intensification, and biodiversity. The following lectures were directed to such various components of agricultural ecosystems as soil (improved infiltration and retention capacity through conservation tillage, impact of environmental conditions on soil respiration) and plants (interactive effects of environmental factors upon the climate change impacts on agricultural crops) and up to the levels of whole ecosystems or regions (water balance modelling, new methods for evaluation of energy fluxes, using remote sensing methods). The following discussion demonstrated the need to integrate individual research areas in global analyses and modelling, and to do so especially in order to evaluate impacts on all ecosystem services provided by agriculture and to design new adaptation measures.

The section Global Change and Forestry started with a series of three invited lectures (Prof. R. Ceulemans, University of Antwerp, Belgium; Prof. D. Godbold, BOKU Wien, Austria; and K. Schwärzel, United Nations University, Germany). Individual conference talks reported on changes in tree and forest ecosystem responses and development under such changing conditions as temperature rise, nitrogen deposition, elevated atmospheric CO_2 concentration, and acidification. Specific effects of extreme synoptic situations associated with global change, such as an occurrence of tornadoes in Central Europe, were presented. A number of talks presented the application of new methodological approaches applicable for

monitoring changes in the structure of forest stands or for monitoring and quantifying greenhouse gas fluxes. Among other applications, these new findings and approaches can be used in restoration of damaged forest stands. The discussion thereafter revealed a need for comprehensive and long-term studies of ecosystems, as well as a necessity to connect individual experimental techniques with high-quality process modelling at ecosystem level.

The section Human Dimensions of Global Change Impacts presented various aspects of global change. One of the important aspects concerned attitudes of society towards climate change. Attitudes shape the perception and reaction of individuals and society to climate change. Another important aspect involves the economics of climate change and ecosystem services. Contributions were focused on the social implications of global environmental change, the role of payments for ecosystem services, and cost–benefit analysis of adaptation actions. Climate change will influence cities as places where the majority of people live, and several contributions focused on climate change adaptation in cities along with barriers to and opportunities for successful adaptation. Interlinking the forestry and human dimensions sections, there were reports on the role of urban forests (green urban infrastructure) in climate change mitigation. Other important topics included the roles of carbon forestry, environmental pollution, and biodiversity in adapting to and mitigating global change.

These proceedings cover almost all those conference areas mentioned above and reflect expanding use of new techniques and approaches in research on global change impacts and adaptation. Each contribution included in the proceedings was peer reviewed by two independent reviewers to ensure high quality of the published contributions. Therefore, our special thanks go out to all the reviewers. Careful and professional proofreading by Gale A. Kirking and English Editorial Services, Brno, is gratefully acknowledged.

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From cell to landscape: a multiscale framework to study the climate change effects on forest ecosystems

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ABSTRACT

Global warming is considered one of the major human-induced threats to ecosystem resilience. In particular, processes involving the adaptation capacity of forest ecosystems and the role of forest management to improve mitigation strategies still need to be understood more deeply. Hence, a multiscale framework highlighting the linkages between adaptation of forest ecosystems and mitigation strategies in forest management from cell to landscape scale is proposed, enhancing the role of forestry research within those contexts. At cellular level, the investigation includes analyses of cambial activity and cell features, as well as of synchronism between apical and lateral meristems to describe the effects of climate change on species' response (e.g. growth rates). Findings from such research are demonstrated to support stand-scale studies on tree species' growth rate, tree line shifting, geographical distribution at higher elevation, and stress responses of forest in a context of climate change. At landscape scale, the effectiveness of models and tools combining different data (e.g. remotely sensed, inventory, eco-physiological) was tested in order to facilitate a deeper understanding of structural traits and forest ecosystem dynamics. Scale transition (from cell to broader scale) and theoretical shifting (from adaptation to mitigation approach) represent two important peculiarities of our proposed framework.

INTRODUCTION

Climate change poses a fundamental threat to ecosystem adaptation and resilience (IPCC 2014), inducing significant modification of structure, dynamics, and geography of forests. From an anthropogenic point of view, adaptation and mitigation are complementary topics, as they refer to those actions oriented to reducing the impact of disturbances on humans and ecosystems and reducing the contribution of human

activities to changing climate (e.g. lowering GHGs emissions). Forest management may either intensify or moderate the effects of climate change (e.g. Naudts et al. 2016). On the one hand, a complete understanding of both processes and implications involving the adaptation capacity at different spatial and temporal scales is currently lacking (Vincent 2007). On the other hand, there is a need to highlight further how forest management and planning may improve the mitigation strategies, and especially in such fragile and degraded environments as Mediterranean forest landscapes (Fabbio et al. 2003). Therefore, this work proposes a multiscale research framework to disentangle the linkages between adaptation processes and mitigation strategies in forest management. The framework derives from a multiscaled review directed to monitoring climate change effects on forest ecosystems (cell and stand scales) and on analysing the effects of forest management on ecosystem functionality and resilience (broader scale). Hence, the proposed approach is expected to bridge the gap between science and management sides while supporting decision-makers to tackle climate-related issues.

MATERIAL AND METHODS

Through a downscaled review exercise, current issues and trends in climate adaptation and mitigation by forest ecosystems have been investigated. A detailed, keywords-based search was conducted using the SCOPUS database for the reference period 2000–2016. The search process was based on search strengths according to selected sections and research fields. The most relevant review results (i.e. peer-reviewed articles) were then deeply analysed according to main contents and scale.

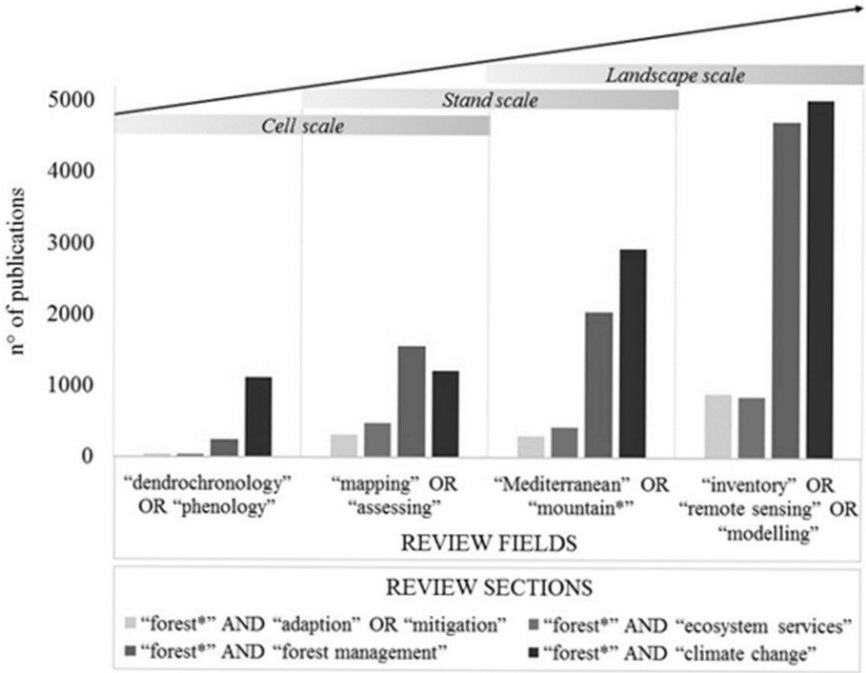

Fig. 1: *Number of publications resulting from the review process.*

RESULTS AND DISCUSSION

The main results of the review process (Fig. 1: Number of publications resulting from the review process.) showed an increase in the number of publications for the reference period (2000–2016), according to the scale of analysis (i.e., cell, stand, and landscape). Hereinafter, contents from selected publications are discussed while considering the scale issues in the light of climate change effects.

From cell to stand scale

Seasonal analyses of cambial cell production, such as day-by-day stem radial increment, can help to elucidate how climate modulates wood formation in tree species. Dendrometer records and cambial activity, as well as cell features, indicate the potential for adaptation to environmental variability, including climate change, and, in turn, demonstrate that the phenology of cambial cell depends on latitude and altitude (e.g. Antonucci et al. 2016, Cocozza et al. 2016a). The synchronism between apical and lateral meristems is defined as the relationships between the different organs of trees and climatic drivers (Antonucci et al. 2015). From cell to stand scale, the adaptation process to climate change involves tree growth rates (Perone et al. 2016), tree-line shifting (Palombo et al. 2014), species distribution at high elevation (Calderaro et al. 2015), and changes of intra- and inter-specific forest composition due to environmental stress responses (Tognetti et. al 2014, Conte et al. 2016). Furthermore, the integrated use of tree rings and woody tissues, such as barks and leaves, is useful to reconstruct the impacts of airborne pollutants over space and time through using trees as bio-indicators (Cocozza et al. 2016b). These approaches provide the basic knowledge to implement effective mitigation strategies at a broader scale (from regional to global level).

From stand to landscape scale

The integration of ecosystem modelling tools with feasible and accurate data is important to better understand the ecosystem dynamics and energy fluxes in a context of changing climate, and, as a consequence, for improving the effectiveness of mitigation strategies. An example of these applications regards the use of models and tools for mapping and assessing forest ecosystem services (e.g. Chirici et al. 2014, Bottalico et al. 2016, Bottalico et al. 2017, Vizzarri et al. 2017). The effectiveness of mitigation strategies also relates to the frequency and spatial representativeness of monitoring processes, which currently represent the bases to support decision-making processes towards improving the adaptation of forest resources to climate change, as well as reducing the anthropogenic impact on forest functionality and resilience (e.g. mapping and assessing fire risks in Italy's Molise region; Corona et al. 2015). Moreover, specific forestry interventions contribute to climate change mitigation through enhancing carbon sequestration (e.g. increasing the amount of deadwood in forest, Lombardi et al. 2008), maintaining the provision of important goods and services (e.g. biodiversity and habitat conservation, Vizzarri et al. 2015, Foresta et al. 2016; ecological connectivity, Tonti & Marchetti 2016), and even from a socio-economic perspective (Marchetti et al. 2014). The implementation of climate change mitigation strategies can also be achieved by enlarging the spectrum of analysis to additional forest resources at regional scale (e.g. through the characterization of trees outside forests; Ottaviano et al. 2015) and on biological communities in mountain ecosystems (e.g. monitoring and modelling the impact of climate change and habitat degradation on flora, Evangelista et al. 2016; and fauna, Di Febbraro et al. 2015).

Final remarks

In forest management and planning, strengthening adaptation and mitigation strategies requires a deeper understanding of the effects of climate change on forests over space and time (Fares et al. 2015). This in turn calls for including and integrating new approaches and tools in decision-making processes. At first, decisions should be driven by observing the physiological response and limits of species to climatic variation at smaller scale (cellular and stand scale). Then, because scales are nested, the integration between analysis of forest ecosystem adaptation and evaluation of the effectiveness of management and planning may be used as key strategies to bridge the gap between research activities and implementation of climate-related policies. Furthermore, understanding the effects of forest management and planning on ecosystem functionality and resilience is extremely important to emphasize the adaptation and mitigation efforts at broader scales. For example, the implementation of a suitable set of Criteria and Indicators (C&I) in Europe remains a key challenge to unravel the mitigation effects of forest management on forest ecosystem adaptation and resilience (Santopuoli et al. 2016).

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Impacts of hydrometeorological extremes in South Moravia based on documentary evidence

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ABSTRACT

Hydrometeorological extremes have influenced human lives significantly in the past, just as they continue to do today. To analyse these influences in the past, information is needed from before the start of systematic meteorological and hydrological observations. Documentary evidence constitutes a very rich source of information about past hydrometeorological extremes. This paper focuses on impacts of hydrometeorological extremes on agriculture and material property and their socio-economic consequences. It also discusses the potential and limitations of such documentary evidence. Despite documentary evidence's several limitations (e.g. spatial and temporal uncertainty, uncertainty in the annual distribution of records, in the type of extreme, etc.), it is a promising source of information useful for future studies.

INTRODUCTION

Hydrometeorological extremes (hereinafter HMEs) influence human activities and cause material damage and even loss of human lives in the present, just as they did in the past. To improve our knowledge of past HMEs, it is necessary to search for sources of information covering the time before the beginning of systematic meteorological and hydrological observations. In the Czech Republic, this generally began in the latter half of the 19th century. Documentary evidence constitutes a promising and rich source of data. The information can be used for analysis of long-term series of HMEs (Brázdil et al. 2012) or focusing on such individual types of HMEs as floods (Brázdil et al. 2014), hailstorms (Brázdil et al. 2016), and drought episodes (Dolák et al. 2015). The aim of this paper is to show the main types of documentary evidence, demonstrate its potential for the study of HMEs' impacts on farmers in the past, and to discuss its limitations.

MATERIAL AND METHODS

In historical climatology and hydrology, different types of documentary evidence are used. The main types of documentary evidence containing information about HMEs are the following:

a) narrative sources: annals, chronicles, and memoirs containing reports about damage caused by HMEs;

b) visual daily weather records: short or detailed information about occurrence of HMEs;

c) records of economic character:

c1) taxation and damage reports – documents related to the taxation process (the taxation system in Moravia allowed farmers and landowners to apply for tax relief if their crops, buildings, and land had been affected by selected HMEs);

c2) insurance reports – documents estimating damage to harvest caused by torrential rains, hailstorms, or floods;

c3) wind damage records – documents describing the damage caused mostly by windstorms or frosts in the forests;
d) other financial-related documents: requests for help and financial or subsistence support for people stricken by disastrous events (used also in the remainder of the Czech Lands and other parts of the Austrian empire);
e) newspapers: reports about extreme weather and HMEs and their disastrous impacts; and
f) early instrumental meteorological observations: information about meteorological phenomena added to measured variables.

The documents usually contain information about the type of extreme event, date and location of its occurrence, and the damage caused. HMEs include in particular hailstorms, torrential rains, floods and flash floods, thunderstorms, windstorms, late frosts, and droughts.

RESULTS

1. Impacts of HMEs on agriculture

a) Impacts on fields and crops

Field crops could be damaged mainly by hailstorms, often in connection with torrential rain and flash flooding. Hailstorms also damaged fruit trees or knocked down fruits in orchards and gardens. Strong winds broke tree branches or whole trees. Very often, multiple damaging phenomena occurred together, such as a windstorm and hailstorm on 10 July 1865 in Diváky: *"A tremendous gale tore through on Monday 10 July at 4 p.m., [...] immediately followed by an awful hailstorm [so fierce] that all the field crops are now [so] squashed into the ground [that] it is difficult to imagine that a single straw might be salvaged. The hailstones resembled large nuts with spikes; the trees that remain are crushed and stripped to the wood, and will dry out for the greater part. Many hares, as well as partridges and other birds, were found beaten to death in the fields."* (Moravské noviny, 13 July 1865, No. 83, p. 331). Crops were also endangered by drought and late frosts. The cereals most widely grown were commonly affected, although some regional differences are evident (e.g. vineyards in the southern part of the region were very vulnerable to damage caused by HMEs).

Fields were damaged in particularly by remaining under water after torrential rains and floods. Parts of fields were covered by sand, gravel, and stone sediments which led to loss of the arable potential, reduced harvest or no harvest at all, and the necessity of removing sediments. Water could also remain in the fields for a longer time, thereby causing crops to die out. Sometimes, fields had to be ploughed under and might be unusable for one or several years. In other cases, torrents of water may have caused erosion and washing away of soil.

b) Impacts on meadows and pastures

Meadows and pastures situated near watercourses were prone to flooding. Grass was fouled with sand, gravel, mud and stones, hay (or second hay – aftermath) was destroyed, and haystacks carried away. Water could run off and left only sediments or it formed long-lasting lagoons. In some cases, it was impossible for several years to use flooded or clogged pastures or meadows. For example, information about a flood in June 1804 on the Židlochovice estate reports: *"The heavy rain that started on Tuesday [12 June] in the*

evening continued nearly uninterrupted [up to 16 June], and in the higher mountains perhaps even more intensive, [and] made the water rise to such a height that even the oldest people could not remember... such a flood [of the River Svratka] in the month of June. Because all the meadows in Pohořelice and Ivaň, also Blučina, are under water, the best hay has been destroyed. Prospects for the coming winter are particularly dismal." (S3).

c) Impacts on livestock

Cattle sometimes starved as a result of flooded and clogged pastures and meadows. Problems with pastures and meagre harvests could then lead to a lack of fodder in winter and result in forced reductions in the number of cattle. The results from cutting cow numbers could be especially severe, largely because of decreased milk production. As a consequence, the amount of manure available for fertilizer also would be reduced. Livestock and poultry often died in floods and they were also vulnerable to fire (as a consequence of a lightning strike), either as direct loss during the fire or as a consequence of fodder shortage if a fodder stack burned.

2. Impacts of HMEs on material property

Almost all HMEs could damage property, but floods were the most disastrous among them. Water broke into houses, farm buildings, yards, gardens, meadows, and fields. Buildings were themselves damaged, as were the belongings inside. Roads and bridges were also damaged, movable property (farm tools, domestic equipment), haystacks, and woodpiles were carried away. Water destroyed riverbanks and altered the contours of floodplains. Floods also threatened watermills, putting them out of service. Damage to a mill usually indicated events of particular severity.

Material property could be damaged also by other types of HMEs. Hailstones often broke windows or damaged roofs. Fires as a consequence of lightning strikes destroyed not only buildings, but also equipment, wood supplies, food, clothing, stored food and feedstuffs. These effects could be increased by strong wind spreading the fire to other buildings.

3. Socio-economic consequences of HMEs

The impacts of HMEs on agriculture and its production, as well as direct material damage, could lead to significant socio-economic problems. Partial or total loss of harvest meant a lack of seeds to sow in the following year. In that case, a loan from the contribution fund (established by Joseph II in 1788 (Vondruška 1989)) could help, such as is stated in a report from the Dolní Rožínka estate: *"...[to provide] the Albrechtice community, which suffered damage to its field crops due to a hailstorm on 26 June of this year [1833], some support [in terms of] corn compensation as follows: to Josef Alexander from No. 4 – 2 měřice [123 litres] of rye; Georg Juraczka from No. 18 – 2 měřice [123 litres] of rye; [...] and the widow Swoboda from No. 2 – 4 měřice [246 litres] of rye and 2 měřice [123 litres] of oats; ..."* (S1). These loans were made only in response to really extreme events, however, and they had to be paid back within a year, including interest. Loss of harvest also led to decrease in financial income from the sale of grain, which could in turn lead to an inability of HMEs victims to repay the grain loan. Farmers were often forced to take out money loans for more seeds and their daily sustenance. Repayment periods on such loans extended to several years and the outstanding debt was subject to further interest. People might be unable to pay taxes and therefore be forced to take out additional financial loans or to leave the land and sometimes their homes. The impacts of an

extreme event were more intense if HMEs hit a single area several times within a short time period, be that either the same villages several times in one year or for several consecutive years. The long-term results of repeated extremes were decreased cereal production, lack of funds, curtailed spending, and impoverishment of all those who worked the land.

DISCUSSION

Although documentary evidence is an important source of information, it has several limitations and associated uncertainties, as follows:

a) spatial and temporal uncertainty: density of records reflects the number of surviving documents;

b) uncertainty in the annual distribution of records: damage to agricultural crops is recorded mostly during the vegetation period (May–August), and stages of crop phenophase influence the extent of the damage, such as is mentioned in a report about a hailstorm at Ledce on 15 May 1811: *"The Ledce community will not feel the damage [done] by weather too badly, because the hailstones fell on summer fields [with summer crops], where rye and barley [were] still small, and they avoided damage. But for the Medlov community and further to Němčičky and Bratčice, the damage may be considerable."* (S2);

c) uncertainty in the type of extreme: there existed a rich terminology concerning HMEs and imprecise expressions were used;

d) uncertainty in the damage: only events with heavy damage are recorded (damage great enough for entitlement to tax relief or to merit reporting in the newspapers, etc.);

e) uncertainty in the duration of HMEs: the beginning and end of some extreme events are not clear (e.g. episodes of droughts).

This study shows documentary evidence to be an important source of data contributing to better understanding of HMEs and their impacts in the past. Knowledge of past HMEs in combination with the data from instrumental measurements may be used for purposes of present risk management and with potential for contributing to reducing potential hazards.

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Water-use efficiency of winter wheat under heat and drought stress

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ABSTRACT

Because such extreme weather events as dry spells and heat waves are expected to occur more frequently due to climate change, the issue of appropriate water management for sustainable agricultural production is increasingly important. This study focuses on wheat, the second most widely grown cereal in the world and the most common cereal in European countries. The study assesses the effects of short periods (3 and 7 days) of high temperatures (26°C as a control, 32°C, 35°C, and 38°C as daily temperature maxima from 12:00 to 14:00) and drought stress at different developmental stages (DC 31 – beginning of stem elongation, DC 61 – flowering, and DC 75 – early grain filling) on water-use efficiency (WUE) in winter wheat cultivar Tobak. This cultivar is one of the most widespread winter wheat cultivars in Czech Republic fields. The analysis of WUE showed that the cv. Tobak plants were able to withstand drought stress conditions through increased WUE. In contrast, wheat plants were stressed more markedly if exposed to higher temperatures and drought in combination. Generally, the wheat plants were most sensitive to drought at DC 31.

INTRODUCTION

High temperatures and drought are two major environmental factors limiting growth and productivity of wheat (*Triticum aestivum* L.) (e.g. Prasad et al. 2011). A combination of heat and drought stress is generally more detrimental than is either stress alone, and consequences of drought on all physiological parameters are more severe at high than low temperatures (e.g. Kaur et al. 2016). According to a report of the IPCC (2013), mean global air temperatures are predicted to rise on average 0.3–0.6°C per decade over the next century. Yields of wheat are predicted to decrease in both tropical and temperate regions (Challinor et al. 2014). Heat stress consisting of even brief periods of high temperatures above crop-specific critical thresholds is already causing large reductions in cereal yields in North America, Europe, and Asia (e.g. Lesk et al. 2016). Water scarcity, often accompanying the increasing air temperature, is a more serious issue for sustaining agricultural production (e.g. Perdomo et al. 2016). A more detailed understanding of responses and acclimation of major crops to water deficit and high temperature is key to mitigating the negative impacts of climate change on plant productivity (Perdomo et al. 2016). Water-use efficiency (WUE) is often equated with drought resistance and improving crop yields under stress (Blum 2005). WUE is a basic indicator for measuring the effectiveness of water-saving approaches to agriculture (Sekhon et al. 2010). Therefore, the aim of this study is to analyse instantaneous WUE (based on open gas-exchange measurements) of winter wheat cv. Tobak (one of the most widespread winter wheat cultivars in the Czech Republic). Plants were exposed to simulated heat and drought stress conditions, as expected under future

climate, within growth chambers to determine: (1) the developmental stage at which the plants are most sensitive to such stress conditions, and (2) the effect of exposure to these two stressors relative to the effects of single stressors.

MATERIALS AND METHODS

Seeds of winter wheat cultivar Tobak were sown in plastic pots (inner dimensions: 10.5 × 10.5 × 21 cm). Two seeds were planted per 1 pot containing a luvic chernozem soil with a silt–clay texture (coming from an experimental station at Polkovice, Czech Republic) on 12 October 2015 at Mendel University's vegetation hall with concrete floor and ambient weather conditions (mesh fence against birds instead of classical roof). Different, randomly selected, pots were transported from the vegetation hall to growth chambers of Global Change Research Institute CAS for 7 days of acclimation to the control chamber protocols followed by their exposure to stress conditions (heat/drought) at each studied developmental (DC) stage (DC 31 – beginning of stem elongation, DC 61 – flowering, and DC 75 – early grain filling). The plants were exposed to heat stress through artificially established protocols in four separate growth chambers and to drought stress by dividing pots into groups exposed to different irrigation regimes. The daily courses of environmental factors in the chambers were: (1) PAR (photosynthetically active radiation in $\mu mol\ m^{-2} s^{-1}$): 0 from 24:00 to 6:00, increasing from 0 to 1500 from 6:00 to 12:00, 1500 from 12:00 to 14:00, and decreasing from 1500 to 0 from 14:00 to 20:00, 0 from 20:00 to 24:00; (2) RH (relative humidity in %): increasing from 85 to 90 from 24:00 to 4:00, 90 from 4:00 to 6:00, decreasing from 90 to 45 from 6:00 to 12:00, 45 from 12:00 to 14:00, increasing from 45 to 75 from 14:00 to 20:00, increasing from 75 to 85 from 20:00 to 24:00; (3) temperature (in °C, temperature maximum = t_{max} was different in each chamber: 26°C in control chamber, 32°C, 35°C, and 38°C): decreasing from 20 to 18 from 24:00 to 4:00, 18 from 4:00 to 6:00, increasing from 18 to t_{max} from 6:00 to 12:00, t_{max} from 12:00 to 14:00, decreasing from t_{max} to 22 from 14:00 to 20:00, decreasing from 22 to 20 from 20:00 to 24:00. The pots inside each growth chamber (28 pots per chamber) were divided into two groups (14 pots per group): (1) pots exposed to stress conditions (heat/drought) for 3 days, (2) pots exposed to stress conditions (heat/drought) for 7 days. The pots were further divided into two other groups within these two groups as follows: (1) well-watered (control) pots, where the soil volumetric moisture was maintained around 30% (field capacity), were irrigated with sufficient amounts of water (until drainage was reached); (2) drought-stressed pots, where the volumetric soil moisture was maintained around 15–20%, were irrigated with 100 ml per 1 pot (this dose is slightly above wilting point 10%). The volumetric soil moisture was controlled using a ML3 ThetaProbe sensor (Delta-T Devices, United Kingdom). The plants were exposed to such stress conditions (heat/drought) in the growth chambers for 3 and 7 days at each studied DC stage and these pots were moved to another growth chamber with control chamber protocols after completing the stress exposure. The pots were transported back to the vegetation hall after the abovedescribed stress episodes at the given DC stage, and they were left there until full ripeness (DC 92 – grain is very hard, cannot be dented by thumbnail). The harvest was carried out manually in the middle of July 2016. The pots were regularly irrigated to prevent drought stress (128 mm as a total amount) as well as treated against common diseases and fungi and insect infestations at the vegetation hall. The amounts of nutrients were based on an analysis of available nutrients at the time of sowing and were kept at levels to avoid limitation by these factors. The pots were surrounded with expanded clay up to the full height of the pots to prevent damages to roots caused by frost in winter and drying out in summer. The physiological measurements were carried out 3 and 7 days after stress exposure,

and using an LI-6400XT (LI-COR Biosciences, USA). The LI-6400XT device enables measurement of those parameters required to calculate the instantaneous WUE. WUE is defined as the moles of CO_2 absorbed per mol of H_2O lost through transpiration (Ali & Talukder 2008) by the following equation: WUE $= A/T$, where A is a light saturated CO_2 assimilation rate at growth CO_2 concentration and T is a transpiration rate (LI-COR Biosciences 1998).

RESULTS

DC 31 at 3 days showed the least sensitive response, as the decrease in WUE values was very small (Fig. 1). When the plants were exposed to heat and drought stress conditions for a shorter period (3 days), the differences among drought-stressed and well-watered treatments were similar across all treatments. On the contrary, the differences in WUE values of drought-stressed and well-watered plants after longer periods of stress conditions exposure (7 days) were significant. The results indicate that response of wheat plants to drought stress occurs through increases in WUE, which is higher with longer time of exposure to such stress conditions. In case of the heat stress, however, that causes a drop in WUE regardless of the water status (Fig. 1). When the temperature is too high (38°C) for the longer period (7 days), this mechanism is disrupted (i.e. the plant is not able to withstand such conditions without a noticeable decrease in WUE).

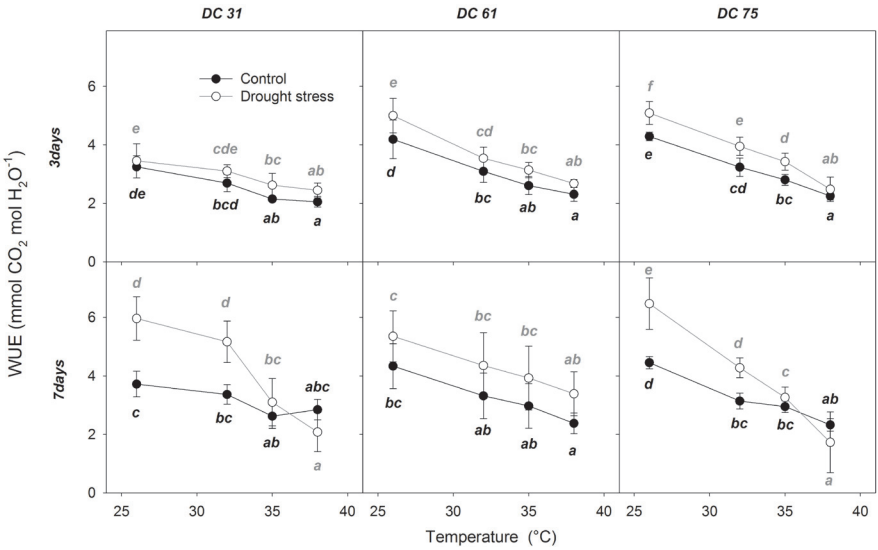

Fig. 1: WUE of winter wheat cv. Tobak after 3 and 7 days of stress: mean values and standard deviations as error bars, different letters denote statistically significant differences among means tested by ANOVA Tukey's post-hoc test (P = 0.05) within each growth stage and length of treatment separately.

DISCUSSION

The increase of instantaneous WUE observed in our study presumably resulted from stomatal closure under drought stress, as reported by, for example, van den Boogaard et al. (1997) and Rekika et al. (1998). This increase of WUE depends on the severity of the drought stress. A relevant increase in WUE can be expected as a result of moderate water scarcity in bread wheat plants (e.g. van den Boogaard et al. 1997,

Rekika et al. 1998). When wheat is exposed to severe drought stress, on the other hand, a decrease in WUE might be expected (e.g. El Hafid et al. 1998, Shanguan et al. 2000) as a consequence of decreased photosynthesis due to metabolic causes, such as by non-stomatal limitation as reported by, for example, Lawlor (2002). As a consequence of such severe drought stress, WUE can decrease if photosynthetic capacity is affected even when the transpiration is decreased by partially closed stomata (Tambussi et al. 2007). Increase in instantaneous WUE of spring wheat following exposure to water-deficit and high-temperature conditions at anthesis in the controlled environment of growth chambers, where temperature treatments were 22/12°C and 32/22°C during day/night, respectively, was reported by Zhang et al. (2010). The decrease in instantaneous WUE under drought stress was also reported by Allahverdiyev (2015) at booting stage (DC 45 – boot just swollen) and watery ripe (DC 71 – kernel watery) of bread and durum wheat. These results are in accordance with results obtained in our study.

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Simulating tomato growth in the CROPGRO-Tomato model and evaluations against field data in Central Bohemia

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ABSTRACT

The CROPGRO-Tomato model was used to simulate the growth parameters of the Thomas F1 bush tomato cultivar grown under open field conditions at two locations in Central Bohemia having different soil and climate. The comparison of leaf area index (LAI) simulated by the model and that measured under field conditions showed adequate representation with root mean square error (RMSE) of 0.86 $m^2\ m^{-2}$ and 1.11 $m^2\ m^{-2}$. Although there was a good fit for LAI between the simulated and measured data during the first part of the growing season, increasing differences were found in the final part of the growing cycle. Additionally, the greatest differences between the measured and simulated LAI values were recorded in those growing seasons with higher temperature and precipitation anomalies.

INTRODUCTION

Although crop models have great potential for practical use particularly in horticultural field production, their use remains limited (Potopová et al. 2017a). Tomato has been a pioneer vegetable species for crop modelling. In recent decades, most of the modelling effort on tomato crop has been put on the carbon fluxes and development processes in relation to the crop environment (Boote et al. 2012). There are a number of crop growth models for tomato, some of which are adapted for greenhouse production and others for field production systems (Boote 2016). In field production, modelling has been more focused on predicting harvest date and dry matter production, as well as to estimate water and nutrient requirements. The CROPGRO-Tomato model was adopted by Scholberg et al. (1997) to simulate field-grown tomato. Boote et al. (2012) developed a module for predicting fresh tomato weight and fruit size, which was added to the Decision Support System for Agrotechnology Transfer (DSSAT) software (Hoogenboom et al. 2010). In the Czech Republic, the application of various dynamic crop models to simulate growth parameters of mainly cereals were provided by a team of the Mendel University of Agriculture Brno (e.g. Hlavinka et al. 2015). Our team deals mainly with the possibility of using CROPGRO for modelling the yield parameters of field-grown tomato (*Solanum lycopersicum* L.) in conditions of changing climate in the Elbe lowland. This model is process oriented (processes of carbon, water, and N balance), and it simulates daily progress towards flowering and fruit set as well as daily growth of leaves, stems, roots, and fruits over time until maturity or final harvest. CROPGRO was applied to identify suitable sites for extension of a new thermophilic assortment of vegetables in the Elbe lowland while taking into account regional specificity of climate change, and also to determine prospective areas for growing thermophilic vegetables in the study region (Potop & Tűrkott 2014, Potopová et al. 2017b). Productivity can be increased by extending the production period and reducing the number of limiting factors through better control of vegetables' physical and biological environment. For tomato production, it is necessary to (i) fulfil the water and nutritional

requirements of the crop for optimal production, (ii) consider the environmental impact of production, and (iii) offer nutritious and safe tomatoes to consumers (Boote 2016). There were two main objectives in this study: (1) parameterization of the CROPGRO-Tomato model and simulation of the crop growth cycle of the Thomas cultivar, and (2) to analyse the ability of CROPGRO-Tomato to simulate the time-series of LAI (leaf area index) from transplanting to harvest.

MATERIALS AND METHODS

To run CROPGRO-Tomato, we used the following four basic data set groups: 1) crop species and cultivar characteristics, 2) meteorological daily data (rainfall, global solar radiation, maximum and minimum air temperatures), 3) soil conditions, and 4) cultivation technology (term of transplanting, term and dose of irrigation, fertilizing and harvesting). Specific soil parameters required for model input, such as lower limit, drained upper limit and saturation, drainage coefficient, and runoff curve number, were estimated from measurement of soil profile. Haplic Chernozems (Prague–Suchdol, site 1) and sandy–loamy Cambisol (Mochov, site 2) are the prevailing soil groups. Field data sets from 2014 to 2016 were used for evaluating the CROPGRO-Tomato model, which is a part of the DSSAT V4.5 software. We applied the newly calibrated values of ecotype file and cultivar coefficients for LAI and yield (Potopová et al. 2017b). In cooperation with a vegetable farm, since 2014, a field trial has been carried out at two experimental sites (Hanka Mochov s.r.o., 189 m a.s.l. and Praha-Suchdol, 287 m a.s.l), where input data for the model were obtained. The general cultivar information and experimental data on phenology and yield components have been described previously (Potopová et al. 2017b, Tűrkott et al. 2017). Evaluated were the measured and simulated growth and development of the fresh-market Thomas F1 bush tomato cultivar grown under open field conditions at two locations in Central Bohemia having different soil and. The sampling plants were collected once in 14 days for analysing basic physiological parameters: LAI and RGR (relative growth rate). Phenology was observed weekly. LAI was determined by the semi-empirical method, and this was followed by infrared image analysis (infrared photographs with 8 Mpx resolution). The images were processed with the analytical tool in Adobe Photoshop. Parameters affecting leaf growth, dry biomass production, and dry biomass of leaves, stem, and generative organs from planting to harvest were calibrated against the measured data. The main objective of model calibration was to adapt the model parameters to local environmental conditions (e.g. soil types and weather conditions) and crop cultivars to obtain good overall agreement between simulated and observed values. The CROPGRO model was calibrated using the experimental data. Statistical indicators (i.e. the root mean square error [RMSE] and coefficient of determination [R^2] were used for evaluating the performance of CROPGRO-Tomato.

Table 1: *Analysis of relative growth rate (RGR), total dry biomass production (Σ), dry biomass of leaves (L), stem (S), and generative organs (G) from transplanting to harvest of Thomas F1 at Mochov.*

Date	***Dry biomass*** *(g)*				***RGR*** *(g g⁻¹ day⁻¹)*		
	L	*S*	*G*	*Σ*	*L*	*S*	*G*
23 May 2016	4.56	2.90	0.01	7.46	0.0823	0.0480	0.2295
17 Jun 2016	35.66	9.64	3.10	48.40	0.0413	0.0327	0.0297
30 Jun 2016	61.00	14.74	4.56	80.30	0.0130	0.0635	0.1861
13 Jul 2016	72.22	33.66	51.24	157.12	0.0419	0.0187	0.0754
26 Jul 2016	124.45	42.91	136.62	303.98	-0.0106	0.0137	0.0214
11 Aug 2016	104.97	53.42	192.29	350.68	0.0087	0.0217	0.0019
22 Aug 2016	115.57	67.82	196.37	379.76	0.0099	-0.0023	-0.0011
30 Aug 2016	125.07	66.58	194.68	386.33	0.0002	0.0259	0.0109
13 Sep 2016	125.41	95.71	226.93	448.05			

RESULTS

The weather conditions during the tomato growing seasons of 2014, 2015, and 2016 produced extreme drought and heat stress. Experimental results show that fruit formation in the tomato cultivar decreases as both extreme temperature and drought frequency increases. Drought-heat stress during fruit formation reduces yield by 30% (e.g. each 1°C above 28°C reduced the yield by 10%). The higher number of days with heat stress in the 2015 and 2016 tomato growing seasons caused a slowing in the relative growth rate of dry matter. The large amounts of global radiation and heat waves resulted in necrosis in the tomato fruit tissue. The lowest growth rate (especially in generative organs) was recorded in the last third of June 2016 (Tables 1,2). The highest LAI was measured for Suchdol in 2016 at 100 days after transplanting (1.79 $m^2\ m^{-2}$), and the lowest in 2014 (0.73 $m^2\ m^{-2}$). Although there was a good fit for leaf area between the simulated and measured data during the first part of the growing season, increasing differences were found in the final part of the growing cycle (Fig. 1). The model properly simulated leaf area index, as given by RMSE of 0.86 $m^2\ m^{-2}$ (Mochov) and 1.11 $m^2\ m^{-2}$ (Suchdol). As shown in Fig. 1, the ranges of R^2 fits for site 1 ranged from 0.79 to 0.88, and for site 2 from 0.75 to 0.91, respectively. The greatest differences between the measured and simulated LAI values, however, were recorded in the growing seasons with the higher temperature and precipitation anomalies. The highest LAI was simulated under extremely hot and dry conditions during July–August of 2015 at Mochov, overestimating the field observation by 22%. The accumulated dry mass was overestimated by the model for all experimental years at both sites, although the simulations did follow the course of observed data during the crop cycle. Furthermore, the model properly predicted accumulation of dry mass, with R^2-values between 0.66 and 0.77 (not shown).

Table 2: *Analysis of relative growth rate (RGR), total dry biomass production (Σ), dry biomass of leaves (L), stem (S), and generative organs (G) from transplanting to harvest of Thomas F1 at Suchdol.*

Date	***Dry biomass*** *(g)*				***RGR*** *(g g⁻¹ day⁻¹)*		
	L	*S*	*G*	*Σ*	*L*	*S*	*G*
18 May 2016	3.56	1.87	0.01	5.43	0.0583	0.0455	0.1441
13 Jun 2016	17.17	6.39	0.49	24.05	0.0681	0.0585	0.1761
29 Jun 2016	51.07	16.28	8.20	75.55	0.0240	0.0375	0.1050
21 Jul 2016	86.57	37.14	82.60	206.31	0.0010	0.0049	0.0523
4 Aug 2016	87.75	39.78	171.68	299.21	0.0187	0.0309	0.0116
18 Aug 2016	114.08	61.29	202.02	377.39	0.0272	0.0137	0.0051
7 Sep 2016	196.36	80.67	223.83	500.86			

DISCUSSION

In our previous study (Potopová et al. 2017a, b), we evaluated the impact of climate trends on vegetable crop yields in the key producing regions of the Czech Republic. To estimate the short- and long-term yield response functions to temperature and precipitation changes, we integrated the regression models and dynamic growth models. Regression models have been considered because of the unavailability of the extensive experimental input data required in crop models for all studied vegetables. By assessing historical and current trends in temperature variables, we found positive long-term impacts of recent warming on fruiting vegetables (from 4.9% to 12.2% $^{\circ}C^{-1}$; Potopová et al. 2017a) but decreasing yield stability of traditionally grown root vegetables in the warmest areas over the past 26 years. Boote et al. (2012) improved the CROPGRO-Tomato model for predicting growth and yield response to temperature. This resulted in a reduction of the model's RMSE compared to the experimental parameters by 44% for leaf area index, 71% for fruit number, and 36% for both aboveground biomass and fruit dry weight simulations. When using the model in Central Bohemian conditions, CROPGRO-Tomato overestimated LAI in comparison with its measured values, especially in periods with temperature anomalies. According to results of simulating tomato growth and yield response under N-limited and water-limited conditions (Tűrkott et al. 2017), the temperature and precipitation patterns significantly affect the onset and length of the individual stages of the tomato plants. For the Mochov farm, in all experimental years, the tomato fruits began to reach harvest maturity earlier.

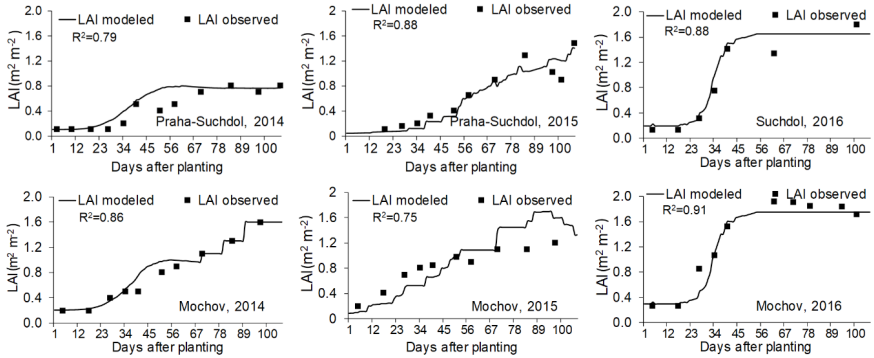

Fig. 1: *Comparison of the simulated leaf area index (LAI) with the measured values (2014–2016).*

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Comparison of leaf area index dynamics and radiation use efficiency of C3 crops in the Czech Republic

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ABSTRACT

Leaf area index (LAI) and radiation use efficiency (RUE) are key parameters for plant growth and productivity. Because of irregularities in weather conditions, accurate estimation of crop production requires understanding relationships between weather, LAI, RUE, and final production. It is thus important to study how the LAI dynamics, leaf area duration (LAD), and RUE are related to aboveground biomass production for different crops. In our study, we compared aboveground dry mass production, LAI dynamics, RUE, and LAD in three C3 crops (spring barley [SB], winter wheat [WW], and oilseed rape [OSR]) in the Czech Republic. LAI was measured on the basis of transmitted photosynthetically active radiation, LAD was calculated by counting the number of days in the growing season, RUE was measured using Beer's law, and the aboveground dry mass was estimated at the time of harvest. Results of our study showed high biomass production and RUE in SB while there was highest maximum LAI (LAI_{max}) and LAD in OSR. We concluded that LAI dynamics or LAI_{max} do not fully reflect the crop production and that RUE may be considered as a better indicator for aboveground dry mass production.

INTRODUCTION

The productivity of crops can be significantly affected by climate change and also related to extreme weather. Because of climate change or unexpected weather changes, food security has become a major challenge. Interception of photosynthetically active radiation (PAR; 400–700 nm) and other environmental factors may affect crop productivity, physiology, and growth (Kemanian et al. 2004). Interception of PAR depends on canopy architecture and particularly on crop leaf area index (LAI) and the crop's ability to intercept and utilize incident radiation (Hikosaka 2005). Total biomass production per unit of intercepted PAR is known as radiation use efficiency (RUE), and to a large extent it regulates the growth and dry mass of crops (Bartelink et al. 1997). The concept of RUE was defined by Monteith (1978) as the ratio between the amount of accumulated intercepted PAR (IPAR) and the amount of dry mass produced, which is a relatively conservative parameter. A crop's canopy size, structure, LAI, leaf angle, leaf area duration (LAD), and leaf orientation alter the net gain of RUE during photosynthesis (Zahoor et al. 2010). RUE of field crops, including winter cereals, without effect of abiotic and biotic stress has been found to be comparatively conservative, with typical species-specific differences (Kiniry et al. 1989). RUE is mainly affected by environmental conditions and can thus be significantly altered by climate change, including in particular, changes in temperature and soil moisture. In several biomass studies, linear relationships between IPAR, RUE, LAI, leaf area duration (LAD), and crop growth have been found in C3 and C4 crops (Kemanian et al. 2004, Zahoor et al. 2010). Studies of these parameters contribute significantly to developing models for predicting crop yields. Nevertheless, the understanding and comparison of LAI, RUE, aboveground dry mass accumulation, and LAD in C3 crops have remained minimal.

In the current study, we compared LAI, RUE, LAD, and dry mass accumulation of C3 crops (spring barley [SB], winter wheat [WW], and oilseed rape [OSR)]). The aim of this experiment was to evaluate the differences in dry mass production, RUE, LAI, and LAD among the different annual crops and compare the role of individual parameters in aboveground dry mass formation.

MATERIALS AND METHODS

Experimental site and treatments

The experiment was carried out at the Domaninek research site (Bystřice nad Pernštejnem, Bohemian–Moravian Highlands; 49°31′N, 16°14′E; 560 m a.s.l.), Czech Republic. Long term (1971–2000) mean annual total precipitation (PPT_{total}) and mean annual air temperature (T_{air}) for this site is 575 mm and 6.8°C, respectively. Soil characteristics are mentioned in detail by Pohanková et al. (2015). In this study, we used SB cultivar Tolar, WW cultivar Etela, and OSR cultivar Rohan.

Field measurements and data collection

All measurements were done in 2012. We measured meteorological parameters (T_{air}, PPT_{total}, and global radiation [GR]), LAI, LAD, RUE, and aboveground dry mass production. T_{air} was measured using an EMS 33 device (EMS Brno, CZ), PPT by a Mentone 370 tipping-bucket rain gauge (MetOne Instruments, USA), and GR by EMS 11 sensors (EMS Brno, CZ). PAR was calculated as 0.5 of GR (Bonhomme 2000). LAI was indirectly measured weekly and biweekly using a SunScan leaf area meter (Delta-T Devices, UK). For daily LAI quantification, we interpolated LAI data using a linear regression equation with cumulative mean daily T_{air} (Tripathi et al. 2016). For estimating the aboveground dry mass we followed a traditional method (Pohanková et al. 2015). LAD was calculated by counting the total number of days from emergence to harvest. RUE was evaluated from IPAR and dry mass using equation (i) according to Cannel et al. (1988):

$$RUE = \Delta W_s / IPAR, \qquad \text{Eq. 1}$$

where ΔW_s = total aboveground dry mass production (g of dry weight m^{-2}). IPAR was evaluated at stand level using Beer's law:

$$IPAR = PAR_{above}(1-e^{-kLAI}), \qquad \text{Eq. 2}$$

where PAR_{above} is cumulated PAR above canopy and k is the light extinction coefficient. For C3 crops such as barley and wheat, k ranges between 0.4 and 0.5, respectively (Monsi & Saeki 1963, Kemanian et al. 2005). In our study, we took an average $k = 0.5$ for all C3 crops.

RESULTS

We measured meteorological parameters during the experiment in 2012 from March to August, where monthly mean T_{air} (°C) reached a maximum of 17.9°C in July (peak of the growing season) and a minimum of 3.9°C in March (beginning of the growing season). The maximum PPT of 86 mm was observed in June and minimum PPT of 9.4 mm in March. Total monthly incident GR varied between 311.7 and 580.8 MJ m^{-2}.

In all C3 crops, LAI dynamics (Fig. 1A) was evaluated from March to August in 2012, where maximum LAI (LAI_{max}) was 5.6, 4.1 and 3.1 m^2 m^{-2} for OSR, WW, and SB, respectively. After the evaluation of LAI dynamics, we evaluated duration of the growing season in terms of LAD (days), which is shown in Fig. 1B. Maximum LAD was observed in OSR. LAD in SB and WW shows similar (almost the same) results.

Total aboveground dry mass production (Fig. 1C) was highest in SB, which was ca 1.5 times greater than in OSR but almost the same as in WW. RUE as a key parameter for aboveground dry mass production in C3 crops (Fig. 1D) showed a maximum in SB (1.9 g MJ^{-1}) and a minimum in OSR (0.7 g MJ^{-1}). RUE of SB and WW was approximately two times higher than in OSR. There was no significant difference in RUE between SB and WW.

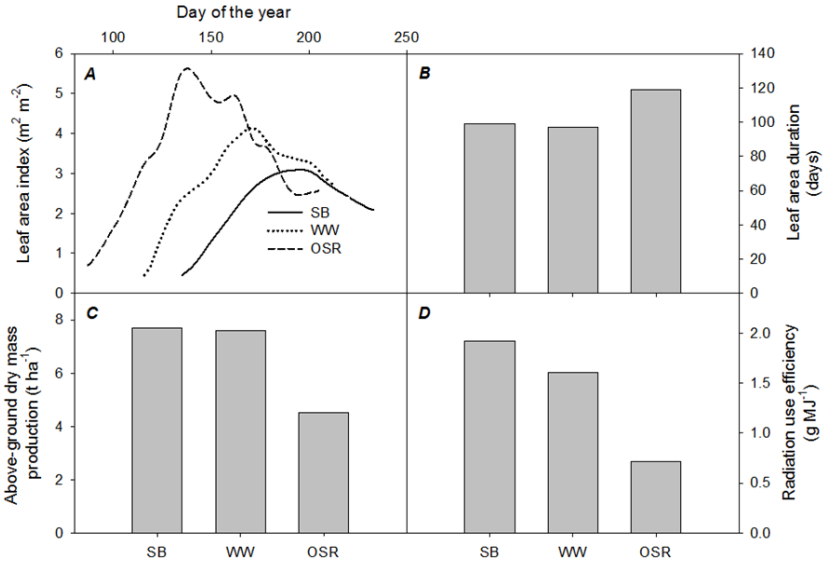

Fig. 1: *Comparison of (A) leaf area index dynamics, (B) leaf area duration, (C) aboveground dry mass production, and (D) radiation use efficiency in SB (spring barley), WW (winter wheat) and OSR (oilseed rape), for growing period 2012.*

DISCUSSION

C3 crops show differences in LAI, RUE, and LAD (Kiniry et al. 1989, Tripathi et al. 2016). LAI patterns were different for all the C3 crops, with LAI_{max} varying from 3.1 to 5.6 m^2 m^{-2}. These LAI_{max} values are in close agreement with LAI_{max} reported in SB, WW, and OSR by other authors (Kemanian et al. 2004, Ahmad et al. 2012, Kuai et al. 2015). Such differences in LAI_{max} could be due to differences in crop physiology, but LAI_{max} also may vary in response to site variation and differences in the genotypes. LAD may be indirectly linked to RUE (Sadras et al. 2016), but in our study the maximum LAD was reported at the same time as lower RUE and aboveground dry mass productivity were observed in OSR. In our study, aboveground dry mass production was high in SB, which was slightly higher than WW, but ca two times higher than in OSR. This aboveground dry mass production is similar to those reported in previous studies conducted in different environmental conditions (e.g. Ahmad et al. 2012). Under favourable conditions, however, the aboveground dry mass production may be higher (10.3–14.2 t ha^{-1}) for barley as observed in the USA (Kemanian et al. 2004). Similarly to aboveground dry mass, RUE was higher in SB as compared to WW and OSR. In SB and WW, the RUE values were more than two times higher than in OSR, while in

SB RUE was slightly higher than in WW. The observed RUE values for SB and WW are similar to those from earlier studies reviewed by Kemanian et al. (2004). Our RUE values in OSR are fairly low, however, as compared to earlier studies, where RUE values observed from 1.07 to 1.09 g MJ^{-1} for OSR (Williams et al. 1965, Kuai et al. 2015). The RUE values could be increased due to such favourable conditions as high water and nutrient (particularly N) availability. It may also be affected by sowing density and genotypes (Kuai et al. 2015).

The results of our study show LAI_{max} and LAD to be high in OSR while aboveground dry mass was highest in SB among the three C3 crops. This means that LAI development, LAI_{max}, and LAD cannot themselves provide accurate estimation of crop productivity among different crops and estimation should be based more on RUE. Our study may contribute to improving evaluation and understanding of crop productivity under ongoing climate change and also to improving selection of crops and genotypes using variation in RUE.

ACKNOWLEDGEMENT

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Interactive effect of UV radiation and CO_2 treatment on extractable volatile organic compounds from European beech leaves

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ABSTRACT

The main objective of this experiment was to investigate the combined effect of different UV treatments and elevated CO_2 concentration on monoterpene and methyl salicylate (MES) content in leaves of European beech during the growing season. Plants were grown under ambient (AC, 400 µmol mol^{-1}) and elevated (EC, 700 µmol mol^{-1}) CO_2 concentrations and three UV radiation treatments (ambient – UVamb, excluded – UV-, and enhanced – UV+). Leaves collected from July to September were extracted in cold heptane to determine volatile organic compounds content using gas chromatography. Our results show that AC plants had higher total content of extractable monoterpenes and MES than did EC plants over the whole growing season and irrespective of UV treatment. Limonene, 2-bornene, and ester MES were the most abundant volatile compounds in beech leaves. The highest contents of 2-bornene and MES were found under the UV- treatment and AC. Contents of α-pinene, β-pinene, and carene decreased during the growing season while the content of limonene increased.

INTRODUCTION

European beech *(Fagus sylvatica* L.*)* is a predominant deciduous tree species in Europe, covering over 7% of the vegetated area (Dindorf et al. 2006). Monoterpenes are widely occurring natural volatile organic compounds (VOCs) produced by vegetation. Monoterpenes have many ecological roles, including broad-spectrum antimicrobial, allelopathic, herbivore deterrent (indirect and direct), and pollinator attractant properties (Dudareva & Pichersky 2008). Monoterpenes might be further involved in protecting plants against abiotic stresses such as high temperature (Loreto et al. 1998) or high ozone concentrations (Calfapietra et al. 2009). They are typically synthesized and stored in special secretory tissues occurring in most vascular plants. Beech trees, however, lack such specialized anatomical structures (Holzke et al. 2006). Accordingly, monoterpenes are synthesized de novo and emitted to the environment almost immediately. Biosynthesis and emission of monoterpenes thus directly dependent on how the rate of photosynthesis is influenced by environmental stressors.

Methyl salicylate (MES) is a VOC naturally produced by many plant species to defend against biotic and possibly abiotic stressors. MES is synthesized from salicylic acid both in infected and non-infected tissues in response to herbivore (Gadino et al. 2012) or pathogen attack (Park et al. 2007). There is also evidence that drought can enhance MES emissions (Bourtsoukidis et al. 2014).

Under natural conditions, plants are frequently exposed to many environmental factors modifying de novo biosynthesis of VOCs and leading to subsequent changes in potential emissions of these compounds. Moreover, Guidolotti et al. (2016) demonstrated that leaf ontogenesis has a substantial effect on rates of CO_2 assimilation and VOC emission. Although several studies have described emissions of monoterpenes

and MES specifically in beech trees (e.g. Dindorf et al. 2006, Holzke et al. 2006), an investigation of how multiple environmental factors influence the extractable content of VOCs in leaves is needed to address our lack of knowledge of this important process.

Accordingly, the main objective of this experiment was to test the hypotheses that (1) the contents of monoterpene and MES in European beech leaves are influenced by dose of UV radiation and CO_2 concentration; and (2) these contents vary during the growing season, particularly in accordance with seasonal changes in photosynthetic carbon assimilation.

MATERIALS AND METHODS

The experiment was conducted at the Bílý Kříž experimental research site in the Beskydy Mountains (49°30′N, 18°32′E; 875–908 m a.s.l.). Glass domes (Urban et al. 2001) were used to cultivate 4-year-old European beech seedlings under ambient (AC, 400 µmol mol^{-1}) and elevated (EC; 700 µmol mol^{-1}) atmospheric CO_2 concentration. Inside each dome, three UV-radiation treatments ($n = 3$) were established equivalent to UV radiation that was ambient (UVamb), excluded (UV-), or enhanced (UV+). Lee U.V. 226 plastic filters (Lee Filters, UK) were used to exclude incident UV-A and UV-B radiation, while a system of modulated fluorescent lamps (Klem et al. 2015) was used to double UV dose compared to the ambient UV treatment. Seedlings were grown under these conditions from May until September. Leaves (about 0.6 g of fresh weight) without visible symptoms of damage, were collected during extended noon hours (11:00–14:00) of sunny days between July and September. After sampling, leaves were weighed, frozen in liquid nitrogen, and kept at –80°C until extraction. Samples were extracted by crushing them using a mortar and pestle, 5 ml cold heptane was added, and samples were refrigerated at 4°C for 24 h. After 24 h, 1 ml of each sample was pipetted into clear 2 ml vials together with 40 µl of an internal standard, Bisabolol, (concentration 100 µg ml^{-1}). Gas chromatography analysis was performed using a TSQ Quantum XLS Triple Quadrupole (Thermo Scientific, USA) on a ZB-5MS column 30 m long and with an internal diameter of 0.25 mm.

The data were statistically analysed using the program Statistica 12 (StatSoft, USA). One-way ANOVA ($P = 0.05$) was used to investigate effects of season, elevated CO_2, and UV treatments on the content of extracted volatile organic compounds. Homogeneity of variance was tested using Cochran's, Hartley's, and Bartlett's tests. Shapiro–Wilk test was used for testing normality. Differences between treatments were evaluated using Tukey's HSD test.

RESULTS

Leaves of AC grown plants had a significantly higher (from 21% to 160%) ($P < 0.05$) total content of extractable VOCs than did their EC counterparts during the whole growing season and under all UV treatments (Fig. 1A). Seasonal decline meant that the differences between AC and EC plants were, however, not statistically significant under UVamb treatment at the end of the growing season (late August and September). The largest differences between AC and EC plants were under the UV- treatment on 21 July and 10 August, when the content of MES was reduced by as much as 86% in the EC compared with AC treatment (Fig. 1B). Monoterpenes limonene and 2-bornene together with organic-ester MES were the most abundant VOCs, making up 94–98% of total VOC content (with 54–72% of limonene as the main compound). 2-bornene and particularly MES were affected by CO_2 and UV treatments. Under both CO_2 treatments, the highest content ($P < 0.05$) of MES (164–511% increase in AC and 94–227% increase in

EC plants when compared to the other two UV treatments) was found in UV- plants except for late August where MES content was irrespective of UV treatment in AC and EC plants both. We observed the similar situation in plants affected by the other two UV treatments, there were no significant difference between UV treatments' effect on MES content in either AC or EC plants. (Fig. 1B). 2-bornene was also significantly affected by CO_2 and UV- treatment, especially on 21 July and 14 September, when the content increased by 189% and 126%, respectively, in AC-treated plants versus EC plants under UV- treatment. On the other hand, 2-bornene content was not affected by the different UV treatments during August.

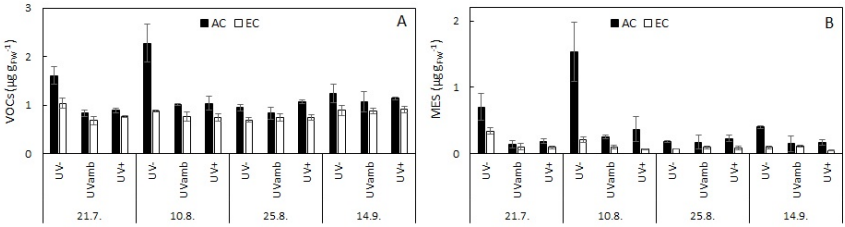

Fig. 1: *Seasonal changes in total contents of extractable volatile organic compounds (A; VOCs) and methyl salicylate (B; MES) in leaves of European beech trees grown under ambient (AC, 400 µmol mol^{-1}) and elevated (EC; 700 µmol mol^{-1}) atmospheric CO_2 concentration and reduced (UV-), ambient (UVamb), and enhanced (UV+) ultraviolet (UV) radiation. Mean values (columns) and standard errors (error bars) are shown for each treatment (n = 3).*

Monoterpenes α-pinene, β-pinene, carene, and limonene showed the greatest seasonal changes among all VOCs detected. In general, contents of β-pinene, carene, and especially α-pinene in leaves of AC-, as well as EC-grown plants, declined during the growing season. For example, α-pinene content decreased by 78% (UVamb treatment) to 92% (UV- treatment) in AC samples from July and September (Fig. 2A). On the contrary, limonene content was observed to increase in AC during the season by 43–65% when comparing July and September samples (Fig. 2B). As with α-pinene, carene content decreased during the growing season by as much as 90% (UVamb treatment) when comparing AC-affected plants from July and September.

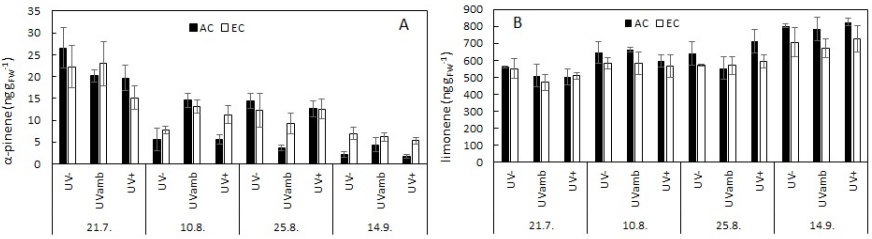

Fig. 2: *Seasonal changes in contents of α-pinene (A) and limonene (B) in leaves of European beech trees grown under ambient (AC; 400 µmol mol^{-1}) and elevated (EC; 700 µmol mol^{-1}) atmospheric CO_2 concentrations and reduced (UV-), ambient (UVamb), and enhanced (UV+) ultraviolet (UV) radiation. Mean values (columns) and standard errors (error bars) are shown for each treatment (n = 3).*

DISCUSSION

Although beech is known as a *de novo* emitter of VOCs, we extracted detectable contents of monoterpenes together with MES. Because the VOCs are synthesized from intermediates of photosynthesis (Loreto et al. 2000), we had assumed in our first hypothesis that growth under elevated CO_2 would result in enhanced production of VOCs while enhanced intensities of UV radiation would lead to reduced biosynthesis of VOCs. However, higher extractable VOCs content and higher MES content were found in leaves of beech trees grown under AC versus EC conditions. Similar findings were reported by Staudt et al. (2001) in *Quercus ilex*. Such a contradiction of our initial presumption could be explained by substrate competition between processes of terpene biosynthesis and cytosolic carbon metabolism (Rosenstiel et al. 2003). Because enhanced intensities of UV radiation sometimes result in reduced photosynthesis (e.g. Klem et al. 2015, Guidollotti et al. 2016), we assumed a reduced content of VOCs under UV+ as compared to UV- conditions. Our analyses, however, did not show a significant effect of UV radiation on the total content of extractable VOCs. This is consistent with earlier findings reported by Turtola et al. (2006) for Scots pine and Norway spruce. Nevertheless, we found that some specific compounds like 2-bornene and MES had substantially increased contents under UV- conditions when the photosynthetic carbon uptake was substantially higher as compared to UVamb and UV+ treatments (data not shown).

The total content of monoterpenes fluctuated through the growing season. In general, the peak contents of α-pinene, β-pinene, and carene, as well as of MES, occurred in most treatments on 10 August before declining on later measurement dates. This is in accordance with findings reported by Staudt et al. (2000). On the contrary, however, the content of limonene, the most abundant monoterpene in beech leaves, followed the opposite trend, being highest at the end of the growing season.

We conclude that beech trees grown under ambient CO_2 concentration have higher content of extractable VOCs than do trees grown under elevated CO_2 concentration. Limonene, MES, and 2-bornene were found to be the most abundant VOCs in beech leaves and contributed dominantly to the differences between AC and EC plants. Although these differences were particularly pronounced at low UV doses, the effect of reducing UV dose on the content of extractable VOCs was less than that of different CO_2 treatment. Finally, although the content of VOCs fluctuates during the vegetation season irrespective of CO_2 and UV treatments, contents of some monoterpene compounds followed opposing trends over time.

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Effect of elevated CO_2 on morphological and photosynthetic parameters in two understory grass species in Beskydy Mountains

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ABSTRACT

We transplanted two grass species, *Calamagrostis arundinacea* and *Luzula sylvatica*, to the understory of a 10-year-old experimental mixed forest exposed to ambient (385 µmol CO_2 mol^{-1}; AC) and elevated (700 µmol CO_2 mol^{-1}; EC) atmospheric CO_2 concentration using a glass dome facility. Effects of EC on plant morphology and photosynthesis were examined after three years of treatment. We tested the hypotheses that shade-tolerant species can profit from EC even at low light conditions and that relatively low accumulation of assimilates at such light conditions will not cause CO_2-induced down-regulation of photosynthesis. We expected that EC can substitute insufficient light intensities under the tree canopy and lead to both higher biomass production and survival of plants in deep forest understories. The typical shade-tolerant species *L. sylvatica* exhibited positive acclimation under EC allowing higher light use efficiency under subsaturating light intensities as compared to plants grown under AC. In contrast, *C. arundinacea* showed higher stimulation of growth and photosynthetic rates by EC mainly under saturating light intensities at the beginning of the growing season, when the forest leaf area is not fully developed and the open canopy allows a greater proportion of incident light to reach the understory. Our data indicate that growth and physiological responses of EC plants in forest understories are species specific, differ from responses of sun-exposed plants, and depend on degree of shading.

INTRODUCTION

In order to predict the responses of natural plant communities to future increase in atmospheric CO_2 concentration, it is necessary to understand the responses of individual species to CO_2 supply. In reviewing research regarding effects of elevated CO_2 (EC) in herb-dominated forest understories, Neufeld & Young (2003) summarized compelling arguments that increasing atmospheric CO_2 can elicit novel response among herb-layer species. The growth of plants in the shade of forest understories is mainly limited by photosynthetic photon flux density (PPFD) (Hättenschwiler & Körner 1996). It has been argued, however, that these species' rate of CO_2 uptake should be particularly sensitive to rising atmospheric CO_2 due to reduced photorespiratory carbon loss (e.g. Farquhar et al. 1980) and hence a reduction of the light compensation irradiance at EC (e.g. Long & Drake 1991). In such case, EC will improve the leaf carbon balance of understory plants even at very low PPFDs.

Here, we present growth and photosynthetic responses of two grass species grown in the understory of an artificially established spruce–beech stand under natural soil conditions. These model ecosystems were exposed to ambient and doubled CO_2 concentrations using a glass dome facility (Urban et al. 2001). The two understory grass species, *Calamagrostis arundinacea* (L.) Roth and *Luzula sylvatica* (Huds.) Gaud., are typical for montane forests in Central Europe. *C. arundinacea* (hereafter *Calamagrostis*) was chosen

because it is an expansive species occurring in the majority of damaged forests within open deforested areas (Fiala et al. 2005). It is a relatively rapidly growing, sun-demanding species, but its ability to persist in shade habitats is remarkable. In extreme cases, it can be found beneath the canopy of dense coniferous forests, where daily PPFD maxima rarely exceed 20 µmol m^{-2} s^{-1} (Gloser & Gloser 1996). On the other hand, *L. sylvatica* (hereafter *Luzula*) is a widespread shadetolerant grass typically occurring in forest understories (Godefroid et al. 2005).

We hypothesized that shade-tolerant species can profit from elevated CO_2 even under low light conditions. We had expected that elevated CO_2 can substitute for insufficient light intensities under the tree canopy and lead to higher biomass production and survival of plants in deep forest understories.

MATERIALS AND METHODS

At the beginning of the 2007 growing season, tillers of *Calamagrostis* and *Luzula* were collected from an open area near the Bílý Kříž experimental station (Czech Republic 49°33´N 18°32´E, 908 m a.s.l.). These were exposed to ambient (385 µmol CO_2 mol^{-1}; AC) and elevated (700 µmol CO_2 mol^{-1}; EC) CO_2 for three growing seasons using a glass dome facility. A technical description of the facility is given in Urban et al. (2001). Ten transplanted plant tufts of each grass species per treatment were planted in the understory of a planted 10-year-old mixed spruce–beech stand (*Picea abies* (L. [Karst.]) and *Fagus sylvatica* (L.)). Plants were grown in the native soil. The geological bedrock is formed by Mesozoic Godula sandstone (flysch type) and is overlain by ferric podzols.

Gas exchange parameters were measured monthly during the 2010 growing season (11–12 May, 8–9 June, 12–14 July, 10–11 August, 7–8 September, and 7–8 October) on vegetative leaves of both species. Biomass analysis was made in September 2010. Light penetration into the tree understory amounted to 80% before leaf development (May), while it was only 20% during the peak of the vegetation season (July–September). Daily maxima of photosynthetic photon flux density (PPFD) in the forest understorey thus were as high as 300 µmol m^{-2} s^{-1}. A Li-6400 open infrared gas exchange analyser (LI-COR Biosciences, USA) was used for measuring the relationship between the CO_2 assimilation rate (A) and PPFD in range 0–1200 µmol m^{-2} s^{-1}. The A-PPFD curves were obtained at constant growth CO_2 concentration (i.e. at 385 µmol CO_2 mol^{-1} in AC plants and 700 µmol CO_2 mol^{-1} in EC plants). Leaf temperature and relative air humidity inside the leaf assimilation chamber were kept constant at 18–21°C and 50–55%, respectively. Assimilation response curves were modelled by quadratic equation based upon a biochemical model of photosynthesis (von Caemmerer 2000).

Sampling of total above- and below-ground biomass of four plants of each grass species was performed in August 2010. The plant material was dried to constant dry weight at 60°C for 48 h. The ratio between root and shoot biomass (R/S) was subsequently calculated.

The data were evaluated by analysis of variance, using the statistical package STATISTICA 12 (StatSoft, Tulsa, USA). Two-way ANOVA was used to test the effect of elevated CO_2 concentration and time period on physiological parameters within each plant species separately. Tukey's post-hoc test was used to separate means.

RESULTS

During the 2010 growing season, the EC treatment led to a higher light-saturated rate of CO_2 assimilation (A_{1200}) in *Calamagrostis* (11.5–16.7 µmol CO_2 m^{-2} s^{-1}) in comparison with *Luzula* (6.4–9.1 µmol

CO_2 m^{-2} s^{-1}), particularly at the beginning of the season (May–July). On the other hand, under low PPFD (50 µmol m^{-2} s^{-1}), higher CO_2 assimilation rates (A_{50}) were observed in *Luzula* than in *Calamagrostis* under both CO_2 treatments, except in October. In EC, A_{50} amounted only to 1.32–1.44 µmol CO_2 m^{-2} s^{-1} in *Calamagrostis*, while A_{50} reached values of 2.00–2.62 µmol CO_2 m^{-2} s^{-1} in *Luzula* (Fig. 1). Substantial stimulation of A_{50} by EC (50–172%) was observed at the beginning (May, June) and end (October) in *Calamagrostis*, but this disappeared during July–September. By contrast, significant stimulation of A_{50} by EC (55–57 %) in July and August was found in *Luzula* (Fig. 1).

Values of above-ground, below-ground, and total biomass at the end of the growing season were significantly higher in *Calamagrostis* (46, 61, and 107 g per plant, respectively) compared to *Luzula* (23, 19, and 42 g per plant, respectively) in AC. In both grass species, the EC treatment increased biomass of all plant parts, except of bases in *Calamagrostis*. In response to EC, above- and below-round biomass was increased by 11% and 32%, respectively, in *Calamagrostis* and by 47% and 170%, respectively, in *Luzula*. Furthermore, root-to-shoot ratio (R/S) revealed that *Luzula* allocated more biomass to the below-ground parts in response to EC. The R/S ratio was doubled in EC compared to the AC treatment (Table 1).

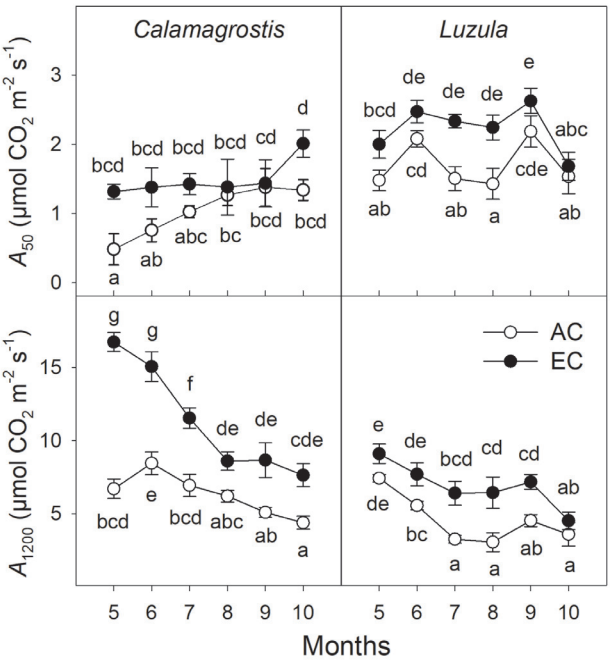

Fig. 1: *Seasonal course of mean CO_2 assimilation rate (A) values at sub-saturating (50 µmol m^{-2} s^{-1}) and saturating (1200 µmol m^{-2} s^{-1}) photosynthetic photon flux densities in Calamagrostis arundinacea and Luzula sylvatica grown under ambient (AC) and elevated (EC) CO_2 concentrations. Error bars represent standard deviations. Differing letters denote significant differences within each species separately (Tukey's HSD test [$P < 0.05$] after ANOVA); n = 5.*

Table 1. *Mean above- and below-ground dry weight (g per plant) and root/shoot ratio (R/S) in Calamagrostis and Luzula grown under ambient (AC) and elevated (EC) CO_2 concentrations and recorded in September 2010. Data are means ± standard deviations. Δ % shows percentage increase (+) or decrease (−) of dry mass in EC in comparison with AC. A t-test was performed to compare mean differences between AC and EC within individual plant species (Tukey's HSD test; n.s. – nonsignificant, * P < 0.05; n = 4).*

	Calamagrostis			***Luzula***		
	AC	EC	Δ %	AC	EC	Δ %
Above-ground	46 ± 4	51 ± 23	+ 11 n.s.	23 ± 6	34 ± 12	+ 47 n.s.
Roots	22 ± 9	43 ± 26	+ 96 n.s.	9 ± 3	31 ± 9	+ 234 *
Bases	39 ± 9	38 ± 12	−3 n.s.	9 ± 3	19 ± 10	+ 104 n.s.
Below-ground	61 ± 16	81 ± 36	+ 32 n.s.	19 ± 3	50 ± 17	+ 170 *
R/S	0.5 ± 0.2	0.8 ± 0.1	+ 69 n.s.	0.5 ± 0.3	0.9 ± 0.1	+ 109 *
Total biomass	107 ± 16	132 ± 59	+ 23 n.s.	42 ± 5	85 ± 27	+ 101 n.s.

DISCUSSION

In general, the degree of increase in A_{max} due to elevated CO_2 varies depending on the functional group and environments (Ainsworth & Rogers 2007). In the present study, based upon photosynthetic light response curves, it can be concluded that the typical shade-tolerant species *Luzula* exhibits a positive acclimation under EC allowing higher CO_2 assimilation under sub-saturating light intensities as compared to plants grown under AC. In contrast, *Calamagrostis* showed higher stimulation of growth and photosynthetic rates by EC mainly under saturating light intensities at the beginning and partly at the end of the growing season, when the forest leaf area is not fully formed and the open canopy allows a higher proportion of incident light to reach the understory. Li et al. (2013) reported an increase in light-saturated net photosynthetic rates for dwarf bamboo growing understory in subalpine dark coniferous forest under EC. In addition, Hättenschwiler & Körner (1996, 2000) found that EC influences, for example, changes in photosynthetic and growth rates, leading to high interspecific variation in plant understory species. This suggests that further increases in atmospheric CO_2 may alter the species composition of the herb layer in forests.

General growth responses to EC include increases in plant biomass, leaf area, leaf thickness, numbers of tillers, leaves and branches, plant height, root length and branching, and carbohydrate accumulation (Newbery & Wolfenden 1996). In the present study, while EC led to higher R/S ratios in *Luzula*, rather physiological effects of doubled CO_2 concentration were found in *Calamagrostis*. In response to EC, photosynthetic parameters of *Calamagrostis* reached maximum values mainly at the beginning (May) or end (October) of the growing season. In contrast, the strongest effects of EC in *Luzula* were found mainly in August, when the greatest shading effect of the tree canopy was observed.

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Stem emissions from poplar hybrids grown in a short-rotation plantation contribute to ecosystem balance of nitrous oxide and methane

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ABSTRACT

The expansion of short-rotation coppices (SRCs) of fast-growing trees can affect the global balance of greenhouse gases (GHGs). These include not only carbon dioxide (CO_2) but also methane (CH_4) and nitrous oxide (N_2O), both naturally produced by soil microorganisms. Trees are known to exchange CH_4 and N_2O with the atmosphere. To date, however, the fluxes of these gases from fast-growing trees have been excluded from estimation of the GHGs balance for SRCs. Our objectives were to quantify and scale up CH_4 and N_2O fluxes from stems of the fast-growing poplar hybrids *Max4* and *Monviso* at an SRC in southwest Germany. Our case study shows that the stems of both hybrids were sources of N_2O and CH_4, even though consumption of CH_4 was also observed. The hybrids did not differ in their exchange capacity. Nitrogen fertilization resulted in higher stem N_2O emissions compared to non-fertilized trees. The emissions of N_2O and CH_4 from stems contributed as much as 1.5% and 1.2% of soil N_2O emission and soil CH_4 uptake, respectively.

INTRODUCTION

After CO_2 and water vapour, CH_4 and N_2O are the most important greenhouse gases (GHGs) whose concentrations have increased since the beginning of the industrial revolution. Over the past decade, short-rotation coppices (SRCs) of fast-growing trees such as poplar, willow, or alder have been established within Europe to reduce release of GHGs into the atmosphere by means of CO_2 sequestration and substitution of fossil fuels (Zenone et al. 2016). The overall balance of GHGs, including CH_4 and N_2O, in SRCs remains under discussion, however. The majority of available studies have focused solely on CO_2 exchange. If CH_4 and N_2O were investigated, almost exclusively their soil–atmosphere exchange was determined (e.g. Díaz-Pinés et al. 2017). Even though trees are known to exchange CH_4 and N_2O with the atmosphere (Rusch & Rennenberg 1998, Machacova et al. 2013, 2016, 2017, Maier et al. 2017), their role in the GHGs balance of SRCs is not considered in any estimation. Moreover, the rapid growth of trees in SRCs is often supported by application of nitrogen (N) fertilizers, which can stimulate production and release of N_2O and CH_4 in the soil (Bodelier 2011). It is evident that both gases can be absorbed by roots, transported into the aboveground tissues, and emitted into the atmosphere (Pihlatie et al. 2005, Machacova et al. 2013).

The objective of our case study was to quantify N_2O and CH_4 fluxes from stems of the fast-growing poplar hybrids *Monviso* (*Populus generosa* x *P. nigra*) and *Max4* (*P. maximowizcii* x *P. nigra*). We hypothesized that (1) stems of poplar hybrids exchange N_2O and CH_4 with the atmosphere, (2) the hybrids differ in their emission potential, and (3) N fertilization increases the emissions of N_2O and CH_4. The investigation of gas emissions at the stem level is a prerequisite for comprehensive study of the overall ecosystem balance of N_2O and CH_4 including also technically more complicated measurements at leaf level.

MATERIALS AND METHODS

Measurements were conducted in an SRC located in Bingen near Sigmaringen in southwest Germany (48°10'N, 9°24'E; elevation 630 m a.s.l.; annual mean temperature and precipitation 7.2°C and 790 mm; Díaz-Pinés et al. 2017). The plantation, established on agricultural soil in May 2009, was divided into two areas (each 1.6 ha). One was planted with the poplar hybrid *Monviso* (*Populus generosa* A. Henry x *P. nigra* L.), the second with the hybrid *Max4* (*P. maximowizcii* A. Henry x *P. nigra* L.). Within each area, four plots were created, each including three randomly organized subplots with different treatments: (i) Subplots V1 were irrigated and fertilized once a month during the growing season with 10 kg N ha^{-1} (NH_4NO_3). (ii) Subplots V2 were only irrigated without N fertilization. (iii) Subplots V3 were neither irrigated nor fertilized. In 2009, each subplot was planted with stem segments of *Monviso* or *Max4* in six rows (each approximately 180 plants) 90 m in length. The tree density was 8000 trees ha^{-1}. The trees in the first rotation were harvested in 2012.

In June 2010, N_2O and CH_4 fluxes from stems of *Max4* and *Monviso* were determined in subplots V1 and V2 to study the natural gas exchange and the effect of fertilization. In each of the subplots, three representative trees were selected. This means a total of 12 trees were measured per poplar hybrid and treatment. In order to avoid negative margin effects, only trees from inside subplot rows were selected. Biometric parameters of the selected trees are given in Table 1.

The exchange of N_2O and CH_4 from stems was determined using static chamber systems enclosing the whole circumference of the stems. The stem chambers (volume 0.0011 m^3) were built of Plexiglas cylinders (for more detail, see Machacova et al. 2013) and were attached to the bottom part of the stem (ca 12 cm above the soil surface). Gas samples (each 10 ml) were taken in intervals of 40 to 60 min 4 to 5 times over a period of 150 to 240 min. The stem gas exchange in *Max4* and *Monviso* was determined alternately in the morning and in the afternoon to balance possible diurnal effect on stem fluxes similarly for both hybrids. The presented flux rates are thus means of morning and afternoon measurements.

Gas samples were immediately analysed using a GC 8610 C gas chromatograph (SRI Instruments Europe, Germany) equipped with an electron capture detector (300°C) supplied with N2 (80 ml min^{-1}) and a flame ionization detector (150°C) supplied with compressed air (250 ml min^{-1}) and H_2 (25 ml min^{-1}). N_2 was used as a carrier gas (20 ml min^{-1}) for both GC columns (Hayesep N for N_2O; Hayesep D for CH_4; SRI Instruments Europe, Germany). Oven temperature was set to 50°C. Calibration was performed with a standard gas (1.78 µmol CH_4 mol^{-1}, 0.574 µmol N_2O mol^{-1}; in synthetic air) (Machacova et al. 2013). The stem fluxes were calculated linearly based on the gas concentration changes over time. The upscaling procedure to per-hectare values, based on tree biometrics (Table 1) and given tree density, assumed constant flux rates within the stem profile (Machacova et al. 2016, 2017).

The non-parametric Mann–Whitney rank-sum test was applied after testing the fluxes for normal distribution (Shapiro–Wilk test) and equality of variances in different subpopulations. Statistical significance was defined at $P < 0.05$. The statistics were run with SigmaPlot 11.0 (Systat Software, USA).

Table 1: *Biometric parameters (mean ± standard deviation) of poplar hybrids Monviso and Max4. V1: irrigated and N fertilized, V2: irrigated only. Stem diameter was measured at the position of stem flux measurements (ca 12 cm above soil surface). Number of lenticels on 1 cm² of stem surface is presented. Statistically significant differences were not detected; n = 12.*

Treatment	***Max4***		***Monviso***	
	V1	***V2***	***V1***	***V2***
Main stem height [m]	2.23 ± 0.26	2.32 ± 0.18	2.55 ± 0.19	2.42 ± 0.13
Stem diameter [m]	0.021 ± 0.003	0.021 ± 0.002	0.021 ± 0.002	0.020 ± 0.001
Lenticels per cm²	1.09 ± 0.25	1.08 ± 0.19	1.32 ± 0.32	1.32 ± 0.33

RESULTS

Both hybrids mostly emitted N_2O into the atmosphere (Fig. 1a). They also were sources of atmospheric CH_4, even though some consumption of CH_4 was observed, especially by individual trees of non-fertilized *Monviso* (Fig. 1c). However, no significant differences in CH_4 fluxes in response to applied treatments were detected for separately analysed individual hybrids. Because the emission rates of N_2O and CH_4 under any given treatment did not significantly vary between *Monviso* and *Max4*, the stem fluxes of both hybrids were combined to study the effect of N fertilization on GHGs exchange. The non-fertilized hybrids emitted 6.52 ± 2.33 µg N_2O m^{-2} stem surface area h^{-1} (mean ± standard error), which corresponded to 3.98 ± 1.42 mg ha^{-1} ground area h^{-1}. On the other hand, trees exposed to N fertilization showed significantly higher N_2O emissions (20.5 ± 5.08 µg m^{-2} h^{-1}, 13.1 ± 3.33 mg ha^{-1} h^{-1}) (Fig. 1b). A similar, but non-significant trend was observed also for CH_4 fluxes (Fig. 1d). Fertilized trees emitted slightly more CH_4 (1.06 ± 0.28 µg m^{-2} h^{-1}, 0.66 ± 0.17 mg ha^{-1} h^{-1}) than did control trees (0.51 ± 0.32 µg m^{-2} h^{-1}, 0.31 ± 0.20 mg ha^{-1} h^{-1}) (Fig. 1d).

DISCUSSION

Our study revealed that stems of poplar grown under field conditions have the ability to emit N_2O and CH_4 into the atmosphere. *Monviso* and *Max4* did not substantially differ in their capacity to exchange N_2O and CH_4 (Fig. 1a,c), even though *Monviso* possessed on average more lenticels per stem surface area than did *Max4* (Table 1). Lenticels are proposed to be responsible for the release of gases from the plants' intercellular spaces - aerenchyma system into the atmosphere. This system is assumed to be a transport pathway for gases in plants (Buchel & Grosse 1990).

The monthly N fertilization significantly increased N_2O emissions from poplar stems (Fig. 1b). According to Díaz-Pinés et al. (2017), the soil was a source of N_2O in spring and summer in 2010 but with no significant effect of N fertilization. The soil emissions ranged between 21.9 ± 1.8 and 27.7 ± 6.8 µg N_2O-N m^{-2} soil surface area h^{-1} for non-fertilized and fertilized plots, respectively (Díaz-Pinés et al. 2017), which corresponded to 688 and 871 mg N_2O ha^{-1} h^{-1}. The scaled-up rates of N_2O emissions from poplar stems thus contributed 0.6% and 1.5% to the soil N_2O emissions at non-fertilized and fertilized plots, respectively.

The stem CH_4 emissions showed similar but non-significant trend in response to N application (Fig. 1d). The slightly higher fluxes under N fertilization might be explained by stimulation of CH_4 production in root-adjacent soil (enhanced root exudation, reduction of N limitation by methanogens; Bodelier 2011) and/or by reduction of soil CH_4 oxidation (e.g. inhibition of methane mono-oxygenase by enhanced

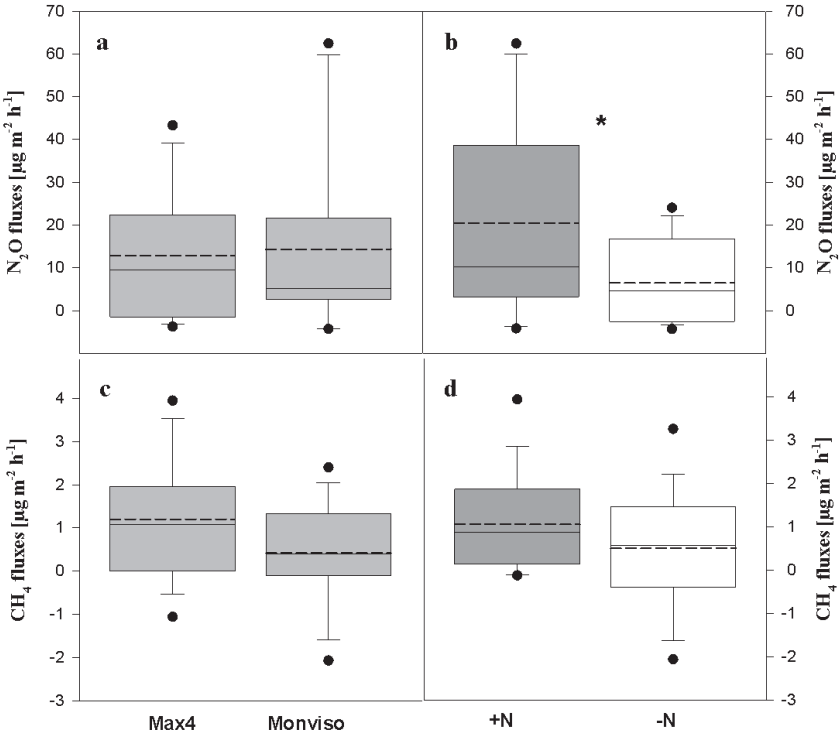

Fig. 1: *N_2O (a, b) and CH_4 (c, d) fluxes from stems of poplar hybrids Max4 and Monviso. The data were grouped by poplar hybrids (a, c) and fertilizer treatment (b, d; +N: irrigated plus N fertilized, -N: irrigated only). Stem fluxes were determined for 12 trees per hybrid per treatment. Fluxes are expressed as medians (solid lines) and means (broken lines). Boundaries within the boxes indicate 25th and 75th percentiles, and the whiskers 10th and 90th percentiles. Dots mark outliers. Statistically significant differences at $P < 0.05$ are indicated by asterisk; n = 12.*

NH_4^+ concentration; Bodelier 2011), provided that CH_4 emitted from the trees originates from the soil. According to Díaz-Pinés et al. (2017), the soil was a sink for CH_4 ranging between −4.0 ± 1.8 and −4.9 ± 2.6 µg CH_4-C m^{-2} h^{-1} (−53 and −65 mg CH_4 ha^{-1} h^{-1}); no effect of N fertilization was observed. The stem emissions of CH_4 therefore accounted for 0.48% to 1.2% of the soil uptake.

The contribution of stem fluxes to the soil N_2O and CH_4 exchange seems to be low and is in agreement with results of a limited number of studies on upland trees under natural field conditions (Díaz-Pinés et al. 2015, Machacova et al. 2015, 2017). We hypothesize, however, that the overall tree contribution might be considerably greater as leaves are assumed to be important sources of both gases (Pihlatie et al. 2005, Machacova et al. 2016). The results of this case study should be verified by a larger experiment directed to studying temporal variability in N_2O and CH_4 exchange of different poplar hybrids in relation to N fertilization while including also flux measurements at leaf and soil levels. Measurements of seasonal variability would enable calculation of the annual GHGs balance of the SRC.

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Modulation of ozone flux in a mountain spruce forest under different cloud cover

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ABSTRACT

Ozone (O_3) fluxes were modelled from a concentration gradient in a Norway spruce forest at the Bílý Kříž experimental station for years 2012–2016. Daily and seasonal O_3 depositions were calculated separately for days with cloudy, partly cloudy, and clear sky conditions. The hypothesis that overcast conditions modulate O_3 flux in the forest ecosystem via controlled stomatal conductance is tested. Indeed, the highest stomatal conductance followed by the highest O_3 deposition was found during partly cloudy and cloudy sky conditions in all seasons.

INTRODUCTION

Ozone (O_3), one of the most phytotoxic air pollutants and greenhouse gases, affects vegetation by reducing its growth and carbon sequestration potential (ICP Vegetation 2011). It has been leading to reduced carbon allocation into forests and wood carbon stock since the pre-industrial age (Wittig et al. 2009). Ozone accelerates senescence and increases the predisposition of plants to be attacked by pathogens and pests (Manning & von Tiedemann 1995). Current levels of tropospheric O_3 are high enough to be considered a substantial threat for forest ecosystems. Several metrics have been developed to define plants' O_3 exposure. Rather than O_3 concentration, stomatal O_3 flux is recommended as a useful tool for quantifying O_3 exposure under the Convention on Long-range Transboundary Air Pollution (LRTAP Convention 2010).

Tropospheric O_3 is known to be produced by photo-oxidation of volatile organic compounds (VOCs), which act as catalysers, in the presence of nitrogen oxides (NO_x). High quantities of O_3 are produced during favourable conditions of bright light, enhanced albedo, and a conducive ratio between NO_x and VOCs, (Tuazon & Atkinson 1990). Indeed, light conditions constitute a crucial factor for O_3 production and in determining conditions suitable for modulating O_3 sink. Two main components of O_3 sink are known: stomatal and non-stomatal (Fowler et al. 2001, Fares et al. 2012). With regard to stomatal sink, O_3 enters stomata and, being a highly reactive molecule, it reacts with inner tissues and damages leaf cell. Non-stomatal sinks include in particular soil, wet surfaces of plants, and reactions with VOCs. The oxidative reactions of O_3 with plant-emitted VOCs lead to the formation of organic compounds with decreased volatility and of secondary organic aerosol (Andreae & Crutzen 1997, Neirynck et al. 2012).

In order to understand the main driving factors of O_3 sinks, we tested the hypothesis that sky conditions modulate O_3 flux in forest ecosystems via stomatal regulation. The hypothesis is based on the fact that cloudiness increases the fraction of blue light while reducing temperature and vapour pressure deficit. Such complex microclimate conditions usually stimulate stomatal conductance (Urban et al. 2012).

Therefore, we expected higher O_3 ecosystem fluxes under cloudy than clear sky conditions in connection with substantial stomatal closure.

MATERIALS AND METHODS

The experiment was conducted at the Bílý Kříž experimental research site in the Beskydy Mountains, located in the north-east part of the Czech Republic (49º 30´N, 18º 32´E; 875–908 m a.s.l.). The region is characterized by low NO_x concentrations (below 10 ppb) and high O_3 concentrations (up to 80 ppb) during summer months (Zapletal et al. 2011). The studied forest stand (99% *Picea abies* and 1% *Abies alba*) had been established in 1981 by row planting of 4-year-old *P. abies* seedlings. In 2012, stand height was 15.2 m, tree density 1368 trees ha^{-1}, and hemispherical leaf area index 7.52 m^2m^{-2} (Urban et al. 2012). The experimental site is equipped with meteorological instruments measuring radiation, air temperature, relative air humidity, air pressure, etc. (see Urban et al. [2012] for details on the instrumentation setup). Eddy covariance technique is suited to continuously measuring and calculating CO_2 and H_2O fluxes (Šigut et al. 2015). H_2O flux was used to calculate level (*G*canopy).

Ozone concentration gradient was measured at three heights (25, 20, and 7 m) above the ground by APOA 370 O_3 analysers (Horiba, Kyoto, Japan). Ozone fluxes were derived from vertical O_3 concentration gradients applying an Inverse Lagrangian Transport Model (Raupach 1989, Juráň et al. 2017). The dataset covers (with small gaps) the years 2012–2016, and it was split according to seasons (spring 1.4.–15.6., summer 16.6.–31.8., autumn 1.9.–15.11., and winter 16.11.–30.3.) with respect to climate specificity of the mountain site. Data were averaged to reach diel values of deposition fluxes. Based on the mean values of diffusion index (DI) during extended noon hours (10:00–13:00 GMT), the dataset was further separated into days with clear (DI ≤ 0.3), partly cloudy (0.3 < DI < 0.9), and cloudy (DI ≥ 0.9) sky conditions. Partial least squares structural equation modelling was performed in SmartPLS 3 software (SmartPLS, Germany) on the whole dataset, resulting in a path diagram describing dependencies among microclimate variables, physiological traits, and O_3 fluxes.

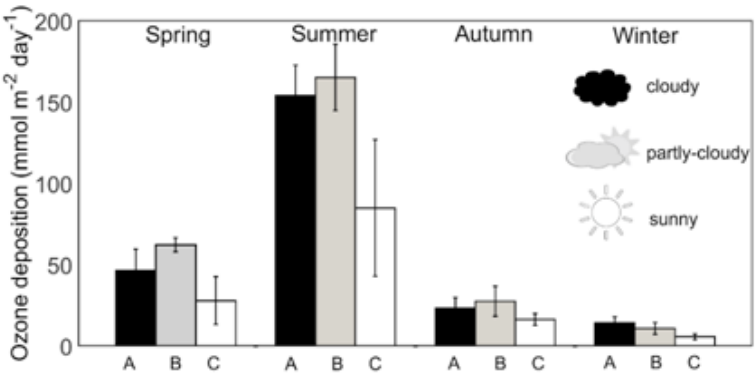

Fig. 1: *Mean daily O_3 deposition in a Norway spruce forest separated by season and sky conditions. Deposition is calculated for daylight hours only. A – cloudy, B – partly cloudy, C – clear sky days. Error bars represent standard deviations of the means (columns).*

RESULTS

Clear skies led to higher daily maxima of air temperature and vapour pressure deficit as compared to cloudy skies. Moreover, substantially higher O_3 concentrations, ranging between 27 and 82 ppb, were observed under clear sky conditions as compared to during cloudy sky conditions, when O_3 concentrations ranged between 8 and 66 ppb (data not shown). These differences almost disappeared in winter months. Despite the high O_3 concentrations during hot, sunny days, the highest O_3 deposition in the forest was observed during partly cloudy and cloudy days. These conditions led to increased daily maxima of O_3 flux and total daily O_3 deposition during the whole year (Fig. 1). The highest values of O_3 flux and daily O_3 deposition were observed during summer months.

The path diagram (Fig. 2) shows the dependencies of O_3 fluxes upon environmental variables and is representative only for the summer season. Photosynthetically active radiation (PAR) acts as the exogenous variable, as it is the only one from the diagram that is not driven by any other variable. Path coefficients range between −1 and 1 and represent the statistical significance of the relationship explained by the whole path diagram. Negative values indicate a negative relationship, which is stronger when being closer to −1, and *vice versa* for positive values.

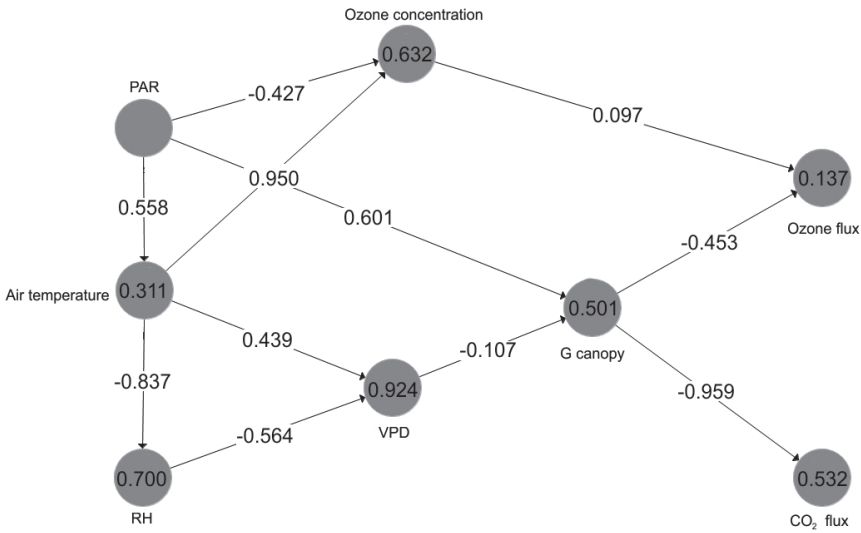

Fig. 2: *Path diagram showing environmental drivers of O_3 fluxes for the summer season. The values in the circles state coefficients of determination (R^2). Path coefficients are written in arrows. Ozone and CO_2 fluxes were loaded into the analysis as negative values. VPD (vapour pressure deficit) and Gcanopy (canopy conductivity) were calculated. PAR – photosynthetically active radiation (μmol m^{-2} s^{-1}), RH – relative air humidity (%), VPD – vapour pressure deficit (hPa), Gcanopy – stomatal conductance at canopy (mol m^{-2} s^{-1}).*

DISCUSSION

The highest O_3 deposition and stomatal conductance at canopy level (up to 0.3 mol m^{-2} s^{-1}) was found to occur in summer during partly cloudy days (Fig. 1). This suggests, in accordance with our hypothesis, that O_3 flux is strongly driven by stomatal opening. Although high concentrations of O_3 precursors (NO_x, VOCs) and high irradiance were observed during summer months, the path analysis revealed dependencies of the O_3 flux on other environmental drivers (such as VPD) to have a relatively low effect on O_3 concentrations but a substantial effect on the O_3 flux (Fig. 2). Moreover, the effect of *G*canopy on O_3 flux was found to be dominant during the summer season. Partly cloudy conditions are characterized by a relatively high fraction of isotropic diffuse radiation (50–60%) penetrating effectively to lower canopy depths (Knohl & Baldocchi 2008). Due to low VPD values (mean 5.77 hPa), stomata of both sun- and shade-acclimated leaves from upper and lower parts of the canopy remain open during the day (Urban et al. 2012). On the contrary, bright light inducing higher VPD values during clear sky conditions might lead to stomatal closure, particularly in the upper part of the canopy.

O_3 deposition during the day as high as 22% has been recorded, and with correlation to relative air humidity greater than 70% (Zhou et al. 2017). This suggests that during cloudy conditions O_3 flux into the stomata is less efficient due to insufficient stomatal opening. This was compensated by a non-stomatal O_3 flux to water surfaces inasmuch as, similarly to our study, rain events were recorded during most of the cloudy summer days.

Similarly, Mikkelsen et al. (2004) recorded the highest total O_3 deposition to Norway spruce forest in summer (May–August), with stomatal removal dominating the O_3 deposition. Turnipseed et al. (2009) investigated O_3 deposition to stomata in a coniferous subalpine forest and found the main drivers of O_3 deposition (accounting for 81% of total) to be light intensity and VPD, both of which influence stomatal opening. To the contrary, a study in mixed temperate forest in Belgium found non-stomatal deposition to be dominating (60%) (Neirynck et al. 2012).

Modulation of stomatal conductance by cloud cover thus seems to be pivotal for O_3 deposition in the studied mountain forest of Norway spruce. We conclude that sky conditions substantially modulate O_3 fluxes in a forest ecosystem. Favourable microclimate conditions during partly cloudy days, and particularly a strong presence of diffuse radiation and low VPD values, increase stomatal conductance of the overall canopy and lead to high O_3 depositions. Non-stomatal O_3 on wet surfaces plays an important role during rainy cloudy days.

ACKNOWLEDGEMENT

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Potential of flux-variance and surface renewal methods for sensible heat flux measurements at agricultural and forest surfaces

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ABSTRACT

Two alternative micrometeorological methods, flux-variance (FV) and surface renewal (SR), based on measurements of high-frequency temperature fluctuation and Obukhov length stability parameter, were tested against eddy covariance (EC) sensible heat flux (*H*) measurements. The study was conducted at three sites representing agricultural, forestry, and agroforestry systems. In terms of measurement setup, these sites represented surface, roughness, and canopy top layer, respectively. As expected, the best match of all the methods was in the surface layer, whilst it was poorer in the roughness and canopy sublayers. Systematic deviation from EC across all three investigated surfaces was within 16% and 8% for FV and SR, respectively. While FV resulted in higher correlation with EC measurements (0.93–0.98 *vs.* 0.89–0.97), SR provided less systematic biases (1.02–1.08 *vs.* 0.94–1.16). In general, both FV and SR provided slightly higher *H* as compared to EC. We suggest that parallel deployment of FV and SR is useful, as both methods require the same instrumentation yet they are based on sufficiently different theories. Therefore, the agreement between FV and SR increases confidence in the results obtained and *vice versa*.

INTRODUCTION

Sensible heat flux (*H*) is an important part of the surface energy budget (Foken 2008). It is of great importance in boundary layer meteorology, as it affects the surface Bowen ratio, as well as dynamics of the atmospheric boundary layer growth and its turbulent mixing, with the related formation of convective clouds and precipitation predisposition (Katul et al. 2012). Sensible heat flux is closely associated with evapotranspiration (*ET*) through the energy balance equation. As a practical consequence, determining of *H*, net radiation, and soil heat flux is commonly used to estimate *ET* indirectly within several micrometeorological measurement techniques or remote sensing and modelling approaches (Foken 2008).

This study evaluates two micrometeorological techniques with capability to quantify *H* from high frequency measurements of the temperature time series and additional measurement of atmospheric stability using flux variance (FV) and surface renewal (SR) methods.

MATERIALS AND METHODS

The study was conducted throughout 2015 at three different sites. The first experimental site was a wheat field located at Polkovice (49.395°N, 17.246°E), the Czech Republic. The second site was a mixed

hardwood swamp forest located at the Alligator River National Wildlife Refuge on the Albemarle–Pamlico peninsula of North Carolina, USA (35.788°N, 75.904°W). The third site, representing agroforestry, was in a pine–switchgrass intercropping system located in Lenoir County in the Coastal Plain of North Carolina, USA (35.268°N, 77.467°W). The measurement height (z), canopy height (h), and plant area index (PAI) are summarized in Table 1. In addition, zero plane displacement (d_0) and roughness length (z_0) were computed according to Shaw and Pereira (1982) from h, PAI and height of the maximum canopy density that was assumed to be $0.8h$ for all sites. Roughness sublayer depth (z^*) was estimated as $15z_0+h$ (Verhoef et al. 1997). At the wheat field, $z \gg z^*$, suggesting that measurements were conducted in the atmospheric surface layer (ASL). At the mixed wetland forest, $h < z < z^*$, indicating measurements in the roughness sublayer (RSL). At the pine–switchgrass site, $h \approx z$, denoting measurements performed in RSL at the top of the canopy layer.

Table 1: *Measurement height (z), canopy height (h), seasonal maximum of plant area index (PAI), zero plane displacement (d_0), roughness length (z_0), and roughness sublayer depth (z^*) for three sites.*

Measured at (during)	**Wheat field** (6/15–8/31/2015)	**Wetland forest** (4/1–8/31/2015)	**Pine–switchgrass** (8/12–11/15/2015)
z (m)	3.4	32.5	7.5
h (m)	1.0	19.8	7.2
PAI ($m^2\ m^{-2}$)	7.7	2.8	4.0
d_0(m)	0.8	15.0	5.7
z_0(m)	0.1	1.4	0.4
z^*(m)	1.6	40.7	13.2

To determine H by both FV and SR methods, unshielded fine wire (75 µm) chromel-constantan (type E) thermocouples (OMEGA Engineering, USA) were used for 10 Hz temperature measurements collected by a CR1000 (Campbell Scientific, USA) datalogger with compact flash module CFM 100 (Campbell Scientific). The raw temperature time series were de-spiked, gap-filled (with linear interpolation applied in case of occasional minor scan skips), and high frequency attenuation was corrected using theoretical transfer function ensuring the inertial subrange spectrum decay by -5/3 in a log-log space. Low-frequency variation related to non-stationary behaviour was removed using a sequential zero thresholding of continuous wavelet transform until flat shape of the second order structure function was reached. For the computation of temperature standard deviation (σ_T), Lorenz thresholding of orthonormal wavelet transform was applied to remove the high frequency variation not related to flux.

In order to compute H using the FV method, the following expression was used (Tillman 1972)

$$H = \rho c_p \left(\frac{|L_O| k_v g}{T}\right)^{1/2} \left(\frac{\sigma_T}{\phi_T}\right)^{3/2}, \qquad \text{Eq. 1}$$

where ρ is the air density (kg m^{-3}), c_p is the air heat capacity (J kg^{-1} K^{-1}), L_O is the Obukhov length (m) (Obukhov 1946), k_v is the von Karmán constant (0.4), g is gravitational acceleration (m s^{-2}), T is mean air temperature (K), and ϕ_T is the dimensionless flux–variance similarity relationship dependent on L_O.

Deriving H using SR can be facilitated by determination of the mean amplitude (a) and mean duration ($d+s$) of the coherent ramp-cliff pattern in the temperature time series related to coherent eddy exchange following (Paw U et al. 1995)

$$H = \rho C_p \frac{a}{d+s}\left(\frac{V}{A}\right), \qquad \text{Eq. 2}$$

where V / A is the volume over the area exchanged during the renewal process via coherent eddies. The V / A term has been a topic of several SR studies and different perspectives exist (Paw U et al. 1995, Castellví 2004, Shapland et al. 2012). In our study, we used a modified version of the expression originally proposed by Castellví (2004), which follows as

$$\frac{V}{A} = k_v^{3/4}\sqrt{\frac{(z-d_0)\,(d+s)}{\pi}}\left(|L_O|\, g\,\frac{\sigma_T}{T}\right)^{1/4} \phi_h^{-1/2}\phi_T^{-1/4}, \qquad \text{Eq. 3}$$

where the newly introduced ϕ_h is a dimensionless universal stability correction function for exchange of heat. As obvious, in both the FV and SR versions applied here, not only temperature but also L_O is needed to compute H. Although L_O can be obtained using a 2D anemometer and iterative procedure, we used direct measurement of L_O by 3D sonic anemometer to minimize the dependence on estimates of d_0, z_0, and z^*. In the cases of both forested covers, z was replaced by z^* throughout Eqs. 1–3 to ensure proper scaling of universal functions that starts to be valid at the top of the roughness sublayer. The comparative measurement by eddy covariance (EC) and measurements of L_O were made using a Gill Windmaster 3D sonic anemometer (Gill, UK) connected to the aforementioned CR1000 datalogger, with memory extension in the case of the pine–switchgrass site, and to the LI-7550 unit (LI-COR Biosciences, USA) in the case of the wheat field and forest wetland sites. All EC measurements were collected at 10 Hz acquisition frequency.

RESULTS

Fig. 1 provides a scatterplot comparison of H measured by FV and EC, and SR and EC for all three investigated sites. The highest correlations were obtained above the wheat field while the lowest was in the case of the wetland forest. FV generally provided slightly higher correlations but also slightly greater systematic biases. Comparison under stable conditions yielded inferior statistics with the highest coefficients of determination in the case of the wheat field (i.e. in ASL).

DISCUSSION

Both FV and SR provided reasonable estimates of H with systematic biases within a generally accepted range of systematic errors (5–15%) for micrometeorological measurements (Foken 2008) across all three tested sites. The correlation with EC was highest in the case of ASL measurements for both unstable and stable conditions. Such result could be expected, considering that the relations described by the similarity functions assume an extensive flat and homogeneous terrain under stationary, planar homogeneous conditions with no subsidence or mean pressure gradient and negligible molecular diffusion of heat (Castellví 2004, Foken 2008). Considering these similarity assumptions, one may further expect the best performance of FV and SR in ASL and poorest in the canopy layer at the bottom of RSL. Our results, however,

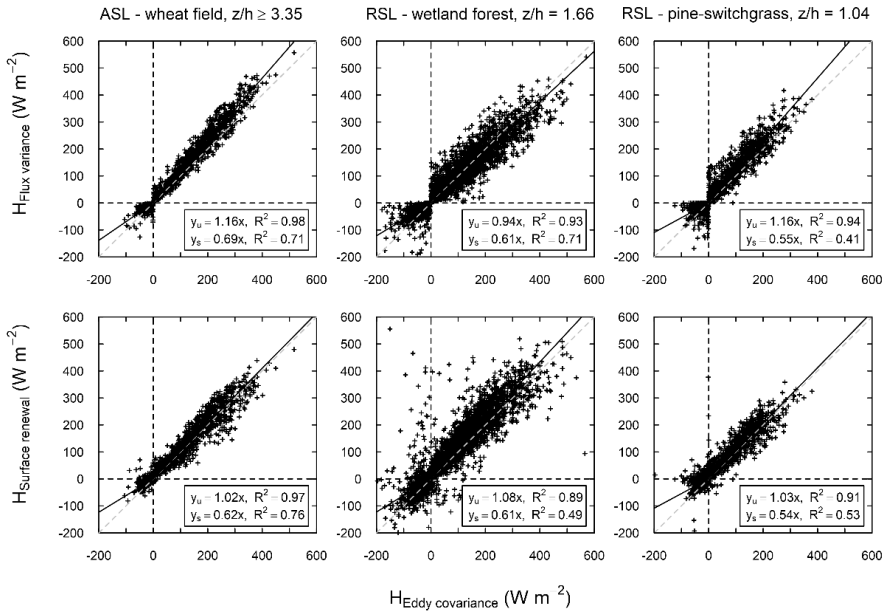

Fig. 1: *Comparison of flux variance with eddy covariance (upper panel), and surface renewal with eddy covariance (lower panel) measurements of sensible heat flux (H). Basic regression statistics are provided separately for stable (s) and unstable (u) atmospheric stratification. Solid black lines depict the linear fit with intercept set to zero while grey dashed lines indicate the one-to-one reference relationship.*

indicate that both FV and SR showed slightly better statistics at the top of the canopy layer than in the higher part of RSL. This might be due to higher accuracy of all the height-dependent input parameters (Table 1) in the case of short pine plantation as compared to the tall wetland forest. In addition, the more even and hence homogeneous plantation stand structure as compared to naturally evolved wetland forest could lead to higher flux homogeneity even when measurements were conducted very close to the canopy elements. The Obukhov length-dependent FV and SR estimates tested here provided better performance as compared to the L_O-independent FV and SR versions tested in other studies (Paw U et al. 1995, Shapland et al. 2012). This supports previous work by Castellví (2004) and demonstrates its general validity in the surface, roughness, and even canopy layers. Our study aimed to prove the concept of FV and SR and used L_O measured directly by 3D sonic anemometer. This direct L_O determination lacks any practical advantage as compared to EC since the same instrumentation is needed, but it clearly supports the validity of the FV and SR theory and within that the adopted assumptions. It was previously hypothesized that due to non-Gaussian properties of temperature statistics, the stability parameter can be estimated only from temperature skewness (Tillman 1972). To our knowledge, however, no further study has directly tested this hypothesis. In a future study, we will therefore examine if the stability parameter can be obtained without the need for velocity measurements (e.g. from temperature statistics), which would provide significant instrumental simplifications and hence great practical advantages.

ACKNOWLEDGEMENT

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Influence of the chlorophylls-to-carotenoids ratio on light use efficiency estimation by optical parameters

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ABSTRACT

The influence is examined of changing leaf photosynthetic pigments concentrations on sensitivity of the photochemical reflectance index (PRI) and ΔPRI optical parameters in relation to light use efficiency (LUE). Photosynthetic and leaf chlorophylls-to-carotenoids (Chl/Car) ratio changes during the growth of European Beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) saplings were induced by altering the living environment inside growth chambers. Point reflectance measurements of each individual tree were recording changes in optical properties while measurements were being taken simultaneously of altering photosynthesis. Based on the evaluation of 45 pairs of measurements conducted on six individual saplings, the observed variability in the strength of the PRI and ΔPRI versus LUE relationships was compared to the resulting leaf Chl/Car ratio of each tree. Data were used to explain the influence of changing pigments on the sensitivity of each individual optical parameter with regards to the LUE estimation.

INTRODUCTION

The photochemical reflectance index (PRI) is a well-established vegetation index (VI) and is commonly used as an indicator of light use efficiency (LUE) in plants. The biophysical rationale of PRI – typically calculated as PRI = $(R_{531} - R_{570})/(R_{531} + R_{570})$, where R is a reflectance at a given wavelength – is to detect biochemical conversions in the xanthophyll cycle pigments pool. Such changes in photo-biochemistry produce fluctuations in reflectance wavebands at around 531 nm (Gamon et al. 1990). Because reflectance at 531 nm, which is sensitive to leaf carotenoids concentrations, is normalized by chlorophylls absorption wavebands at around 570 nm, PRI is criticized for being dependent on the chlorophylls-to-carotenoids ratio (Chl/Car). It has been shown that a large portion of uncertainty in the PRI–LUE relationship originates from adjustments in leaf Chl/Car to various stresses (Solovchenko et al. 2010). A substantial decrease of Chl/Car is observed typically during periods of cold stress, thereby leading to a decrease of PRI (Fréchette et al. 2015). Attempts have been made to deconvolute sources of variability in PRI introduced by changing Chl/Car. Although a correction mechanism has been introduced using differential PRI (ΔPRI) and involving deconvolution of daily observed PRI change from the starting PRI for each day (PRI_0) (Soudani et al. 2014), no detailed explanation as to the influence of changing Chl/Car ratio on sensitivity of ΔPRI as a proxy of LUE has been provided. That is because in previous studies the parameter has been tested either in environments with other strong stresses or in leaves with largely constant Chl/Car ratios.

This experiment aims to clarify the influence of changing Chl/Car ratio during the vegetation period on the sensitivity of PRI and ΔPRI in relation to LUE. We measured PRI of Norway spruce and European beach seedlings in a controlled, growth chambers environment and compared the coefficient of determination (R^2) for the PRI–LUE and ΔPRI–LUE relationship with the varying values of Chl/Car.

MATERIALS AND METHODS

Temperature and photosynthetic photon flux density (PPFD) were adjusted in large (step-in) FS-SI 4600 growth chambers (PSI, Czech Republic). PPFD was set up inside growth chambers by switching light between 300, 600, and 1200 µmol m^{-2} s^{-1} at predefined intervals. Temperature environment was adjusted to induce photosynthesis and Chl/Car changes during the experiment. Between each acclimation regime 10 days long, the maximum temperature inside growth chambers was switched from low daily maxima (21°C) to medium (26°C) to high (35°C), and back to low (21°C) and again to high (37°C) temperature. These temperature changes also were combined with drought stress. The entire measuring cycle lasted 50 days.

Reflectance of six European beech (*Fagus Sylvatica L.*) (July–August) and Norway spruce (*Picea abies L.* [Karst.]) (September–October) saplings placed inside growth chambers was measured using an eight-module JAZ spectrometer (Ocean Optics, USA) measuring with a full width at half maximum resolution of 1 nm. Seven modules of the JAZ instrument were measuring light reflected from each individual sapling and one was used to collect incoming irradiance data. Because each module of the multichannel JAZ instrument measures data within slightly different wavelength intervals and with different grating, the collected radiance spectra were approximated in R software (R development core team, 2013) to spectra with 0.5 nm step. Reflectance was then calculated as the ratio of radiance reflected from trees to incoming irradiance. PRI was then calculated from these corrected and modelled reflectance curves following Gamon & Berry (2012) as $PRI = (R_{531} - R_{570})/(R_{531} + R_{570})$. ΔPRI was calculated accordingly as $\Delta PRI = PRI_0 - PRI$, where PRI_0 was derived from early morning measurements of PRI under PPFD of 100 µmol m^{-2} s^{-1} and a given temperature, PRI was measured at a given PPFD (300, 600, and 1200 µmol m^{-2} s^{-1}) and given temperature conditions throughout the day.

Leaves in the uppermost part of the sapling crowns were measured using the LI-6400 XT portable photosynthesis system (LI-COR Biosciences, USA). Photosynthesis data were collected five times per day during the second and last day of the acclimation according to the changing light and temperature conditions of the growth chamber. The contents of the chlorophyll and carotenoid foliar pigments were measured at the end of the measurements using a Specord 500 spectrophotometer (Analytik Jena, Germany) for six leaves of each examined tree. LUE was calculated as $LUE = A_{CO2}/PPFD$, where A_{CO2} is the instantaneous assimilation rate of CO_2 (µmol CO_2 m^{-2} s^{-1}) and PPFD is the instantaneous photosynthetic photon flux density (µmol m^{-2} s^{-1}).

A logarithmic regression model was used to study the relationships between PRI and ΔPRI optical parameters deduced from steady values at given conditions and LUE obtained from measurements of saplings in changing climatic conditions. R^2 resulting from the regression model was then compared with the Chl/Car ratio from leaves of each examined tree to explore the impact of colour changes on the sensitivity of each examined parameter in relation to the LUE estimation.

RESULTS

Regarding the relationship between PRI and leaf-level LUE, similar total R^2 values for beech and spruce species were observed (Fig. 1). Slightly higher R^2 was observed, however, for beech with higher range in the final Chl/Car (Table 1), thus suggesting positive impact of Chl/Car decrease on the sensitivity of PRI in relation to LUE. ΔPRI provided more accurate estimation of LUE in spruce with lower observed dynamics in Chl/Car. We attribute the lower R^2 between ΔPRI and LUE observed for beech to a rapid decrease of

Chl/Car in beech seedling number four to 2.54. The observed Chl/Car drop produced high ΔPRI, which disturbed the observed relationship between ΔPRI and LUE.

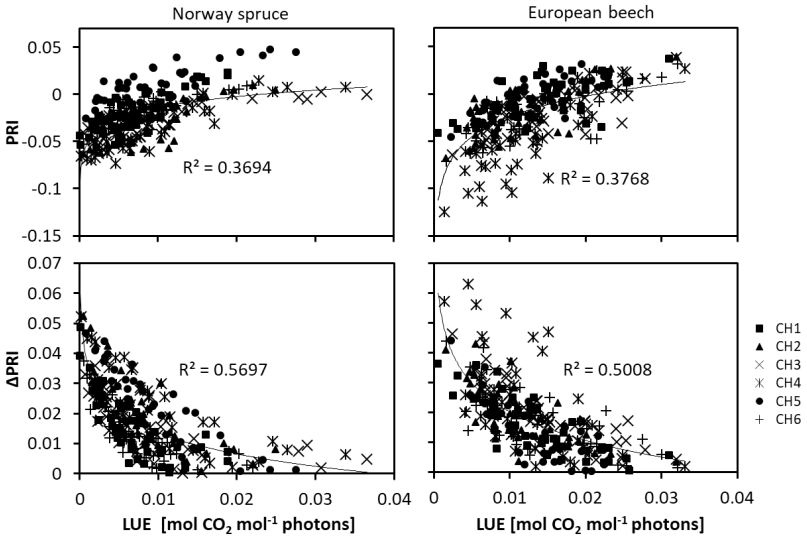

Fig. 1: *Plots connecting measured data points of light use efficiency (LUE), photochemical reflectance index (PRI), and ΔPRI of Norway spruce and European beech saplings. Measurements of individual trees distinguished with marks. R^2 estimated from established logarithmic regression between all measured data (n = 270).*

Suggested Chl/Car impacts on the sensitivity of PRI and ΔPRI towards LUE were confirmed by the comparison of data measured in each individual tree (Table 1). The data summarizing measurements of individual seedlings suggest that sensitivity of PRI in relation to LUE increased with decreasing Chl/Car irrespective of tree species. For ΔPRI, the opposite trend was observed, as sensitivity diminished with decreasing Chl/Car. These effects of Chl/Car on sensitivity of PRI and ΔPRI in relation to LUE are more apparent from data of beech with more-pronounced observed decrease in Chl/Car. Among the spruce trees, the highest sensitivity of ΔPRI to LUE was observed for trees with the lowest resulting Chl/Car of 3.07 (Table 1)

Table 1: *Analysis revealing influence of change in chlorophylls-to-carotenoids ratio (Chl/Car) on sensitivity of photochemical reflectance index (PRI) and ΔPRI in relation to LUE. Shown are coefficients of determination (R^2) for logarithmic relationships between LUE and ΔPRI from measurements of individual trees. R^2 values are compared with Chl/Car values determined at the end of measurements to show the impact of changing pigments stoichiometry on R^2. The trees are ranked according to resulting Chl/Car.*

Norway spruce						
JAZ channel	CH1	CH3	CH5	CH4	CH2	CH6
Chl/Car	3.36	3.31	3.15	3.13	3.07	3.07
PRI–LUE (R^2)	0.42	0.40	0.54	0.62	0.60	0.67
ΔPRI–LUE (R^2)	0.72	0.72	0.66	0.65	0.75	0.80
European beech						
JAZ channel	CH1	CH3	CH5	CH6	CH2	CH4
Chl/Car	3.64	3.56	3.44	3.28	3.26	2.54
PRI–LUE (R^2)	0.30	0.49	0.43	0.44	0.46	0.53
ΔPRI–LUE (R^2)	0.69	0.75	0.71	0.51	0.63	0.35

DISCUSSION

Our results suggest that decreasing Chl/Car ratio can have a positive impact on the relationship between PRI and LUE, as this adjustment in leaf stoichiometry usually represents physiological adjustments of photosynthesis to prevailing environmental conditions and causes decrease of PRI, which produces a larger drop in the stress environment (Peñuelas et al. 1995). Contrariwise, the results also suggest that severe decrease of Chl/Car – and particularly the one leading to yellowing of leaves (observed in leaves of European beech number 4) – resulted in decreasing ΔPRI sensitivity towards LUE. Measurements of spruce suggest, however, that the result may not be unambiguous, because measurements of this species suggested that decreasing Chl/Car may have positive impact on sensitivity of ΔPRI in relation to LUE. Moreover, other authors have reported advantages of using ΔPRI in photosynthesis studies (e.g. Soudani et al. 2014).

It would be important to test the mechanisms identified here also for mature trees, where there may exist additional causes of PRI variation, such as solar angle or canopy structure (Hilker et al. 2008).

ACKNOWLEDGEMENT

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Predicting light use efficiency using optical vegetation indices at various time scales and environmental conditions

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ABSTRACT

This study presents data points acquired during 2 years of measuring optical properties and gas-exchange characteristics of European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) tree species in controlled environments. The observed statistical relationships between 105 pairs of selected optical parameters (i.e. photochemical reflectance index [PRI], ΔPRI, and normalized difference between wavebands R_{690} and R_{630} [where R is a reflectance at a subscripted wavelength]) and light use efficiency (LUE) were considered at assumed different canopy leaf area index, changing pigments stoichiometrics, and daily changing dynamics of environmental conditions. Our measurements suggested that consistency of the LUE estimation using PRI may be disrupted by acclimation responses of plants that reduce energetic carriers for use in photosynthetic CO_2 uptake and the xanthophyll cycle. Also, a changing chlorophylls-to-carotenoids ratio tends to interrupt the PRI–LUE relationship. ΔPRI showed sensitivity to leaf area index of the measured trees that complicated leaf-level estimation of LUE. The most consistent assessment of LUE was achieved using the chlorophyll fluorescence detecting ratio $(R_{690} - R_{630})/(R_{690} + R_{630})$.

INTRODUCTION

Understanding the mechanistic relationships between vegetation indices (VIs) derived from reflectance and photosynthetic activity across a range of time scales is important for developing accurate predictive photosynthetic models calculated from remote sensing (RS) approaches. About 80% of the solar energy absorbed by leaves is converted via photosynthesis into chemical energy in the form of ATP and NADPH. The excess of the absorbed energy is dissipated as heat or emitted as leaf fluorescence. These quantitatively minor physiological processes produce a detectable optical signal that is related to light use efficiency (LUE) and thus provides the opportunity to detect LUE remotely (Gamon et al. 1992, Porcar-Castell et al. 2014).

Thermal energy dissipation of excessive light energy by leaves is mediated via the xanthophyll cycle, which generates reflectance peak fluctuations at wavelength 531 nm in response to violaxanthin-zeaxanthin pigments conversions (Gamon et al. 1992). As light-dependent fluctuations at wavelength 531 nm are commonly normalized with signal produced at 570 nm, which is highly influenced by leaf chlorophylls, uncertainties in LUE estimates through PRI are often attributed to a changing chlorophylls-to-carotenoids ratio (Chl/Car). A correction mechanism for de-convoluting daily observed PRI change from starting PRI of each day (i.e. PRI_0) by introducing differential PRI (ΔPRI) has been proposed to correct for the sources of variability in the PRI versus LUE relationship (Soudani et al. 2014). The measurement of leaves' chlorophyll fluorescence is frequently used as a non-destructive tool for detecting the photosynthetic activity of plants (Papageorgiou & Govindjee 2004). Many unresolved questions remain, however, regarding the interpretation of fluorescence

signal, and the dependency of fluorescence on leaf chlorophylls concentrations is often discussed. Here we focus our effort on evaluating the responses of normalized fluorescence ratio $(R_{690} - R_{630})/(R_{690} + R_{630})$ (Zarco-Tejada et al. 2000) to dynamic changes in LUE. This VI captures a majority of fluorescence emission from photosystem II operating in the maximum chlorophyll absorption region.

This study was designed to evaluate the sensitivity of optical parameters PRI, ΔPRI, and $(R_{690} - R_{630})/(R_{690} + R_{630})$ to LUE of European beech (*Fagus sylvatica* L.) leaves and Norway spruce (*Picea abies* L. [Karst.]) shoots. The experimental design assumed a different leaf area index of studied canopy crowns between two seasons of measurements, together with a changing leaf carotenoids-to-chlorophylls ratio (Car/Chl) and chlorophylls concentrations within each season, as well as dynamic changes in daily regimes of irradiation and temperature.

MATERIALS AND METHODS

Light intensity and temperature were adjusted in large (step-in) FS-SI 4600 growth chambers (PSI, Czech Republic) to measure spectral reflectance, chlorophyll fluorescence, and gas-exchange of European beech and Norway spruce seedlings 3–4 years old and about 1 m tall. Merely constant photosynthetic active radiation (PAR; 400–700 nm) and temperature changes were set up in growth chambers for the first year of measurements. During the second year of measurements, control days were mixed with days of high night temperature and cold photoperiod and vice-versa to increase variability in the data. The temperature ranged between 14°C and 37°C during the measurements under PAR intensities between 300 and 1500 $\mu mol\ m^{-2}\ s^{-1}$.

Reflectance of canopies inside of growth chambers was measured using two JAZ spectrometers (Ocean Optics, USA) set up in a JAZ guard configuration and designed for automatic measurements of spectral data at predefined time intervals and frequencies. Reflectance of trees was measured from a distance of approximately 1 m. The sampled area covering crowns of four individual saplings was ca 50 cm in diameter, which is given by the 25°field of view of the optical-fibre tip. PRI and ΔPRI were calculated following Gamon & Berry (2012) as $PRI = (R_{531} - R_{570})/(R_{531} + R_{570})$, where R is reflectance at a prescribed wavelength, and $\Delta PRI = PRI_0 - PRI$. PRI_0 was derived from early morning measurements of PRI under a PAR intensity of 100 $\mu mol\ m^{-2}\ s^{-1}$ and given temperature. Fluorescence ratio vegetation index was calculated as $(R_{690} - R_{630})/(R_{690} + R_{630})$. Leaves in the uppermost part of the canopy crowns were measured using the LI-6400 XT portable photosynthesis system (LI-COR Biosciences, USA). Ten trees in total were sampled for gas-exchange characteristics, and one representative leaf from each tree was chosen for the measurements. The measured data were averaged to obtain the mean response of photosynthesis to actual conditions. Light use efficiency (LUE) was calculated as the ratio between the instantaneous assimilation rate of CO_2 at a given irradiance, temperature, and PAR defining the light environment inside of the growth chamber.

A logarithmic regression model was used to study the relationships between optical parameters PRI, ΔPRI, $(R_{690} - R_{630})/(R_{690} + R_{630})$, and LUE from measurements of canopies with presumed different LAI (between years), changing leaf Chl/Car (ranging from 4.9 to 2.9 over the season) and changing climatic conditions during the day.

RESULTS

In general, we detected higher sensitivity of optical parameters in relation to LUE in Norway spruce (Fig. 1). PRI provided a good estimation of LUE, with R^2 estimated at around 0.6 during the first year of

measurements and for the two years combined. The strength of the relationship between PRI and LUE diminished in the more dynamic environment during the second year of measurements. The overall relationship observed between PRI and LUE also tended to deteriorate. An improved estimation of LUE when comparing ΔPRI and LUE data collected between 2 years was achieved only in the case of Norway spruce. The most consistent estimation of LUE on a seasonal and interannual scale was provided by the fluorescence detecting ratio $(R_{690} - R_{630})/(R_{690} + R_{630})$.

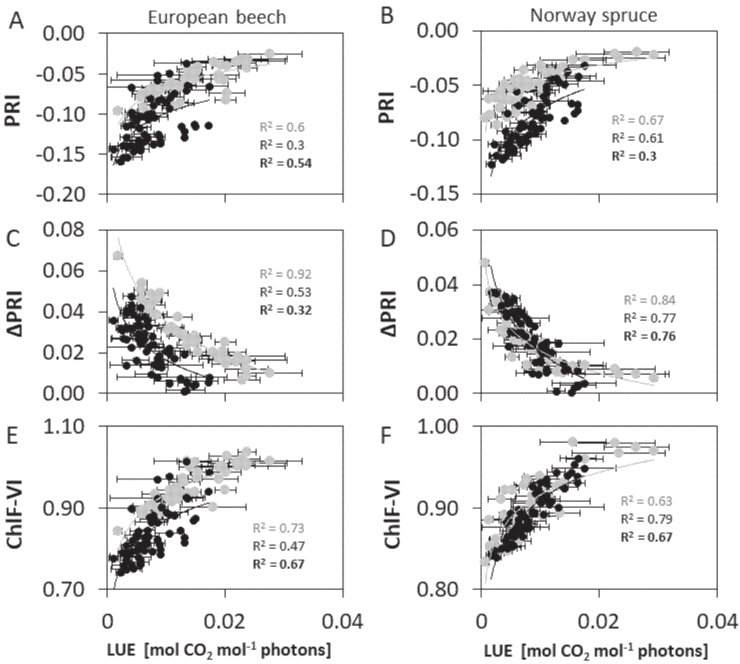

Fig. 1: *Plots showing relationships between LUE and PRI, ΔPRI, and ChlF-VI [ChlF-VI = $(R_{690} - R_{630})/(R_{690} + R_{630})$] measured from beech and spruce canopies separately. Grey and black data points discriminate between measurements during first year in static environment (n = 45, grey points) and second year with more dynamic environment (n = 60, black points). Corresponding coefficients of determination for the established logarithmic relationships between variables are distinguished accordingly. Total R^2 for all 105 pairs of data written in bold font.*

DISCUSSION

Our measurements detected two types of interferences that produce variability in the relationship between PRI and LUE (Fig. 1A,B). The relationship between PRI and LUE deteriorates within season and between years due to acclimatory responses to irradiance and (cold) temperature stress leading to PRI decrease with Chl/Car ratio (Fréchette et al. 2015). Secondly, physiological processes may on the other hand lead to overestimation of LUE from PRI. Such responses include photorespiration or Mehler reaction leading to depletion of energetic carriers (ATP and NADPH) for use in photosynthesis and the xanthophyll cycle, thereby reducing excessive energy in thylakoid membranes (Busch et al. 2009). Similar effects of

decoupling between PRI and LUE have been observed upon recovering photosystem II after stress events (Porcar-Castell et al. 2012) also reducing the demand on thermal energy dissipation via the xanthophyll cycle. Just opposite from the Chl/Car impact on the PRI–LUE relationship, these processes reduce the demand for de-excitation mediated via the xanthophyll cycle and remain undetected by PRI, thereby leading to LUE overestimation from PRI.

We tried to overcome the discussed issues of estimating LUE using PRI by introducing ΔPRI. The correction mechanism de-convoluting PRI from an early morning PRI value helped to improve LUE estimation from PRI readouts (Fig. 1C,D). ΔPRI improves estimation of LUE in both species as a consequence of high sensitivity to daily observed thylakoid ΔpH (Soudani et al. 2014). However, the differences in ΔPRI between seasons at corresponding LUE in European beech suggest sensitivity of ΔPRI to leaf area index (LAI). For Norway spruce we assume similar LAI between seasons with no significant effect on ΔPRI.

A strong relationship between $(R_{690} - R_{630})/(R_{690} + R_{630})$ and LUE (Fig. 1E,F) confirmed the result of a similar study conducted by Dobrowski et al. (2005) measuring canopy reflectance and physiology measures in the environment of phytochambers, thus revealing potential uniqueness of this fluorescence ratio for detecting photosynthetic responses to stress. In this study, $(R_{690} - R_{630})/(R_{690} + R_{630})$ was proven as a parameter resilient to differences in leaf chlorophylls concentrations, as well as to differences in canopy structure when examining LUE changes in the environment with changing temperature and switching light intensities between 300 and 1500 μmol m^{-2} s^{-1}. Responses of fluorescence ratio to photosynthesis changes induced by PAR were overlapping changes in this signal as a consequence of changing chlorophylls concentration.

This study showed the potential for several optical methods to estimate plants' LUE. It will be important to validate further the mechanisms identified here on mature trees and in natural systems, where additional causes of reflectance variation, such as sun angle or canopy structure, are likely to add another level of complexity to the signal detected from canopy reflectance measurements.

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Application of multispectral remote sensing indices for estimating crop yields at field level

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ABSTRACT

Remote sensing can be used for yield estimation prior to harvest and can replace or complement classical ways of estimating crop yields. This study was undertaken in Polkovice, located in the Czech Republic's Haná region. For 2015 and 2016, two data sets of satellite imagery were used: the Moderate Resolution Imaging Spectroradiometer and the Landsat 8. Vegetation indices from satellites were compared with crop yields at the level of land blocks. Winter wheat and spring barley yield data, representing crops planted over the analysed period, were used for the comparison. The results of the index–yield comparison showed that vegetation indices from remote sensing data provide reliable information for yield estimation prior to harvest. Indices are also able to evaluate the spatial variability of a crop within the field. The results showed that remote sensing data need to have detailed spatial resolution in order to provide reasonable information about yield at such a detailed level.

INTRODUCTION

Remote sensing can be useful in the area of drought monitoring, providing valuable spatiotemporal information about yield-limiting moisture conditions and crop response under current climate conditions (Anderson et al. 2015a). Satellite data can provide excellent spatial detail, but no single satellite provides all the information required to adequately support all agricultural applications (Anderson et al. 2015b).

Satellite systems have ability to collect radiances in the visible and near-infrared portions of the electromagnetic spectrum that can be used for vegetation monitoring (Tucker et al. 1980). The red and near-infrared spectral bands are often used together to derive a dimensionless proxy of plant vitality and standing biomass in the form of the normalized difference vegetation index (NDVI). The enhanced vegetation index (EVI) has been demonstrated to be the more sophisticated vegetation index for crop monitoring (Huete et al. 2002).

There exists a variety of modelled biophysical products used for crop monitoring, such as fractional photosynthetically active radiation (FPAR) or the leaf area index (LAI) (Myneni 2012). Another class of remote sensing indicators can be connected with different aspects of the surface moisture, such as evapotranspiration (ET) (Anderson et al. 2007). Clearly, there is a benefit to combining a wide range of information from different satellites to have a full suite of information required for agricultural management down to the field level (Anderson et al. 2015b).

The presented contribution provides a comparison of NDVI and EVI with yields of the crops winter wheat (*Triticum aestivum* L.) and spring barley (*Hordeum vulgare* L.) planted in the study area. These two crops together cover the largest planted area of field crops in the Czech Republic (https://www.czso.cz/csu/czso/areas-under-crops-survey-as-at-31-may-2016). The two crops have different timing as to their growing

seasons (winter *vs.* spring crop), which causes them to have different moisture sensitivity (Hlavinka et al. 2009, Trnka et al. 2012).

The goal of the contribution is to test vegetation indices (VIs) from a Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat 8 to support yield estimation prior to harvest at field level. The contribution also describes the ability of satellite products to evaluate the spatial variability of a crop within the field.

MATERIALS AND METHODS

Yield and satellite data were provided for the study area in Polkovice (49°23'50.05"N, 17°14'52.25"E) that is located in the Czech Republic's Haná region. The study area is divided into two land blocks – Niva (26.08 ha) and Trávník (24.38 ha).

In the study, we focused on yield estimation at field level. For the period 2015–2016, yield data were available for both land blocks, Niva and Trávník. There were two different crops planted in Polkovice over the compared period: winter wheat in 2015 and spring barley in 2016.

For the compared period, remote sensing data were collected from MODIS at a spatial resolution of 250 m and from Landsat 8 at a resolution of 30 m (Fig. 1). Time-series of two VIs were analysed: NDVI and EVI. Index values were compared over the period from 16 April to 22 July. This period was chosen because various studies (e.g. Johnson 2016 or Becker-Reshef et al. 2010) have shown that correlation between cereal crop yields and NDVI values peaked one or two months prior to harvest. Both crops were harvested at the beginning of August.

On any given date, cloud cover may impact the quality of satellite imagery. Composite products are used to overcome this issue by picking up the "best of" pixels over a given period. For the MODIS data, 16-day composites from the Terra satellite were used in the study. The 16-day compositing period was chosen because it was seen as sufficient time to obtain at least one clear sky observation. Johnson (2014) had noticed that an 8-day compositing period was not long enough to assure pixels without noise (caused by cloud cover). The errors appeared more in the early or later periods of the growing season and in more northerly locations (for the Corn Belt region in US).

For MODIS, 9 composites for 2015 and 8 composites for 2016 were used for index–yield comparison. For Landsat 8, 6 scenes for 2015 and 7 scenes for 2016 were used for analysis. Availability of the Landsat 8 scenes depended primarily on the cloudiness of Landsat scenes for the analysed area.

For Landsat 8, the spatial averages of index values over the land blocks were used for the index–yield comparison. Due to the coarser MODIS resolution, the index value of one representative pixel within each land block was selected for the comparison (Fig. 1). ArcGIS (ESRI, USA) was used for the calculation of indices and extraction of average values over land blocks. The NDVI and EVI were compared with yield data (in tons per hectare) for 2015–2016. The comparison was done for both land blocks for the period from 16 April to 22 July. The 4th degree polynomial fit for NDVI and EVI as a function of day of year was used to conduct regression analyses. Subsequently, VIs interpolated in this way were averaged over the entire period and then compared to crop yield.

RESULTS

The index–yield comparison for the period 2015–2016 showed there to be a strong relationship between VIs and yields. Scatter plots with linear regression for 2015–2016 (Fig. 2) provide deeper insight into the index–yield relationships.

The NDVI and EVI from both Landsat 8 and MODIS showed positive relationships with yields for the compared period, even though the index–yield comparison of the EVI from MODIS showed a weak relationship (as seen in Fig. 2). This is caused by two factors. First, the EVI utilizes a blue band. The EVI values might be more problematic due to the more difficult and varying atmospheric correction schemes of the blue band (Fensholt et al. 2016). Secondly, the MODIS data set has a coarser resolution (250 m compared to the 30 m of Landsat 8) that is not fine enough to provide a reasonable analysis at such a detailed (field) level. MODIS data should instead be used for larger areas or larger field blocks.

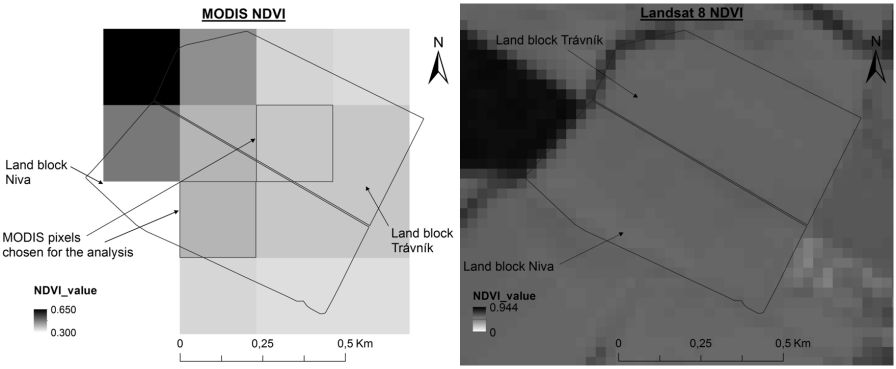

Fig. 1: *Examples of MODIS NDVI from 12 July 2015 (left) and Landsat 8 NDVI from 19 July 2015 (right) of the study area. The image of MODIS NDVI shows MODIS pixels that were used for the index–yield comparison. It is obvious from the resolution of images that there are approximately 70 Landsat pixels within one MODIS pixel.*

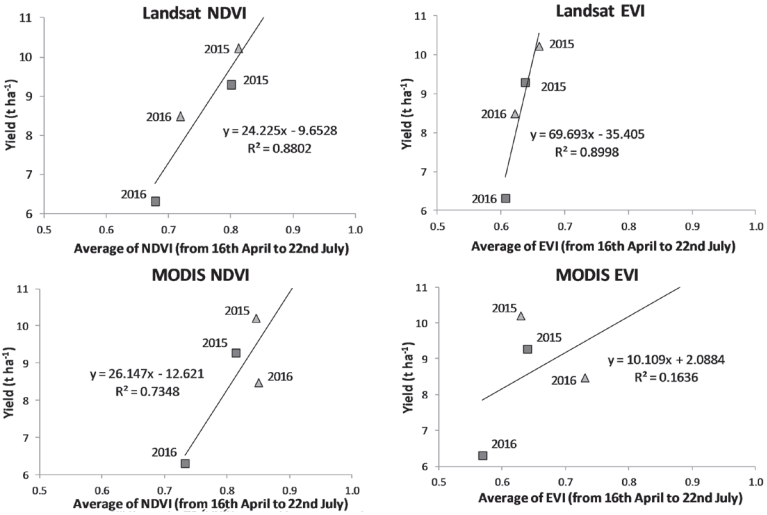

Fig. 2: *Scatter plots of yield vs. NDVI and EVI obtained from Landsat 8 and MODIS (from 16 April to 22 July). Correlations of NDVI and EVI variants to yield are provided for period 2015–2016.*

DISCUSSION

The results of the comparison show that remote sensing data must be of detailed spatial resolution in order to provide reasonable information about yields at field level. For future work, it will be useful to include larger areas or larger field blocks to allow more rigorous evaluation of Landsat and MODIS data for yield estimation. This contribution presented the initial analysis of an ongoing study, and further research is needed to better understand relationships between crop yields and remote sensing products at field level. Future investigation will cover other vegetation indices and remote sensing indicators.

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Towards a combining of remote sensing and in situ evapotranspiration measurements

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ABSTRACT

This study provides preliminary results from combining *in situ* Bowen ratio energy balance (BREB) and evapotranspiration (ET) measurements techniques with physically based remote sensing ET estimates determined by the Atmosphere-Land Exchange Inverse (ALEXI) model. Evapotranspiration measurements and ALEXI estimates were analysed in an agricultural area close to Polkovice, the Czech Republic during 2015, when a drought spell and intensive heatwaves appeared in the country. The BREB system was monitoring a winter wheat (*Triticum aestivum* L.) field (~26 ha) while the ALEXI pixel (~5 km resolution) covered a wide range of crops, including mainly winter wheat, spring barley, and winter rape. The study results showed that, although the applied methods work at different spatial scales (field *vs.* landscape), their combination can provide further insights into ET at both scales. For instance, such approach can be used to identify whether a specific ecosystem investigated *in situ* contributes to cooling or warming of the landscape.

INTRODUCTION

Evapotranspiration (ET) is the key component of the land water balance, wherein water is transported from land surface to atmosphere. It consists of two separate processes whereby water leaves the ecosystem through evaporation or through plant transpiration (Allen et al. 1998). It is estimated that at the global scale, 0.0655 10^6 km^3 of water is transported from terrestrial ecosystems into the atmosphere annually (Oki & Kanae 2006). As the existence and functionality of most terrestrial ecosystems are determined by temporal and spatial characteristics of water balance components, there is a continuing urgent need to develop and test new approaches to quantifying ET water losses. Various methods exist either to measure or to estimate ET on different spatial and temporal scales. *In situ* measurements can provide reliable and detailed information about ET, but upscaling of ET measurements to larger spatial units (e.g. region, continent) is not trivial and can lead to biased ET estimates. Remote sensing (RS) products based on satellite imaging are useful for spatial analysis of ET at much larger scales as compared to *in situ* techniques, yet this ability precludes to focus, in most cases, on one single field. The presented contribution provides an initial analysis of an ongoing study aiming to evaluate the role of specific ecosystems in regional ET and landscape energy balance by combining *in situ* and RS approaches.

MATERIALS AND METHODS

ET estimates were analysed over a 26 ha study field at Polkovice, the Czech Republic (49.395° N, 17.247° E), located at low elevation (ca 200 m a.s.l.). In 2015, the cultivated crop was winter wheat (*Triticum*

aestivum L.), ripening between day of year (DOY) 183 and 197 and harvested at DOY 217. The experimental site was surrounded by a mosaic of agricultural landscape dominated by spring barley, winter wheat, and winter rape fields.

The Atmosphere Land Exchange Inverse (ALEXI) model utilizes the morning land surface temperature (LST) rise in combination with weather forecast reanalysis to determine components of the surface energy balance and ET (Anderson et al. 2011). The global ALEXI product currently in use and testing (Hain & Anderson 2017) uses day/night LST differences from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board the polar orbiting Aqua satellite. A time series for one single pixel (0.05°, i.e. ~5 km resolution) of ET_{ALEXI} was analysed at the Polkovice site area. Climate data from Climate Forecast System Reanalysis and land use classification (both on a global scale) were involved in calculating ET_{ALEXI} estimates.

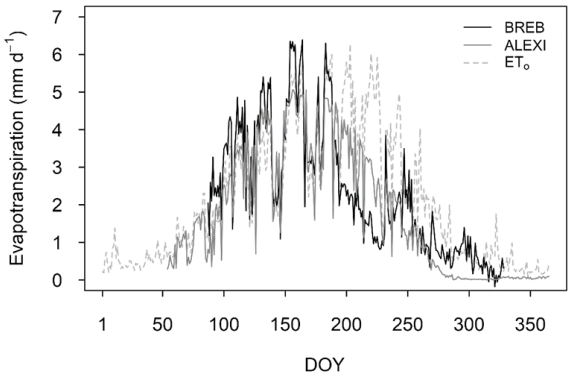

Fig. 1: *Seasonal (2015) course of ET measured by the BREB technique (solid black line) and by the ALEXI land surface model (solid grey line). The reference evapotranspiration (ET_o) is provided for comparison (grey dashed line).*

The Bowen ratio energy balance (BREB) method enables to calculate ET_{BREB} from measurements of surface boundary layer air temperature and humidity gradients and additional measurements of surface radiation balance and soil heat flux. The energy available at the surface–atmosphere interface is converted into two portions: (i) energy used to evaporate water from the surface (latent heat flux, i.e. ET expressed in energy units), and (ii) energy used to heat the atmosphere (sensible heat flux). The ratio between these two, the Bowen ratio, can be approximated from the measurements of air temperature and humidity profiles. The temperature and humidity gradients were measured at three levels (3.5 m, 2 m, and 0.5 m aboveground) by combined EMS 33 R sensors placed in AL 070/1 radiation shields (EMS, the Czech Republic). Radiation balance was measured using an NR01 net radiometer (Kipp & Zonen, the Netherlands) 3.5 m aboveground and two HFP01 soil heat flux plates (Hukseflux Thermal Sensors, the Netherlands) placed 5 cm below the ground's surface. Measurements were taken each 20 s and stored as 10 min averages. Raw flux data were subjected to quality control filtering according to Guo et al. (2007). Gaps in the flux data were filled using the look-up tables algorithm implemented in the R package REddyProc (Falge et al. 2001). The meteorological measurements from the BREB system were additionally used for computation of the reference evapotranspiration ET_o following the standard methodology (Allen et al. 1998).

RESULTS

Mean annual temperature for 2015 was 10.7°C, annual precipitation 446 mm, and annual ET_o 742 mm. This data implies that 2015 was warmer and drier than the long-term mean (1961–1990), characterized by mean annual temperature of 8.7°C, mean annual precipitation 556 mm, and mean annual ET_o 662 mm. Both ET_{BREB} and ET_{ALEXI} responded strongly to the evaporative demand of the atmosphere expressed as ET_o and reached maxima of ca 6 mm day^{-1} during hot summer days. In the first half of 2015, ET_{BREB} overestimated ET_{ALEXI} and ET_o while it significantly decreased around DOY 190 and remained low until a cold front entered the Czech Republic during DOY 229–231, bringing 65 mm of precipitation to the Polkovice site (Fig. 1). The seasonal pattern of ET_{BREB} was closely related to phenology and physiological activity of winter wheat characterized by a decline of photosynthetic activity and transpiration and hence a decline of ET at the transition of heading and ripening phases. The contrasting winter wheat physiological activity is also illustrated in Fig. 2, showing the normalized difference vegetation index (NDVI, based on polar orbiting satellite Landsat 8) of 0.94 and 0.26 at DOY 126 and 216, respectively. ET_{ALEXI} was in most cases lower than ET_o and the differences between these two rates were more pronounced during the second half of the growing season (Fig. 1). The physiological activity of all the fields integrated across the entire ALEXI pixel can again be inferred from Fig. 2, with mean NDVI of 0.75 and 0.40 at DOY 126 and 216, respectively. In addition, it is obvious that the wheat field with the BREB tower showed higher NDVI than the ALEXI averaged pixel at DOY 126 while it showed lower NDVI than the ALEXI averaged pixel at DOY 216. This is in line with ET_{BREB} exceeding ET_{ALEXI} during the first half of the season and ET_{BREB} being below ET_{ALEXI} in the second half of the season (Fig. 1).

DISCUSSION

The presented study combines *in situ* ET measurements technique with physically based remote sensing ET estimates. Although the applied methods work at different spatial scales (field *vs.* landscape), their combination can provide further insights into ET at both scales. For instance, using this approach, it can be identified whether the specific ecosystem investigated *in situ* contributes to cooling or warming of the landscape. The ET_{BREB} exceeding ET_{ALEXI} in the first part of the season thus suggests that winter wheat had higher ET than the average of all nearby ecosystems and therefore contributed to cooling and increasing the landscape's relative humidity. During the second part of the season, however, ET_{BREB} was lower than ET_{ALEXI}, indicating that the winter wheat field contributed to heating and to decreasing the landscape's relative humidity. As supported by the analysis of annual precipitation and ET_o and shown in other studies (Trnka et al. 2016), the year 2015 was characterized by a drought spell and intensive heatwaves which struck the country in the second half of summer. In this context, the analysis initiated in this study might provide information useful for designing a land-use less sensitive to drought stress and a landscape that would mitigate the effects of heatwaves. The presented study is not intended to be comparison of the methods, but rather their fusion. In previous studies, the BREB method was validated by eddy covariance and scintillometry at the Polkovice site (Pozníková 2016) while the ALEXI approach was, for example, validated by Yang et al. (2017). Future work will include similar analysis at flux-tower sites across the Czech Republic, and the validation of ALEXI will be facilitated using its disaggregated form (DisALEXI) and application of water balance models at the Polkovice site.

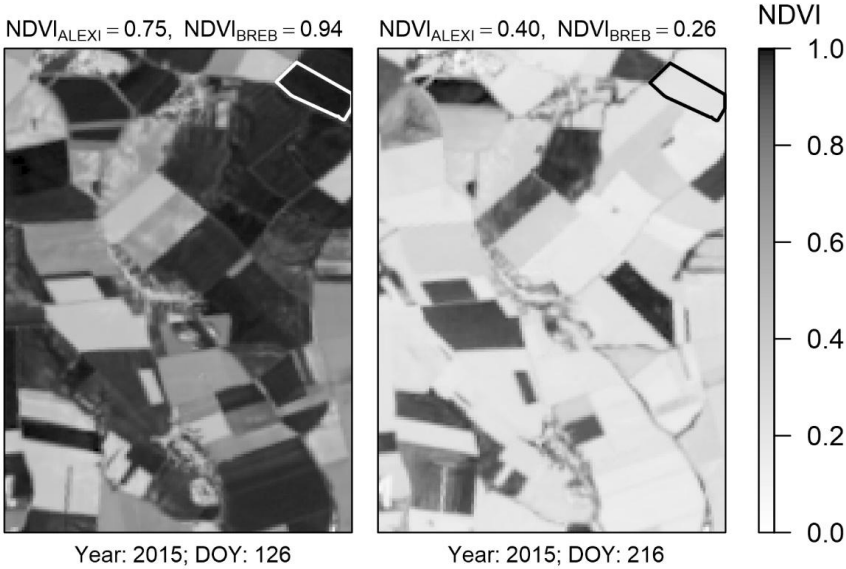

Fig. 2: *Landsat 8 based NDVI at single ALEXI pixel (0.05° resolution) during two days in 2015. The field with BREB measurement is indicated by white and black borders for DOY 126 and 216, respectively (upper right corner). The mean NDVI of the entire ALEXI pixel and of the marked field is summarized at the top of each panel.*

ACKNOWLEDGEMENT

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Large-scale assessment of changes in Europe during a 33-year period using GIMMS NDVI and E-OBS gridded climatic data sets

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ABSTRACT

This study demonstrates possibilities for assessing spatio-temporal responses in the vegetation activity of Europe during the past 33 years and climate-driven impacts. It integrates global-scale satellite data and terrestrial daily climate gridded data sets. The results provide evidence for a warming-induced geographic pattern in the seasonal normalized difference vegetation index (NDVI) trends across Europe and, in addition, evidence regarding the impact of climate change across forest areas in Central and South-eastern Europe, in particular. The applicability of global chronological data for understanding climate–vegetation processes and dynamics at regional scale is presented. The results provide insight into the complex relationship of seasonal vegetation activity (NDVI), temperature, and precipitation for the forest areas of Central and South-eastern Europe. In general, an increase of temperature in winter and spring affect the positive rise of vegetation activity but an increase of temperature in summer and autumn triggers reduction in vegetation growth. On the other hand, no clear relationship of an impact of precipitation on seasonal NDVI was observed other than some evidence of a boost to vegetation due to excessive rainfall in summer.

INTRODUCTION

More than three decades of continuous application of AVHRR (advanced very high resolution radiometer) sensors to measure NDVI (normalized difference vegetation index) data provides a reliable data set about changes in vegetation dynamics anywhere in the world (Sobrino & Julien 2011). NDVI data from different AVHRR sensors are revised and assembled in the framework of the Global Inventory Monitoring and Modelling System (GIMMS; Pinzon & Tucker 2014). These data are freely available as bimonthly NDVI series at an 8 km pixel resolution for 33 years, from July 1981 to December 2015. The specific goals of this research were to (i) assess the rate of change per season (winter, spring, summer, and autumn) of GIMMS NDVI and climate data across Europe using pixel-based raster analysis of the gridded data; and (ii) detect seasonal changes in GIMMS NDVI due to the changing climatic condition at regional scale using only predetermined forest areas in Central, Eastern, and South-eastern Europe.

MATERIALS AND METHODS

The GIMMS data in version NDVI3g.v1, the latest synthesized product of the NOA AVHRR mission, are freely available as a set of semi-annual NetCDF files at ecocast.arc.nasa.gov. ECA&D (European Climate Assessment and Dataset) E-OBS data files (Haylock et al. 2008) contain daily 25 × 25 km gridded data for five elements: daily mean, minimum and maximum temperature, daily precipitation sum,

and daily averaged sea level pressure. The data files are available for download from the www.ecad.eu site in the NetCDF format.

The processing and graphical presentation of data were carried out using existing packages in the R (www.r-project.org) programming and statistical framework: ncdf4, rgdal, raster, sp, maptools, rts, and in particular the R "gimms" package for direct download, rasterization, rearrangement, and monthly aggregation of GIMMS NDVI data sets. Pixel-wise raster analysis of seasonal climate and NDVI data sets required aggregation of 804 bimonthly GIMMS rasters into the seasonal (winter – DJF, spring – MAM, summer – JJA, autumn – SON) NDVI averages and construction of stacks/bricks with 33 seasonal raster layers. A similar seasonal aggregation was conducted with E-OBS daily grids. The pixel-wise Mann–Kendall trend test contained in the "gimms" package was conducted on raster composites of NDVI and climatic data for each season. The first step in the regional assessment was to create a forest mask file based on Corine Land Cover 2012 forest categories for countries of Central and South-eastern Europe. Only 8 × 8 polygons containing more than 50% of forest cover – 6202 in total – were extracted for further processing.

RESULTS

The results of the pixel-based raster trend analysis over Europe (Fig. 1) showed the presence of a geographic spatial pattern of NDVI changes in particular during winter. This pattern was somewhat less evident in summer and autumn and practically absent in spring. In general, most pixels manifested increasing vegetation activity during the 33 years of observation. An increase in NDVI was evident mostly in the continental part of Europe, as well as in the Mediterranean, North Africa, and the northern forested areas of Russia. Distinctive negative NDVI trends were present during summer and autumn in the Pannonian Basin and in the steppe areas of Ukraine and Russia, and particularly so during the winter period in areas of south Ukraine and Russia. The spring season was characterized by relatively random occurrence of changes without distinguishable spatial structure in relation to other seasons. Maps also showed a decrease in vegetation activity during the summer period in the vicinity of some large urban areas.

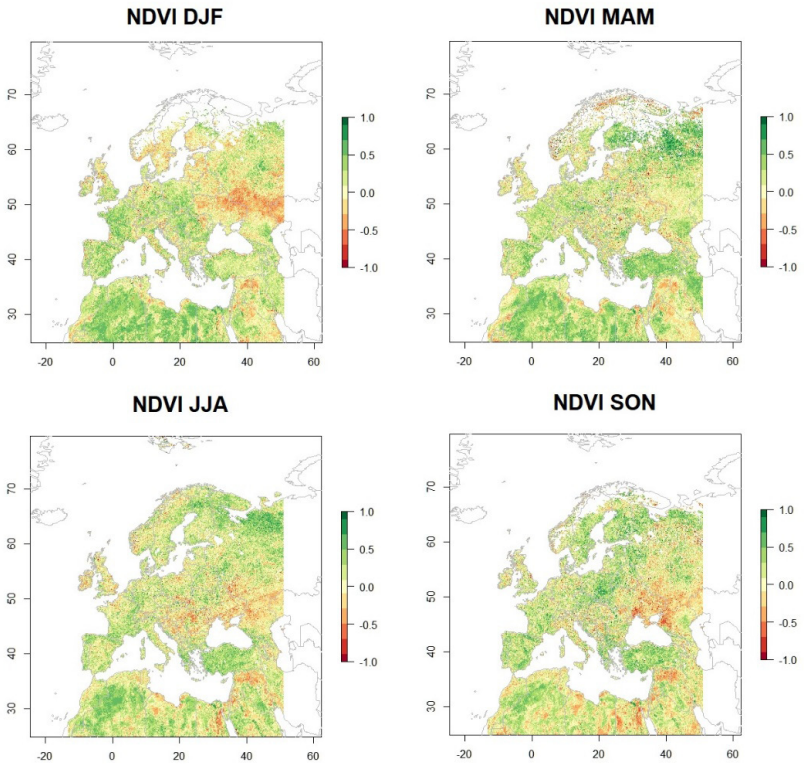

Fig. 1: *Pixel-wise, 33-year trends in normalized difference vegetation index (NDVI) for winter (DJF), spring (MAM), summer (JJA), and autumn (SON).*

Analysis of the seasonal mean temperature trends from the E-OBS data set (European high-resolution gridded data set of daily climate) showed that temperature changes were most prominent in the summer and autumn season and significantly less noticeable during winter and spring (Fig. 2). Areas of Central, Eastern, and South-eastern Europe were significantly affected by changes in temperature from 1981 to 2015 during summer and autumn. Evidence of changes in the seasonal amounts of precipitation has not yet been confirmed, and there were only small random patches of grids that show significant trends. Regional analysis of the relationship between NDVI and climate at the selected 6202 forest locations in Central and South-eastern Europe (Fig 3) provide more detailed evidence of seasonal climate–vegetation interactions. There is an obvious pattern of increase in NDVI due to the rise in temperatures (Fig. 4) during winter and spring and, on the contrary, a reduction in NDVI due to increased temperatures in summer and autumn. Meanwhile, precipitation data (Fig. 5) showed a much weaker relationship with NDVI than did temperature, the only exception being the summer period, when excessive amounts of rainfall can stimulate extended vegetation activity and forest growth.

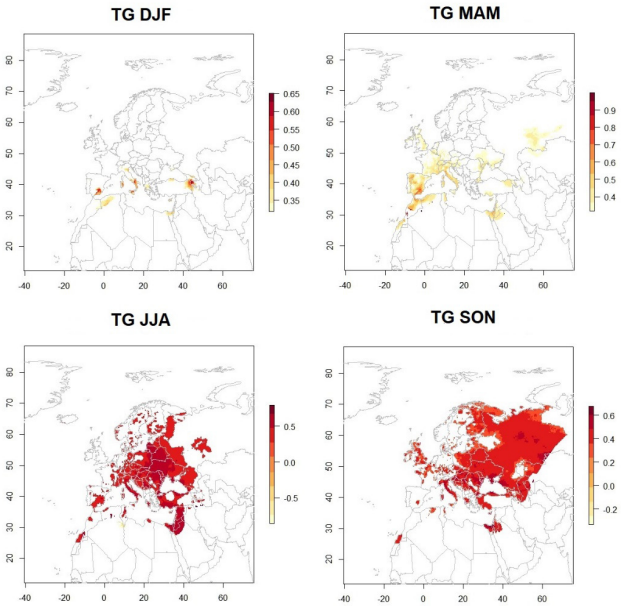

Fig. 2: *Significant pixel-wise trends (1981–2015) of mean temperature (TG) for winter (DJF), spring (MAM), summer (JJA), and autumn (SON) season in ºC from the E-OBS data set.*

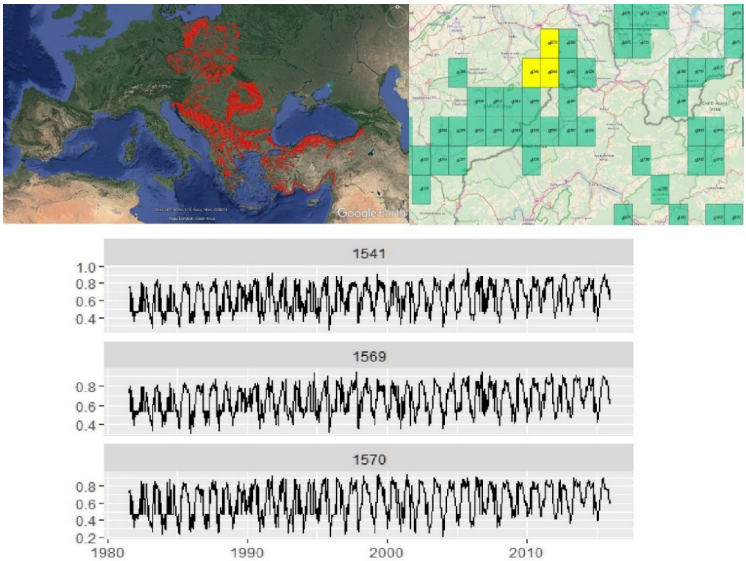

Fig. 3: *Selected forest areas (>50% forest cover) of Central and South-eastern Europe included into the assessment (top left). Examples of bimonthly GIMMS NDVI from 33-year time series (bottom), for three tiles in Beskids, Czech Republic (top right).*

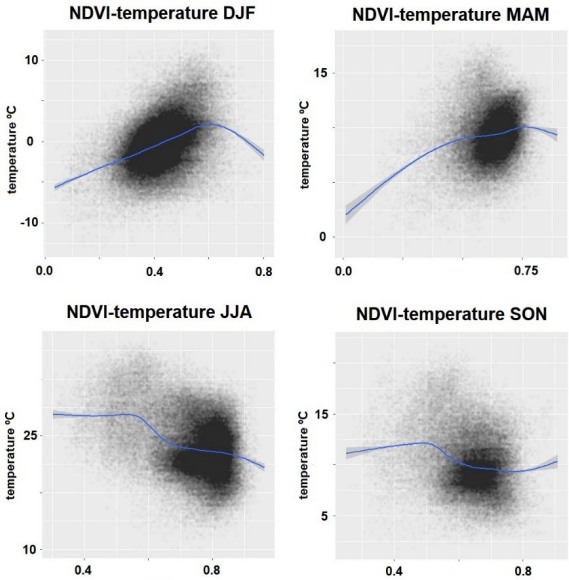

Fig. 4: *Relationship of NDVI (horizontal axis) and mean seasonal temperature in ºC (vertical axis) in winter (DJF), spring (MAM), summer (JJA), and autumn (SON) season at forest locations in Central and South-eastern Europe.*

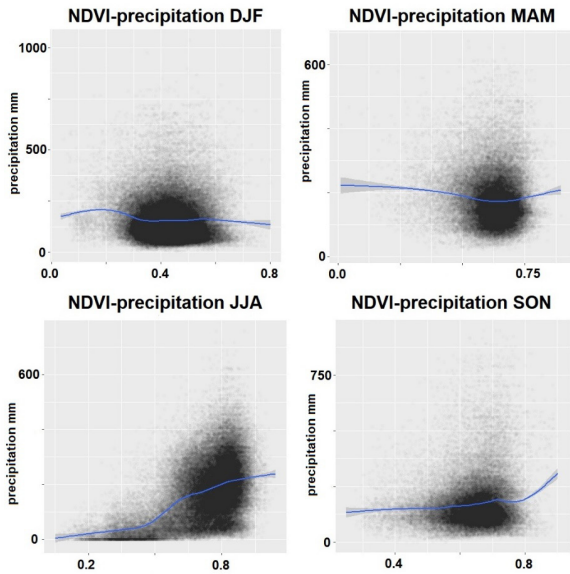

Fig. 5: *Relationship of NDVI (horizontal axis) and total seasonal precipitation in mm (vertical axis) in winter (DJF), spring (MAM), summer (JJA), and autumn (SON) season at forest locations in Central and South-eastern Europe.*

DISCUSSION

The results of the seasonal GIMMS NDVI assessment showed a dominantly positive vegetation trend over Europe during the observed 33-year period. In the Mediterranean area, where the effect of global warming is expected to be most prominent in Europe, an unexpected increase in the NDVI trend was observed. An increase in the vegetation trend was also prevalent across most of North Africa, as also confirmed by the NOA AVHRR study (Olsson et al. 2005). Negative trends were more pronounced in the summer and autumn seasons, particularly in Central, Eastern, and South-eastern Europe. The results show these regions can be characterized also as warming significantly more than other parts of Europe, in particular during the summer and autumn seasons. This provides a possible explanation for the spatial synchrony between a reduction of vegetation activity and the higher temperatures. It is also evident, however, that decreasing NDVI was primarily observed in areas without forest cover, such as the Pannonian Basin and the dry steppe areas of southern Ukraine and Russia. This suggests that increased summer warming most probably caused desiccation of grasslands, a reduction in soil moisture, and earlier cessation of vegetation activity. Desiccation was less evident in the spring season due to lower temperatures and the availability of water in soils after the winter season, and, therefore, no negative NDVI trends prevailed. By contrast, noticeably large areas in Ukraine, Russia, and the Scandinavian Peninsula showed a reduction in vegetation activity during the winter season which cannot be explained by climatic processes at this stage. GIMMS NDVI also disclosed a reduction of vegetation activity around urban agglomerations due to the possible effects of air pollution or urban development (heat islands and soil sealing).

A regional study of climate–vegetation interactions in forest areas of Central and South-eastern Europe showed that a winter and spring temperature rise has, in general, a beneficiary effect on forests due to the possible displacement of harsh mountainous climatic limitations and a prolongation of the growing season's length. It is also evident that with the increase of temperatures in summer and autumn vegetation activity ceased in general. Therefore, the effect of global warming on forests in these regions of Europe can be explained by two, commonly opposing drivers of forest growth: (1) a positive effect from prolongation of vegetation activity in spring along with a reduction of winter climatic limitations, and (2) the effect of cessation of activity during summer and autumn most probably related to deficiency of soil moisture. Nevertheless, the local environmental conditions where there are sufficiently deep soils and with less intense summer warming can possibly mitigate this effect of summer dryness that results in continuous growth intensification during the observed period. Such effect of a recent 'vegetation boost' has been observed at various locations in Europe, such as at common beech sites on the Balkan Peninsula (Tegel et al. 2014).

ACKNOWLEDGEMENT

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Intellectual information platform for thematic services creation with integrated use of ERS and in-situ data

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ABSTRACT

This article describes an intellectual information platform aimed at implementing interdisciplinary projects and providing services in the field of monitoring and analysing natural-technological objects. This platform is based on a service-oriented architecture and arranges combined and coordinated operation of diverse data processing modules where particular thematic issues are solved. The platform assures maximum automation in monitoring, analysing, and forecasting processes in agriculture, forestry, and other areas where thematic integrated processing of Earth remote sensing (ERS) and in-situ data are needed.

INTRODUCTION

Earth remote sensing (ERS) data are becoming more popular for monitoring natural and natural-technological objects and systems (NNTOs), including agriculture, forestry, and other subject areas. Further prospects for their active use are associated with moving from relatively simple monitoring tasks to forecasting NNTOs' status under anthropogenic impact and climate changes, proactive management of NNTOs, and decision-making support for this management under normal and emergency conditions.

Today, there are multiple sources of remote sensing data available at different levels of processing. Moreover, there are many affordable internet-services for monitoring NNTOs using ERS data, such as:

Copernicus Land Monitoring Service (http://copernicus.eu/main/land-monitoring),

Forestry Thematic Exploitation Platform (https://forestry-tep.eo.esa.int/), and

Basemap (https://www.digitalglobe.com/products/digitalglobe-basemap).

At the same time, there is a lack of applications and decision-making support services that could be adapted for a user who does not have special skills in information technologies and ERS data processing. This gap presents a significant obstacle to wider usage of accumulated and steadily growing volumes of ERS data.

MATERIAL AND METHODS

To solve the aforementioned problem, information systems of a new level are required. These systems need to be aimed at the integration of ERS and other ancillary data (both spatial and non-spatial) with models of NNTOs' status forecasting and proactive management in automatic mode. This means that information systems under creation should focus on the operational coordination of a considerable number of modules that perform various functions in accumulating and processing diverse (ground-based and remote) data, NNTOs' status forecasting, and decision-making support for their management. Moreover, the models' choice and adjustment of their parameters must as well be carried out automatically. In addition, all these processes are to be "hidden" from the end-users, who, as a rule, do not have expertise in the sphere of information technologies and are willing to interact with a simple and convenient interface.

The modular framework of the prospective information systems is the most advanced in the context of creating integrated software-based and simulation complexes, especially when developing these within international programmes and projects. That is because, in this context, autonomous designing and functioning of the independent modules are provided by various institutions on the territories of different countries. Moreover, if such an information system structure is used, there is no need for transition of designed modules to the information resources of a particular institution because the possibilities to use cloud technologies have become affordable.

With regard to creating the distributed software architecture, the advanced decisions are as follows:

- development of the components to build information systems fully controlled by a single institution (Bell 2016); and
- development of the components that allow uniting independent program engineers and combining diverse software, including software based on service-oriented architecture (SOA) (Siddiqui & Tyagi 2016).

SOA implements an essentially modular approach to software design that is based on the use of distributed, loosely bound, replaceable components having standardized interfaces for interaction according to standardized protocols (Paik et al. 2017). In addition, each module is implemented as a web service and can be created with the help of any programing language in any environment.

The potential advantages of SOA determine its choice as a basic construct for creating the suggested intellectual information platform (IIP). The general architecture of the developed IIP is given in Fig. 1. The abbreviations REST API, SOAP, JSON, and CSW denote standard protocols specifications for the components interaction and exchanging structured information in the implementation of web services within computer networks.

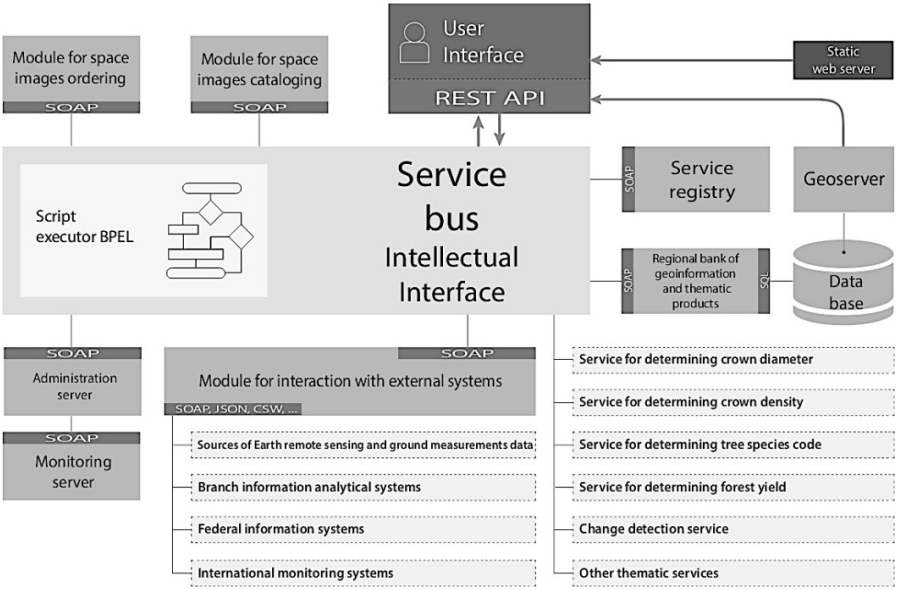

Fig. 1: *General architecture of intellectual information platform (IIP).*

The main components of this platform are as follows: a service bus as a "backbone" of the platform framework; software modules for thematic data processing and decision-making support that are performed as web services; business process execution language (BPEL) tools for forming components interaction scenarios; and an intellectual interface for choosing necessary models and adjusting their parameters.

Also, in the structure there are modules performing ordering of ERS data and their cataloguing in automatic mode; program interfaces providing interconnection of diverse ERS and ancillary data sources, and other supportive components.

Further, the brief characteristics of the key components of IIP are described. *The service bus* ensures an event-oriented approach implemented into the distributed information systems (He & Xu 2014). In so doing, independent functioning of diverse modules is provided and there is no need for resetting the system when connecting a new module.

To arrange general computing processes and automated control of the set of services, an approach based on "web services orchestration" is used (Wang et al. 2016). In the IIP, services orchestration is implemented according to *Business Process Execution Language (WS-BPEL)* (Kuo et al. 2016). The application of this language allows for arranging the logic of the interaction between modules and web services when solving a specific problem, including the use of a visual editor. So doing provides visual construction of algorithms for work utilizing various data sources and services.

A theoretical foundation for creating the *Intellectual Interface* is provided by methods of information fusion models qualimetry developed in recent years at Saint Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences (SPIIRAS) (Sokolov et al. 2014b, Zelentsov et al. 2016). Now this theoretical basis enables embodying the intellectual multi-criteria choice of models and setting their parameters without operator intervention.

A significant part of the IIP components (Intellectual Interface, modules performing ordering of ERS data and their cataloguing) was developed for the first time, and the joint use of all described components (including service bus, BPEL, etc.) is also original.

RESULTS

The suggested platform enables using and integrating data from different Earth observation satellites, including Sentinel series, Russian Resurs-P satellites, and others, as well as production and provision of new information services in different modes – from interactive, through automated, to fully automatic mode. Successful case studies have been conducted to confirm the possibility of creating services on the basis of the IIP for monitoring agricultural lands, forest management, detecting changes in forests' states, environmental protection, flood forecasting, etc. (http://litsam.ru/index.php/en/homepage-en/, Sokolov et al. 2014a).

Currently, the contents of the thematic services under formation include more than 20 items. For instance, in Fig. 2 there is presented an example of a user interface when solving the problems of revealing changes in wetlands boundaries within the territory of a forest area.

It is noteworthy that while solving these problems distributed infrastructure was created that had data processing modules on the territories of various institutions. Meanwhile, the system appears as an integrated whole at the user's end.

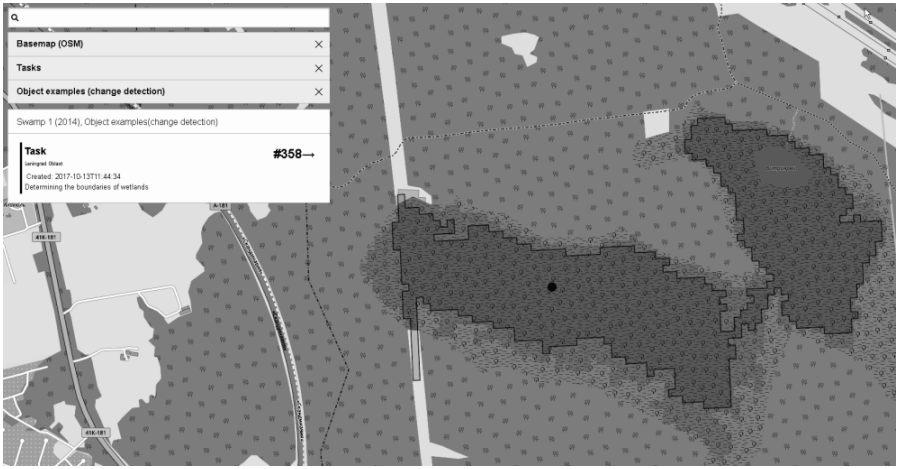

Fig. 2: *User interface of intellectual information platform (IIP).*

DISCUSSION

In conducting an analysis of existing and advanced technologies of distributed information resources integration when solving the problems of monitoring and analysing NNTOs, it became apparent that there is a feasible reason to use service- and event-oriented architectures in combination with technologies of platform-independent universal description, automatic search, and web service integration as a basic approach to IIP creation. When taken separately each of the technologies considered has its familiar implementations but their integrated usage is introduced and described for the first time. The examples given and testing results show that this application approach ensures full implementation of the necessary IIP functionality. In addition, the requirements are met to maximize automation of diverse modules' integrated operation. Also, SOA implementation permits creating a cross-platform user interface to allow utilizing all advantages of the IIP through remote mobile access. In general, the developed platform is a universal constructor or software suite that allows producing services and downstream applications in different fields of practice. Further research should relate to determining the most effective applications for the developed platform.

ACKNOWLEDGEMENT

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Forest regeneration within the treeline ecotone in the Giant Mountains under climate change

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ABSTRACT

Natural regeneration of mountain spruce forests began in the Giant Mountains 25 years ago after a reduction of severe and long-enduring air pollution. This process has been influenced by climatic change. The aim of our contribution was to present background data for the potential elevational shift of spruce regeneration under conditions of climate change. These upslope shifts may also depend on constraints such as climate extremes, unfavourable soil conditions, absence of ectomycorrhizal symbionts, and lack of microsites suitable for seedlings. Since 2014, we have studied the main driving factors affecting Norway spruce regeneration, and in particular soil conditions, ectomycorrhizal symbionts, ground vegetation cover, and forest health, in six transects across the treeline ecotone located on a NW-to-NE transect through the Giant Mountains. Microclimatic measurements showed that the mean difference in growing season temperature between the montane spruce forests and forests at the treeline was −0.54°C. The model HADGEM2 predicted that in 20 years the temperature at the treeline will be similar to the current one at montane elevations. The difference in prevailing soil types between the montane spruce forests and forests at the current treeline (i.e. podzol *vs*. ranker type) could be an important factor limiting success of the upslope spreading of spruce. Furthermore, areas covered by microsites favourable for natural spruce regeneration, especially spruce litter patches, decaying wood, mosses, and *Avenella flexuosa* stands, were shown to decrease with increasing elevation. It is likely that spruce will move upslope in response to climate change, but the process is likely to be slow or even blocked for some periods, especially by unfavourable soil conditions and climatic extremes.

INTRODUCTION

The synergistic effect of severe air pollution (especially SO_2), climatic stress, and infestation of weakened forests by spruce bark beetle (Vacek et al. 2013) led to extensive decline and dieback of Norway spruce forest ecosystems in the Giant Mountains during the 1970s and 1980s (Kooijman et al. 2000). The decline of spruce stands was accompanied by extensive changes in the forest understory. In damaged forest stands, grasses (especially *Avenella flexuosa* and *Calamagrostis villosa*) prevailed over other microhabitats more suitable for spruce seedlings' emergence and survival, such as litter patches, mosses, or *Vaccinium myrtillus* stands (Chumanová-Vávrová et al. 2015). These changes resulted in deteriorated conditions for spruce regeneration (Vacek & Matějka 1999). In the first half of the 1990s, air pollution began to decrease as a result of desulphurization of power stations and since that time forests have started to regenerate their ecosystem functions (Vacek et al. 2013). The natural regeneration has been influenced also by climatic change. The season mean temperature for the period 1991–2015 increased by 0.7°C compared to the period 1961–1990, and the treeline shifted upwards by 0.43 m per year in the Giant Mountains during the past

70 years (Cudlín et al. 2017). Climatic conditions seem to be favourable for an upslope treeline shift in the coming decades, although many constraints such as different geomorphological, geological, and pedological conditions, soil heterogeneity (Fridley et al. 2011), and extreme climatic conditions can constrain such a shift. In that context, we are asking several questions. These include what are the likely effects of temperature and precipitation, the co-influence of soils, the abundance of suitable microsites, and the density of spruce seedlings and saplings across the ecotone. Finally, we ask whether there is sufficient natural regeneration in montane spruce forests under current climatic conditions.

MATERIALS AND METHODS

Since 2014, we have studied the main factors driving Norway spruce regeneration under conditions of climate change. Most measurements were performed in 24 circular sample plots, each of 500 m^2, regularly placed in six transects across the treeline ecotone, situated in three sites from the West to East Giant Mountains (Alžbětinka, Modrý důl, and Pašerácký chodníček). Each transect consisted of four plots from 1210 to 1390 m a.s.l. (P4 – mountain spruce forest, P3 – spruce forest under treeline, P2 – spruce forest under treeline with dwarf pine, P1 – forest at treeline, i.e. dwarf pine stand with scattered spruce trees). Soil surveys were done only at three transects (i.e. on one transect at each site). Furthermore, we installed three microclimatological stations in the natural spruce forest stands at the beginning of June 2016 and another three stations in the forests at treeline at the beginning of June 2017. The stations were equipped with instruments for measuring precipitation, temperature, and air humidity at 0.3 m and 2 m, temperature in three soil horizons, photosynthetically active radiation, and direction and velocity of wind.

Three regional CORDEX models with RCP 4.5 and RCP 8.5 were tested for predictions of changes in temperature and precipitation. Finally, a regional model MOHC-HADGEM2-ES - RCA4 with RCP 8.5 was applied. Detailed soil survey was done using soil core (14 mm in diameter) on a 1 × 1 m grid. Soil types and subtypes were classified, detailed soil maps of the plots created, and chemical analyses of pH, total C and N content performed. Occurrence of ectomycorrhizal (ECM) fungi was evaluated by occurrence of fruit bodies, identification of ECM fungi on root tips using polymerase chain reaction, and occurrence of ECM fungi in soil analysed by next generation sequencing (Vašutová et al. 2016). Emergence and survival of spruce seedlings, ground vegetation cover, as well as favourableness of microsites for spruce regeneration have been studied in mountain spruce forests at our sites since 1994. In 2015, phytocoenological relevés were recorded and dead wood was measured and localized using Field-Map tools in all 24 plots on transects.

The survey of spruce regeneration (including occurrence of seedlings in microsites) was performed in all plots in September 2015. Survival curves for spruce seedlings were calculated based on the results of yearly surveys of spruce regeneration done in the mountain spruce forests since 1994 and the amount of seedlings that could potentially survive at our sites to the age of mature forest stands was estimated. The relationships between spruce regeneration and other characteristics of the plots were analysed using principal component analyses (PCA) with added passive variables (Canoco for Windows; Šmilauer & Lepš 2014).

RESULTS

Montane spruce forests were compared with forests at treeline concerning the present state of spruce regeneration as well as related environmental conditions to evaluate the probability of Norway spruce's upward shift in the Giant Mountains. Based on our results, we answered the following questions:

1. *How do the mountain spruce forests and forests at treeline differ in ground temperature and precipitation under current conditions?*
   The mean difference (for our three sites Alžbětinka, Modrý důl, Pašerácký chodníček) between the mountain spruce forests and forests at the treeline was –0.54°C (ranging between –0.02 and –0.9°C) and 134 mm (range from –12 to 289 mm).

2. *How many years will the temperature in forests at treeline need to rise according to the climatic model to reach the value currently measured in mountain spruce forests?*
   According to the model MOHC-HADGEM2-ES - RCA4 with RCP 8.5 it will take 20 years.

3. *Are there any other constraints on the spruce regeneration above the treeline?*
   The differences in prevailing soil types between mountain spruce forests and forests at treeline could be a serious constraint for the shift of spruce seedlings. Rankers predominantly occurring in the forests at the treeline provide less favourable growth conditions for spruce seedlings in comparison with podzols prevailing in mountain forests. Occurrence of ectomycorrhizal symbionts seems to be sufficient for forests regeneration above the treeline.

4. *How do the density of spruce seedlings and abundance of favourable microsites change along the elevational gradient?*
   The highest recruitment density was found in montane spruce forests and the quantity of spruce seedlings decreased along transects towards the highest-elevation positions reflecting the diminishing canopy cover and height of living mature spruce trees (Fig. 1). The number of seedlings (height up to 1 m) was positively correlated with the cover values of spruce litter patches and decaying wood while higher individuals (height from 1 to 2 m) occurred predominantly in plots with high cover of *A. flexuosa*. The abundance of microsites favourable for emergence and survival of spruce seedlings, such as *A. flexuosa* stands, spruce litter patches, and decaying wood and mosses, decreased with increasing elevation, while the cover values of *C. villosa* and *V. myrtillus* stands responded in the opposite way to the elevational gradient.

5. *Is the current state of spruce regeneration in mountain spruce forests sufficient for their spontaneous regeneration?*
   It depends on the site. Natural regeneration was found sufficient for spontaneous regeneration of Norway spruce stand at the Modrý důl site but completely insufficient at the Alžbětinka site. The state of spruce regeneration at the Pašerácký chodníček site was intermediate.

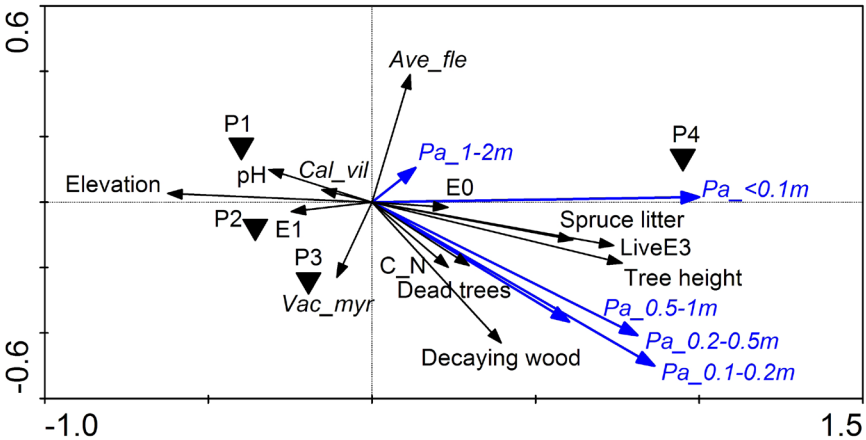

Fig. 1: *Variability in seedling and sapling numbers density (divided into five height categories: <10 cm, 10–20 cm, 20–50 cm, 50–100 cm, 100–200 cm) assessed by principal component analyses (PCA) and its relationship to site and stand characteristics of the plots, including abundance of the most important microsites passively projected in the analysis. Number of individuals in height categories Pa < 0.1 m, 0.1–0.2 m, 0.2–0.5 m, 0.5–1.0 m, and 1.0-2.0 m; positions at the treeline ecotone transects (P4 – mountain spruce forest, P3 – spruce forest under treeline, P2 – spruce forest under tree line with dwarf pine, P1 – forest at treeline, i.e. dwarf pine stand with scattered spruce trees); Elevation (m a.s.l.); pH (soil pH); C_N (carbon-to-nitrogen ratio of the soil); Tree height (average height of live spruce trees in meters); Dead trees (ratio of dead spruce tree number from all spruce trees in %), LiveE3 (crown cover of live spruce trees in %); Spruce litter (cover of spruce litter patches in %); Decaying wood (cover of decaying wood in m²); E0 (cover of moss layer in %); E1 (cover of herb layer in %), Ave_fle, Cal_vil, Vac_myr (cover values of the ground vegetation dominants in %, i.e. Ave_fle – Avenella flexuosa, Cal_vil – Calamagrostis villosa, Vac_myr – Vaccinium myrtillus).*

DISCUSSION

Growing season temperature is presumed to be the main limiting factor for an upward shift in treeline position in mountains (Körner & Paulsen 2004). Although the growing season temperature in the forests at treeline will probably reach the value currently measured in the montane spruce forests in the Giant Mountains in the next 20 years (according to climatic models), it is unlikely that spruce will spread above the current position of the treeline due to adverse geomorphological and pedological conditions at higher elevation (Holtmeier 2009). The transformation of rankers, the prevailing soil type above the treeline, into podzols by the process of production and decomposition of tree litter will necessarily take a long time. Surprisingly, despite the lower abundance and diversity of ectomycorrhizal symbionts of spruce in forests at the treeline compared to montane spruce forests, their current state seems nevertheless to be sufficient for spruce regeneration in forests at the treeline in the Giant Mountains (Vašutová et al. 2016). The cover values of the most suitable microsites decreased with increasing elevation of our transects in the Giant Mountains. Only *V. myrtillus*, the suitable microsite for spruce regeneration according to Vacek (1981) and Vávrová et al. (2007), showed the opposite trend. However, we observed only few seedlings in this microsite in our plots. Furthermore, our results suggest the importance of the abundance and height of mature spruce trees for the occurrence of spruce seedlings and saplings, as was reported by Matthew et al.

(2002) for the alpine treeline ecotone. There may be an upslope shift of Norway spruce seedlings within the treeline ecotone in the Giant Mountains, but the process will be slow and for some periods even blocked, mainly by the unfavourable soil conditions and by climatic extremes. We expect new plant communities to establish themselves as the climate continues to change during the coming decades (Urban et al. 2012).

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Approaching dangerous impacts of global climate change

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ABSTRACT

Current global policy efforts are focused on limiting the global rise in mean temperature to well below a 2 K warming compared to the pre-industrial temperature. It is questionable if achieving such goal is still feasible. Here, I review published works that suggesting that to keep global warming below or at a 2 K level cannot be considered as safe, as is often assumed. A large body of studies have emerged recently investigating the impacts of global climate change (GCC) at a 1.5 K or 2 K warming. The impacts range from changes in the hydrological cycle, increasing frequency and intensity of extreme weather events, triggering of change feedback processes at various spatio-temporal scales, affecting biological processes from the molecular to ecosystem levels, and to disrupting socio-economic conditions. In this short review, I present the latest scientific knowledge regarding some of the most important impacts of GCC on natural ecosystems, human-made systems, and societies.

INTRODUCTION

Paris Agreement

Current global policy efforts, as stated in the 2015 Paris Agreement, aim to hold "*the increase in the global average temperature to well below 2ºC above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5ºC*" (UNFCCC 2015). Global temperature already has increased by more than 1 K compared to the 1850–1900 period (Hansen et al. 2017) and by even slightly more if the period prior to the start of burning fossil fuels (i.e. 1401–1800) is selected (Schurer et al. 2017). If the temperature increase limit of below 2 K is to be achieved, global greenhouse gas emissions must start to decline by 2020 at latest and reach zero by 2040 (Figueres et al. 2017). Based on the observed and near-future impacts of GCC, it is postulated that crossing the 1.5 K limit is already dangerous (Xu & Ramanathan 2017). Here, I provide further evidence as to the impacts of GCC that are either already observed or are expected to become real if the world succeeds to limit the global temperature increase to between 1.5 and 2 K, even though the probability of this being feasible is ever smaller (Raftery et al. 2017), and particularly so if the climate sensitivity is greater than currently acknowledged (Armour 2017).

Extreme heatwaves and rainfall

Thanks to our understanding of basic physics and long-term time series, it is often possible to observe and attribute changes in the occurrence and/or spatio-temporal extent of extreme weather events to GCC, which is termed the "new normal" (Lewis et al. 2017).

A recent study analysing such regional heatwave characteristics as duration, occurrence, and severity concludes that global temperature rise by more than 2 K would have disastrous consequences (Perkins-Kirkpatrick & Gibson 2017). Even less warming will have serious consequences, and especially in the

tropical regions with their more frequent, longer, and warmer heatwaves (Mora et al. 2017). A similar analysis concluded that with only 1.5 K of warming an additional 350 million people will become regularly exposed to severe heat in megacities (Matthews et al. 2017) and in densely populated parts of the eastern US and China (Russo et al. 2017) by 2050. If the greenhouse gas emissions remain unchecked, increased heat coupled with high humidity will result in exceeding the limits for human adaptability in parts of the Middle East and India (Pal & Eltahir 2016, Im et al. 2017).

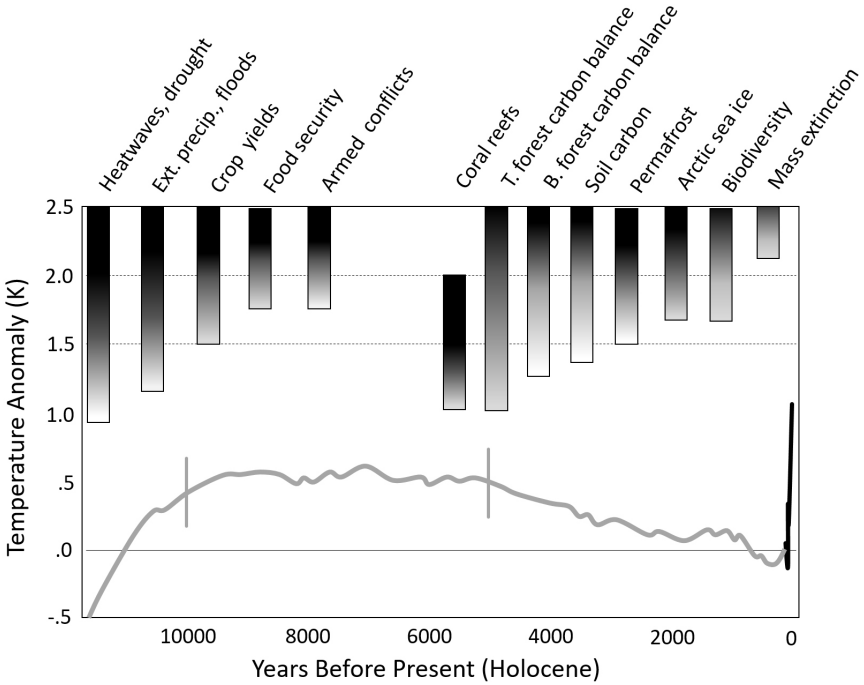

Fig.1: *Reconstructed (grey line) and measured (1880–2017) (black line) global temperature anomaly during the past 11,700 years with uncertainties (vertical grey lines). Horizontal dashed lines show lower and upper limits of the temperature rise as defined in the Paris Agreement. Vertical columns show impacts of climate warming on selected processes and elements of the Earth System. The grey-tone shows the severity of impact (light grey = little impact; black = strong/irreversible impact). The temperature graph is adapted from Hansen et al. (2017). The impact on coral reefs is based on Hughes et al. (2017), impact on soil carbon is based on Crowther et al. (2016), impact on permafrost is based on Wennrich et al. (2016) and Chadburn et al. (2017), and impact on Arctic ice is based on Notz & Stroeve (2016). Ext. precip. = extreme precipitation; T = tropical; B = boreal.*

A human contribution to more extreme precipitation has been observed in two-thirds of weather stations within the Northern Hemisphere (Min et al. 2011). Currently, about 18% of extreme precipitation events can be attributed to GCC, while this proportion will increase to about 40% at a 2 K warming (Fischer & Knutti 2015). A recent analysis discovered tripling of widespread floods in Central India (Roxy et al. 2017) and tripling of extreme Sahelian storms (Taylor et al. 2017) during recent decades. A rapid increase in

convective precipitation has been reported for the Eurasian region (Ye et al. 2017), which is in accord with the global trend of rising 1-day extreme precipitation (Lehmann et al. 2015, Donat et al. 2016). Furthermore, the precipitation extremes (99.9th percentile) will rise at the fastest pace and are predicted to nearly double the rate of water vapour increase (Bao et al. 2017). At the 2 K limit, precipitation extremes in Australia will rise by 11–30%, while globally this variability can vary between 5% and 15% (Pfahl et al. 2017). Resulting changes in the water cycle will directly impact about half of the world's population (Sedláček & Knutti 2014), while at a 3 K warming precipitation totals during rain events can increase by more than 10-fold, making adaptation of current infrastructure very challenging (Neelin et al. 2017). Regionally, flood risk and frequency of flooding are already increasing (Criss & Luo 2017) and the recent global assessment of flood risks concludes that at 2 K warming the affected population and damage to infrastructure will both increase by 170% compared to today (Alfieri et al. 2017). Without GCC mitigation the damage from floods can increase globally by about 20-fold (Winsemius et al. 2016).

IMPACTS OF GCC ON ECOSYSTEMS AND SOCIETY

Forest ecosystems

It is expected, often based on vegetation models, that global forests will remain increasing carbon sink as was the case during past decades. Some evidence of saturating carbon sink at smaller scales has not yet been demonstrated on the global level, at least not by 2011 (Cheng et al. 2017). Indeed, recent satellite data confirm strong greener-for-longer planetary vegetation, and the authors speculate that this could be a result of CO_2 fertilization, although it remains unclear where the water and nutrients should come from to facilitate such an increase in C stock (Zhu et al. 2016). Arriving at a regional picture is more complicated. The most comprehensive study to date, from 321 inventory plots across the Amazon forest, shows a declining strength of the carbon sink (Brienen et al. 2015). Another study concludes that, when accounting for deforestation and forest degradation, tropical forests on each continent are a significant net source of carbon (Baccini et al. 2017). Forests' loss of strength as carbon sink in other parts of the world is manifested through a decelerating tree growth rate (Chen & Luo 2015) and increased mortality (Peng et al. 2011). Particularly managed forests in many parts of the world are – and will be further – under increased stress from unprecedented spread of bark beetles (Kurz et al. 2008, Lesk et al. 2017), drought and higher temperature (Allen et al. 2015, Anderegg et al. 2015), or forest fires (Kelly et al. 2013, Abatzoglou & Williams 2016). Regionally, some forest ecosystems have already become carbon source as a result of more wildfires (Kelly et al. 2015) or increased winter temperature (Commane et al. 2017). Furthermore, forest damage from large-scale windstorms has tripled in Europe since 1990 (Gregow et al. 2017).

Agro-ecosystems and food security

Global agriculture and complex civilizations started with the beginning of the Holocene period almost 12,000 years ago when the last Ice Age ended. Global average temperature did not fluctuate by more than a 1 K within predictable seasonal and year-to-year changes. Once previously stable and characteristic weather changes too quickly to ensure higher crop yields, feeding a growing number of people will become a difficult challenge. A recent review paper determined an average decline in yields of four main crops at 3–6% per K of warming (Zhao et al. 2017). Drought is increasing globally (Dai & Zhao 2016) and is already reducing crop yields on a global scale (Lesk et al. 2016). Excessive heat (when daytime temperature exceeds

30°C) can decrease maize and soybean yields by as much as 6% without irrigation (Schauberger et al. 2017). Crop pests and pathogens are migrating northward at a rate of almost 3 km per year (Bebber et al. 2013). In India, rising temperature during the past three decades increased the suicide rate among farmers by 7%, equivalent to almost 60,000 suicides (Carleton 2017). Together with other interactive negative impacts of CCG, such as increased rainfall variability, reduced crop duration, lower crop nutrient content, or increased weed damage, global food security will be under stronger pressure (Myers et al. 2017) and there will be a greater chance of global food shocks in future (Kent et al. 2017).

Impacts on biodiversity

GCC is today only a minor factor in species extinction, with only one documented extinction of a mammalian species (Gynther et al. 2016). Regarding local population extinction or decline, however, it already has extensive and significant impacts (Paxton et al. 2016, Wiens 2016). Even some of those species best adapted to hot and dry conditions are already negatively impacted by GCC (Rey et al. 2017, Woodroffe et al. 2017). It is expected that the rate of temperature change will outpace the ability of species to react by about 200,000 times on average (Jezkova & Wiens 2016). A recent meta-analysis concluded that a 2 K warming will bring the extinction of about 6% of species (Urban 2015). It may be the case, however, that models are severely underestimating the risk of extinction resulting from GCC (Sears et al. 2016). Recent analysis of paleoclimate data revealed that at a 2 K warming limit oceans may have dissolved enough CO_2 to trigger mass extinction on a global scale lasting for thousands of years thereafter (Rothman 2017). Of great concern is not only the extinction of species per se but also their redistribution (favouring adaptive species and diminishing keystone species), thereby severely impacting ecosystem balance and productivity on land (Carlson et al. 2017) and in the oceans (Nagelkerken & Connell 2015, Vizzini et al. 2017).

Socio-economic impacts

The socio-economic situation is critically dependent upon and adapted to the existing climate conditions. Any rapid environmental change has potential to trigger an adverse cascade of events in society. There exists a variety of mechanisms through which GCC impacts the social system. Hsiang et al. (2013) found that a 1 K temperature rise increases interpersonal and intergroup violence by 4% and 14%, respectively. Where societal order is already fragile and facing unfavourable environmental conditions, GCC increases the risk of armed conflicts (Schleussner et al. 2016). Drought worsened by GCC has probably contributed to the internal displacement of people within Syria, where a combination of other negative factors has led to a civil war (Kelley et al. 2015, Cook et al. 2016). It is further expected that under the 2 K warming limit people in tropical regions would need to migrate on average more than 1000 km by the end of the century (Hsiang & Sobel 2016). Finally, recent calculations of potential damage from unmitigated GCC put reductions in global gross domestic product at as much as 23%, which is 2.5–100 times more severe than previously estimated (Burke et al. 2015).

CONCLUSIONS

GCC is already manifesting itself through a range of impacts of varying intensity and having serious consequences for local ecosystems and society. Considering the long-term impacts of climate change, any future level of warming may already be too high for some locations. The more the global temperature will rise, however, the more feedback processes and severe consequences will affect society on larger scales.

It does seem the notion that GCC is "safe" with temperature rise of 1.5–2 K is at least questionable. Some of the very dangerous impacts and others to which adaptation is very difficult already are unavoidable. Nevertheless, there still remains some leeway to mitigate the impacts of GCC.

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Carbon-smart forestry for building resilience to global change

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ABSTRACT

The specific role of mountain ecosystems in the carbon cycle and their importance as carbon sinks already has been noted within the broader debate about climate change. There has been progress in designing and attempts towards implementing such mountain-specific strategies as green economies, global and regional conventions, frameworks, and institutions. There is still need, however, for new and integrative approaches to governing mountains in a sustainable and adaptive way with local and global contributions. The proper institutional arrangement, adaptive forest management, and sustainable use of forest ecosystems can make a substantial contribution to the well-being of local communities as well as contribute to mitigating global climate change by provisioning of carbon sequestration ecosystem service. This paper examines how reconfiguration of social practice in forest-dependent communities can address urgent societal challenges. In particular, it considers the potential of a common pool resource regime for governance and carbon-smart forestry in innovative management of mountain ecosystems to meet societal and natural challenges.

INTRODUCTION

As global debates about the need to decrease CO_2 in the atmosphere intensify, significant political attention has been shifted to mountain regions. Despite that European mountains are covered predominantly by forests, their importance for carbon sequestration has long been overlooked. The specific role of mountain ecosystems in climate change regulation arises from their capacity to capture significant amounts of carbon in vegetation and soil organic matter over the long term. Ineffective sectoral policies and unsustainable use as well as failure to recognize the value of these ecosystems have caused their degradation. It is evident that there exists an urgent need for policy action, a new agenda, and strengthening of the institutional framework in sustainable mountain development. Some important steps already have been undertaken in the policy arena at the global level. The important Intergovernmental Panel on Climate Change (IPCC) was established in 1988, and through its efforts the United Framework Convention on Climate Change (1992) and Kyoto Protocol (1997) were signed with the aim of reducing emissions in the atmosphere. More recently, the Paris Agreement (2015) was signed. It highlights the importance of land-based carbon sinks. To achieve carbon-smart forest management, it is important to understand relationships between entities in a complex forest social – ecological – technological system (SETS) (McGinnis & Ostrom 2014) and to determine factors (variables) conditional for developing social innovation and maintaining the robustness and sustainability of SETS (Kluvánková et al. 2017).

MATERIAL AND METHODS

We examined the governance regime and forest management innovation of local communities within forest located in Slovakia's Low Tatras National Park. We analysed the reconfiguration of social practice in this local forest common pool resource (CPR) regime as SETS according to the social innovation theoretical concept developed in the SIMRA H2020 project (McGinnis & Ostrom 2014, Kluvánková et al. 2017). Within this qualitative research method, we examined the relationships between entities in complex SETS (Fig. 1).

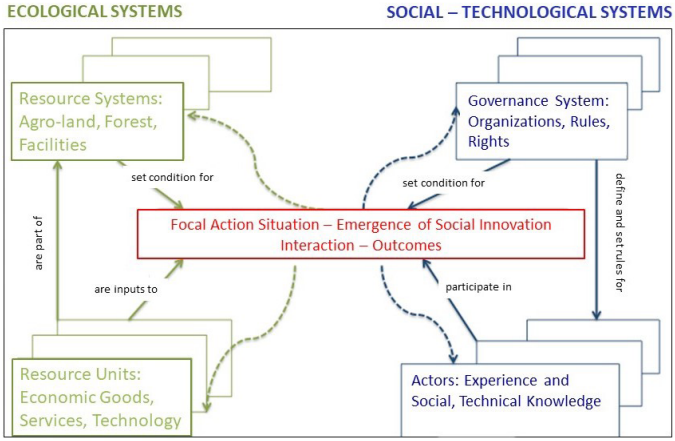

Fig. 1: *Social – ecological – technological systems (adapted from Ostrom 2009).*

Social innovation (SI) is seen as "the reconfiguring of social practices, in response to societal challenges, which seeks to enhance outcomes on societal well-being and necessarily includes the engagement of civil society actors" (Polman et al. 2017). There are considerable expectations of the potential of SI to address urgent societal challenges. Following the principles of SETS, the innovation system indicates that SI can only be successful when a holistic approach to innovation and its governance is applied (see e.g. Ostrom 1990, Ostrom 2009, Kluvánková-Oravská et al. 2013, McGinnis & Ostrom 2014). The aim is to identify the relationships between entities of SETS and variables that enable or constrain efforts with respect to the emergence, nurturing, and development of SI. From this innovation-system perspective, the SETSs are interlinked at multiple levels and their multi-actors interact dynamically. Such a system demonstrates that change in one area can have important spillover effects on other aspects of resource allocation and utilization.

We analysed local forest CPR in order to understand the relationships between natural resources and foresters as actors within multilevel governance systems and to recognize the capacity of SETS for reconfiguration of social practice. CPR regimes are optimal and robust property regimes that could be capable to ensure balanced use and protection of the natural resources, as well as the provision of public goods (e.g. ecosystem services provided to society). In this way, human well-being would be assured not just at a local level but also on a regional or even state and global scale (Ostrom 1990, Kluvánková & Gezik 2016).

RESULTS AND DISCUSSION

In analysing this particular SETS, it is first crucial to realize that despite forests as natural resources systems have clear boundaries regarding their owners, the interaction within the whole forest ecosystem is not limited – forest ecosystems are interconnected and dynamic. To avoid fatal natural disturbances that could have significant influence on forest productivity and provisioning of ecosystem services (resource units), it is important secondly to set up effective governance systems and actors relationships enabling interaction and cooperation. Local users within the forest CPR regime in Low Tatras National Park are capable of crafting their own rules allowing for sustainable and equitable management of CPRs. Due to their self-organization, self-management, institutional maturity, local knowledge, communication and trust, the commoners are more willing to follow their own established rules and monitor others than if an authority were simply to impose its rules. These regimes are preconditions for the continuity of SETSs and are able to resist natural and social disturbances, avoid short-term individual interests, as well as provide public goods over the long term and potentially form a set of independent self-governed systems (Berkes & Folke 1998, Anderies et al. 2004, Poteete et al. 2010, Kluvánková-Oravská 2011).

However, this mature forest CPR regime faces several internal and external disturbances. There is a growing number of young members within this community because shares in forests are inherited from generation to generation. The younger generation, meanwhile, is migrating from villages to cities to pursue better educational and job opportunities. The different life style of the young changes the prevailing values and preferences, traditional knowledge about forest management is eroded, and thus forest management in the CPR regime is even more difficult. In addition, this local forest CPR regime also face external challenges such as global market pressures. If the owners want to be sufficiently competitive, they must adapt their traditional forest management to current globalization trends. This results in higher forest vulnerability if the forest management regime is modernized and intensified. Further, this local CPR regime must deal with the fact that a strong windstorm followed by bark beetle infestation has destroyed a significant expanse of their forest. We examined whether this local CPR regime is able to face such social and natural disturbances. We found that foresters in this community were able to adapt their traditional forest management and, despite that no compensation scheme exists, they are trying to intensify the innovative carbon-smart forestry practices (Brnkalakova 2016). This results in higher forest resilience and greater forest biodiversity through intensifying natural regeneration. Moreover, the local CPR regime is more cost-efficient in comparison to a state forest management regime within the same locality affected by the same natural disaster (Brnkalakova 2016).

This case shows that the forest CPR regime has proven its robustness and capacity for adaptation. In spite of several challenges, this community was able to adapt and reconfigure its traditional forest management to innovative management, even without any financial or governmental support. The community recognized the need to innovate and adapt its forest management to natural and social disturbances, and thus to secure the well-being of the local community. In addition, its maturity, self-governance, self-organization, and trust between community members are crucial variables enabling reconfiguration of this traditional social practice.

The results of our examination are confirmed by several studies analysing forest CPR regimes in terms of their effective management of natural resources, contribution to public goods, social innovativeness, and overcoming of global challenges. Bogotaj & Krč (2014) and Prempl et al. (2015) found that Slovenian CPR regimes are a potentially effective response to forest management challenges but also a potential model

for social cohesion and balancing forest use and conservation. In addition, it has been recognized that Swedish forest CPR regimes have contributed to positive development of municipalities and could play an important role in promoting biodiversity even more effectively than in forests of other ownership categories (e.g. Lidestav et al. 2013). Significant status of forest CPR regimes in the area of climate change mitigation is also confirmed by newly established CPR regimes (so-called woodlands in the UK) that are created by local communities with the aim of improving poor forest ecosystems' quality along with the quality of life for the local population. Woodlands in the UK use forests for multifunctional purposes (education, recreation, protection) and are supported by several social programmes and the woodland carbon fund (Valatin 2012, Nijnik & Pajot 2015).

SETS analyses of self-organized and self-managed traditional forest CPR regimes have proven their adaptive capacity. This local community was able to adapt its traditional forest management practices in favour of innovative, carbon-smart forestry even without greater financial inputs. The emphasis in the policy arena on carbon management in forest CPR regimes not only could play a crucial role in climate change mitigation and long-term carbon storage but could also contribute to an improved economic performance and well-being of marginalized mountain regions. In this sense, carbon-smart forestry is a promising, innovative, and vital economic technological-governance model. To develop the social innovation in this case, the voluntary engagement of local community members was important. In addition, the motivation to increase the resilience and quality of forest that ensures well-being of the local community, for example by the income from wood sold or as a place to relax, was also a crucial variable that enabled the development of social innovation.

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Urban ecosystem services in climate change mitigation

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ABSTRACT

Climate change and global warming rapidly affect urban residents' well-being. More than 72% of Europeans live in urban environments, and their well-being is closely related to environmental quality. How cities are planned and structured can exacerbate the negative effects of climate change even as natural elements and green areas are shrinking. The impact of high temperature on human health during heat waves will be one of the most serious problems associated with climate change, and especially in large urban areas. Heat islands are mainly due to high concentration and large areas of impermeable surfaces, low moisture, few green areas, and poor ventilation. We present results from measuring heat islands at two locations in Bratislava and interview key actors from three cities to identify risk perception regarding climate change. Expected results aim to mainstream ecosystem services into spatial planning in cities in support of operationalizing microclimatic function of green infrastructure to mitigate negative impact of climate change in cities.

INTRODUCTION

Ecosystem services (ES) are benefits for people from healthy ecosystems affecting human life. The ES concept was introduced in the 1970s, both as an analytical concept and a policy tool for conservation management to address the relationship between human societies and the natural environment. Its aim has been to overcome traditional approaches to managing natural resources (Reid et al. 2005), which have been based on static conservation of nature and landscape and often overlook ecosystems' functioning and the resilience of complex biophysical systems. The main expectation for millennium ecosystem assessment is to introduce a paradigm shift in natural resource management by targeting ecosystems with the aim of providing essential values for human well-being through service provisions.

With their capability to produce ecosystem services essential to social, environmental, and economic health of urban areas, healthy ecosystems constitute the foundations for sustainable cities. Purposeful green city management thus requires due consideration for ecosystem services capable to mitigate risks of climate change (CC).

We follow the ES classification known as CICES – Common International Classification of ES (available online at http://cices.eu/). CICES defines three ES categories: provisioning, regulatory, and cultural. Our paper addresses a particular group of regulatory ES: micro-regulation ecosystem services in urban areas. We argue that operationalizing the microclimatic function of green infrastructure into city development and management are essential to triggering behavioural change of ecosystem providers and users and effectively achieving CO_2 mitigation targets.

The intensity of urban heat islands is related to the density of buildings in that area, size of the area, and type of active surface with typical low evapotranspiration. Green infrastructure is seen as one suitable adaptation measure for cities because it can utilize the potential of ecosystem services. Cities have 'green',

‘grey’, and ‘blue’ infrastructure. Green infrastructure incorporates trees, shrubs, lawns, climbing plants, etc. Grey infrastructure encompasses such built-up areas as buildings and roads. Blue infrastructure includes such aquatic resources as lakes, rivers, and fountains (Rouse & Bunster-Ossa 2013). Dominance of grey infrastructure and its spatial complexity are the main factors contributing to urban heat islands, which are parts of a city or metropolitan area substantially warmer than their surroundings (EPA 2016). Surface temperatures in cities are generally higher than in the surroundings due to the types and colours of materials used. Dark surfaces typical of buildings, roads, and other grey infrastructure, absorb more radiation, thereby increasing temperature and heat island effect. In Brno, Czech Republic, for example, during clear summer days temperatures of artificial dark surfaces may reach 70°C while green areas reach only about 30°C (Novotný et al. 2016).

The microclimatic function of green infrastructure is an important aspect of urban spatial planning because it can mitigate the negative impact of CC by evapotranspiration of water, but only if certain principles are fulfilled. Effective green areas must be sufficiently large and of good quality, and have good water management and low soil compaction.

MATERIALS AND METHODS

Our work consisted of two main tasks: comparative qualitative research of CC risk and meteorological field measurements. A case study approach was used to determine perception of CC risk aversion for three Slovak cities: Bratislava, Trnava, and Ružomberok following project UrbanAdapt - Development of urban adaptation strategies using ecosystem-based approaches to adaptation (http://urbanadapt.cz/en). Cities were selected for their differences in size, geographical location, stage of development, and implementation of CC adaptation strategy and planning. Semi-structured interviews were conducted with key actors. From each city, 10 experts from national and municipal authorities such as CC and urbanization ministry deputies, mayors, urban planners, water management and hydro-meteorological authorities, and such other stakeholders as universities, tourism actors, and urban forests were selected. We determined CC risk perception and accessibility of adaptation measures in each city. Questions were focused on negative impact of CC in these cities, the aims being to analyse each city’s current situation and then to suggest effective measures to mitigate CC impacts there.

Field meteorological measurement (*ex post facto*) was established in 2016 using small automatic measuring stations for measuring air temperature and relative humidity in two courtyards within Bratislava. The first courtyard was with greenery, the second without. We also compared results from the greenery courtyard with sufficient and insufficient water.

RESULTS

To date, only data from Ružomberok and Bratislava interviews are available. Figures 1A and 1B show four categories of CC risks taken from the project UrbanAdapt. Respondents were asked to rate these risks’ influence on expected impacts. Figure 1A indicates that among the most urgent CC risks for Ružomberok is that of torrential rains. This also concerns the potential danger of flooding and requires pro-active adaptation. Ružomberok is a city less affected by CC compared to Trnava and Bratislava due to its natural conditions and smaller size. On the other hand, Ružomberok has been active in strategic thinking and planning for CC mitigation. Thus, it has opportunity to develop a CC strategy to prevent negative effects while reducing costs and impacts to society and individuals.

Respondents evaluated Bratislava (Fig. 1B) as a city with high risk of heat waves and accompanying negative effects on human health and increasing energy intensity, at risk of drought and impacts of drying of vegetation and deterioration in air quality, and at risk of torrential rains that could cause landslides. Although Bratislava is characterized by poor infiltration of rains, the smallest CC risk was attributed to flooding.

The interviews were aimed to determine actual and potential risks of CC in three cities with diverse intensity of CC effect and capacity for CC adaption strategies and plans.

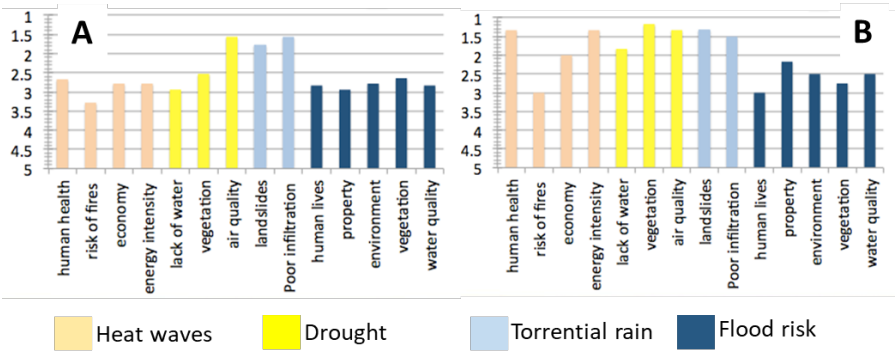

Fig. 1: *Preliminary results from interviews in Ružomberok (A) and Bratislava (B). Risk assessment: 1 – very significant, 2 – more significant, 3 – significant, 4 – less significant, 5 – insignificant.*

The measurements of basic microclimatic parameters (Table 1) – air temperature and relative humidity – in two courtyards showed differences between the courtyard with and without greenery. The difference between maximum observed temperatures in the courtyards was 2.4°C. The relatively small difference was due probably to the small area of the courtyards, where the effect of the greenery (green infrastructure) was outweighed by the effect of surrounding buildings (grey infrastructure). For effective cooling of air, it is necessary to have larger compact areas occupied by greenery. On the other hand, a difference of more than 2°C when the temperature is ca 30°C can be regarded by residents as important and at a threshold between comfort and discomfort.

DISCUSSION

As indicated by the literature on this subject, increased risk of heat islands in our study area is due to low evapotranspiration resulting from such technological weaknesses as impermeable materials, the use of dark roofs on buildings, and inappropriate green infrastructure management practices which cause 'heat traps'. Numerous studies show that use of green areas in cities has beneficial effects of reducing air temperature and mitigating other negative CC impacts. Bowler et al. (2010) found that green parks were as much as 0.94°C cooler during the day than streets. Gill et al. (2007) confirmed these results and added that if cities had 10% more green areas the maximum surface temperature could be reduced by 2.2–2.5°C. This was confirmed also by measurements of microclimatic parameters in the two Bratislava courtyards. Although the differences between the courtyards with and without green infrastructure were not statistically significant, the findings do indicate challenges and opportunities for well created and managed green

Table 1: *Preliminary results from air temperature (Tair) and relative humidity (RH) measurements from two courtyards in Bratislava during August 2017. Presented are a courtyard without greenery and one with greenery.*

	Minimum	Average	Median	Maximum
Without greenery				
*T*air (°C)	14.1	24.1	23.6	38.6
RH (%)	19.6	53.5	51.9	98.2
With greenery				
*T*air (°C)	13.2	23.2	22.8	36.9
RH (%)	21.9	56.5	54.9	100

infrastructure. These findings are confirmed by Maco (2015), who examined the effectiveness of management in green semi-public urban areas constituting more than 30% of existing green areas in Bratislava. In particular, we see an urgent need to reconsider ongoing practices and adopt ecosystem-based adaptation in maintaining trees as a source of larger biomass accumulation (Marek et al. 2011 and outputs of UrbanAdapt available at http://urbanadapt.cz/en).

Considering that three-quarters of Europe's population lives in urban environments and risks associated with CC are rapidly increasing, vulnerability of cities in terms of health, well-being, and quality of the life is becoming serious. Scaling up green infrastructure management within urban spatial planning has significant potential for improving cities' capacities to meet CO_2 mitigation objectives, improve well-being, and reduce risks of potential health or economic collapse.

Results from the assessment of risk perception in Bratislava and Ružomberok indicate both differences and commonalities. Awareness among relevant stakeholders has been increasing over the past decade as CC adaptation has become part of public policy, development planning and implementation, and deliberative processes at city level. There is also evidence of growing knowledge and understanding of the associated risks. Differences in interview responses reflect in part different biophysical conditions. Ružomberok is in a mountainous area and the increased risk of floods is recognized there. Highly urbanized Bratislava, meanwhile, is especially vulnerable to heat waves.

Future research is planned to complete the risk aversion analyses and, in combination with evidence from climate regulation measurements, to draft recommendations for CC-related measures to be incorporated into spatial planning practices in Slovak cities.

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Ecosystem services in environmental policy and decision-making in the Czech Republic

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ABSTRACT

In response to the increasing popularity of the ecosystem services concept among scholars and policy makers on the international level, it has become time to analyse the current state and possibilities for national policy and decision-making in reflecting this concept. This article presents a sneak preview of research focused on content analysis of environmental policy documents. Two current and one outdated climate change policy document are analysed regarding notions of the ecosystem services concept and other aspects of an ecosystem-based approach. The output data show contrasting results, with the Adaptation Strategy scoring very high compared to the Climate Protection Policy, which almost does not reflect the ecosystem services or related ecosystem approach. Implications of the results and the entire context of the research are discussed in respective sections.

INTRODUCTION

When reading contemporary environmental policies, an ecosystem approach is often used to describe complex relationships between humankind and environment. In scientific discourse, increasing attention is being given to the concept of ecosystem services (ES) (Kull et al. 2015), which can help to describe multiple nature–society interactions in a holistic way. Since 2008, which marks the historic year of the first Ecosystem Services Partnership (ESP) conference, the number of peer-reviewed published papers with the keyword "ecosystem services" in its title has more than doubled (authors' own research using the SCOPUS database, search period 2008–2016). It has also become a mainstream topic on a policy level (Bouwma et al. 2017), pushed forward by the latest developments and outcomes of the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) platform (Díaz et al. 2015). The concept of ES provides us with a unique framework that allows us to uncover often invisible or overlooked values and benefits (or disservices) provided by nature to people and to integrate them into policy and decision-making. Moreover, it enables us to visualize synergies and trade-offs (Schaefer et al. 2015).

In general, the aim of this research is to assess the usability of the ES concept in policy and decision-making. This area is still rather in its infancy compared to the plethora of methods and tools developed for ecosystem assessment inclusive of valuation and mapping (Rinne & Primmer 2016). Therefore, it calls for attention from multi- and transdisciplinary research. When aiming to achieve common socio-environmental goals (conservation of biodiversity, sustainable use of ecosystems, etc.), the ES concept can be advantageous in terms of playing the role of a transdisciplinary boundary object, which has the ability to engage different societal actors, including non-scientists and politicians (Abson et al. 2014).

The preliminary results presented here are focused on an analysis of environmental strategy documents. If we accept that institutions (e.g. rules, regulations, but also habits) influence people's behaviour, then we may also ask what rules could produce a specific targeted behaviour (e.g. reflecting the ES concept). What

makes certain ideas able to influence institutions and become part of policies and strategies falls within the focus of the institutionalism stream of political science (Schmidt 2008). The increasing popularity of the ES concept in science (Kull et al. 2015) is closely followed by its increasing institutionalization, such as in environmental policies of the European Union (Bouwma et al. 2017). As previous research suggests, attention to institutions, institutional setting, and higher level policies could enhance the possibility for integrating the ES concept into "real life" policy and decision-making (Greenhalgh & Hart 2015, Rinne & Primmer 2016).

MATERIALS AND METHODS

The qualitative content analysis method provides efficient means and flexibility to describe the use of a certain element in text data (Weber 1990, Hsieh & Shannon 2005). This method is used to answer the question whether existing national environmental policies in the Czech Republic use ES or a related ecosystem-based approach. A secondary question – how has the adoption of the ES concept in the policy changed in time? – was applied to the cases where it was possible to compare an existing and valid policy with its previous, outdated version. The complete list of main national environmental policies contains 19 strategic documents, programmes, concepts, and plans in eight fields (general environment, nature protection, climate change, air protection, water protection, wastes, risks, and sustainable development). This article focuses on national climate change policies of the Czech Republic: the Climate Protection Policy of the Czech Republic (Climate Protection Policy) and the Strategy on Adaptation to Climate Change in the Czech Republic (Adaptation Strategy).

The method of content analysis was used to search for explicit notions of the ES concept and for other aspects of the ecosystem-based approach. Conjunctions of words operating with the term "ecosystem" were coded into either explicit mention of "ecosystem services" or other related topics (e.g. ecosystem functions, protection, restoration, resilience). These topics were then quantified regarding their frequency of occurrence in the documents.

RESULTS

The first policy document analysed in this article is the Climate Protection Policy of the Czech Republic, which was adopted in March 2017 and replaced the previous National Programme to Abate the Climate Change Impacts in the Czech Republic (National Mitigation Programme) from 2004. Therefore, it was possible to compare these two documents to see how climate change policy has evolved over time in relation to the ES concept and the ecosystem approach in general. The number of hits for the searched keywords was in total very low. It fluctuated from 1 to 2 in the actual policy and from 1 to 4 in the previous one (see Fig. 1). There is a clear shift from topics like ecosystem protection and climate change impacts on ecosystems to one explicit hit for ES and support of ES research.

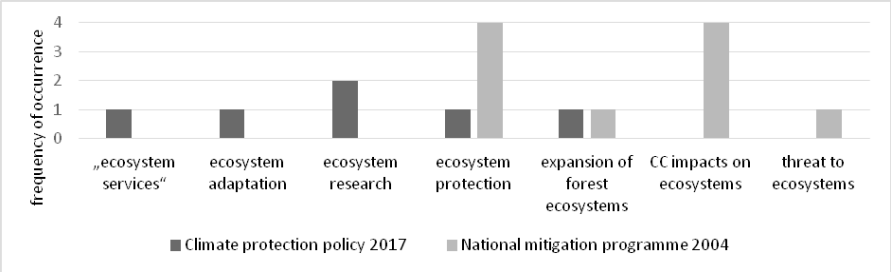

Fig. 1: *Number of hits for topics related to ecosystem services (ES) or ecosystem approach in the Climate Protection Policy of the Czech Republic and the National Programme to Abate the Climate Change Impacts in the Czech Republic.*

The second document constituting climate change policy is the Strategy on Adaptation to Climate Change in the Czech Republic, adopted in October 2015. This document does not have a direct predecessor, even though it partly replaces the previously mentioned National Mitigation Programme from 2004. The number of total hits for the keywords and topics related to ES is very high (see Fig. 2). It fluctuates from 1 to 58 with a great variety of topics. The three most frequent topics are explicit mention of ES (58), followed with a significant gap by ecosystem protection (18) and forest ecosystems (17). The category of ecosystem benefits stands alone, since its meaning is slightly different (Fisher et al. 2009), but it could also be added to the term ES, which would then receive a total number of 60 hits.

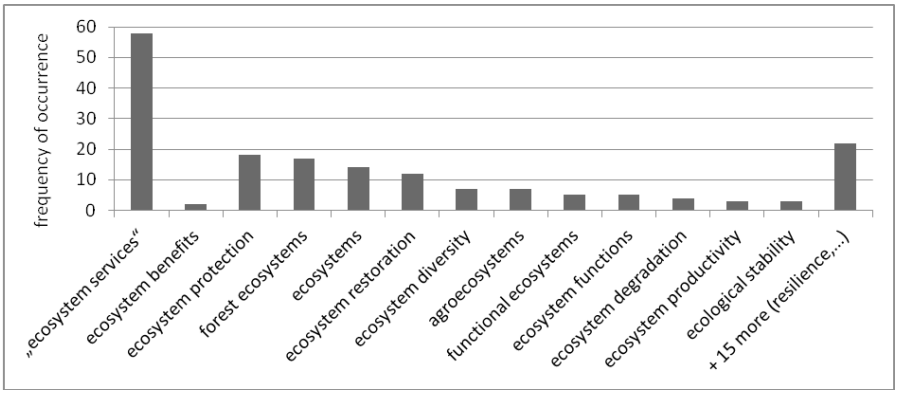

Fig. 2: *Number of hits for topics related to ecosystem services (ES) or ecosystem approach in the Strategy on Adaptation to Climate Change in the Czech Republic (2015).*

DISCUSSION

The content analysis of environmental policy documents is the first essential step in analysing the current level of integration of the ES concept into national policy and decision-making processes. The output data of the climate change policy analysis show contrasting results. The newest Climate Protection Policy mentions the term ES only once, whereas the slightly older Adaptation Strategy scores an astounding 58 hits, along with another 26 topics related to the ecosystem approach. The extent to which the Adaptation Strategy relates to the ES concept is very significant also when compared to, for example, the State

Environmental Policy of the Czech Republic 2012–2020, which had "only" 11 hits. This suggests that the climate change adaptation policy is significantly targeted to ecosystems (and ES). It is possibly a product of ecosystem-based approaches to adaptation, which have their important place next to hard-engineering structures common in this field (Jones et al. 2012).

Results of the content analysis will be used in the next phase of the research to design questions for semi-structured interviews with institutional stakeholders (stakeholders representing institutions with nation-wide operation). The second stage will aim to analyse stakeholders' preferences and attitudes towards the ES concept, as well as to identify priority ES and perceived values of nature. Furthermore, the interviews will be designed to identify power relationships among stakeholders, which influence the flow of ES and create barriers against a "full" use of ES. The power relationships are defined by Felipe-Lucia et al. (2015) as *"the human ability to control or influence the access of others to ES"*. In such a setting, it is hypothesized that environmental policies and decision-making processes may act as another "stakeholder", which can influence the flow of ES. Last but not least, the data from interviews can help to identify barriers to and opportunities for better integration of the ES concept into environmental policy and decision-making.

ACKNOWLEDGEMENT

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Exploring knowledge and attitudes towards climate change among a study sample from Khartoum State, Sudan

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ABSTRACT

In spite of an adaptation plan endorsed by the city's authorities, Khartoum State, the capital of Sudan, has repetitively experienced a series of ravaging climate variability impacts. As in similar cases elsewhere, there are indications of financial and institutional incapacities and shortfalls to run the adaptation process, as well as lack of public knowledge about climate change. It has been argued that having well-informed communities in some developing countries has reduced vulnerability and exposure to climate-origin disasters. Aiming to provide quantitative insight into the community's knowledge and attitudes about climate change, this study presents the results of a survey carried out in 2014 in a simple random sample of Khartoum State residents encompassing 395 households. Data analysis showed that >75% of the respondents were aware of both the term "climate change" and its main causes. Due to certain cultural and religious factors, however, familiarity with its associated risks was less (25–75%). Moreover, knowledge regarding the ongoing government efforts, leading institutions, participating non-government organizations, and beliefs about the capability of Khartoum State authorities to adapt the city to the foreseen impacts was found to be low (<25%). Of the respondents, 49% believed that both human activities and God are responsible for causing climate change. Seventy-nine per cent of the respondents were interested in acquiring information about climate change, but only 55.3% frequently obtain it. Although 79% of the respondents would agree or strongly agree to pay in order to mitigate climate change, 50.4% believed that nothing had been done by local government to mitigate that change. The study provides unprecedented insight into knowledge and attitudes towards climate change among Khartoum State households. The results can be used by city authorities and government politicians to support ongoing adaptive procedures and decision-making while narrowing the knowledge gap concerning climate change risks.

INTRODUCTION

Khartoum State is the capital of Sudan. It has an area of 22,000 km² and 6,534,796 inhabitants (Central Bureau of Statistics 2013). Khartoum State is divided into seven localities and 36 administrative units. Its population consists 54% of men, which figure reflects a male-dominated migration process (Eltayeb 2003). The age structure of the Khartoum State population is as follows: <15 years of age, 37%; 15–40 years of age, 45%, and >50 years, 18% (Central Bureau of Statistics 2013). The overall illiteracy rate in Khartoum State in 2014 was 25% (Higher Council for Strategic Planning 2014). With its vast area and dense population, Khartoum State suffers from a lack of proper infrastructure, such as a rainwater drainage system, and this adds further to the city's vulnerability. Moreover, plausible climate change scenarios anticipate serious climatic consequences in Khartoum State. In 2013, the city's legislative and executive bodies endorsed and mainstreamed a climate change adaptation plan. Meanwhile, Khartoum has

repetitively experienced a series of ravaging climate variability impacts. Similar cases point to financial and institutional incapacities and shortfalls to run adaptation processes, as well as lack of public knowledge regarding climate change. Baldassarre et al. (2010) provided examples of best practices from developing countries where well-informed communities have reduced vulnerability and exposure of many dwellers to climate-originated disasters. Many data have indicated that populations with poor knowledge about climate change impacts and ongoing governmental activities to tackle them may have carefree attitudes towards the problem and that this eventually increases those communities' vulnerability and exposure to the adverse impacts of climate change. Stehr and Grundmann pointed out that knowledge is a first step toward taking needed action (Stehr & Grundmann, 2012).

The present study aimed to investigate the knowledge and attitudes in relation to climate change among a random sample of inhabitants from Khartoum State, the intents being to reveal the extent to which people are aware of risks associated with climate change, the climate topics most of interest to them, and the media sources from which respondents most frequently are obtaining information (Alhuseen 2015).

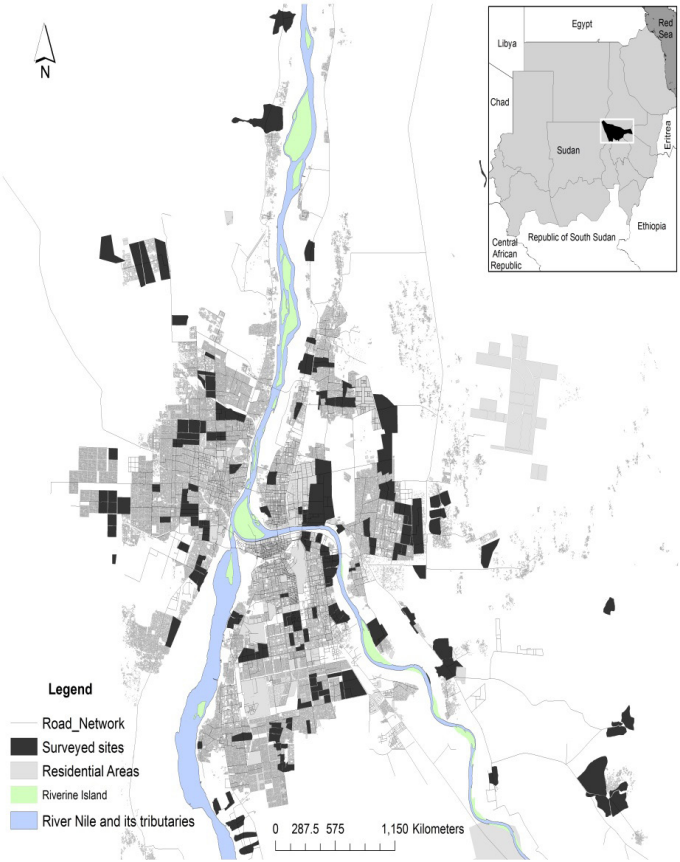

Fig. 1: *Study area location and survey sites (Alhuseen 2015).*

MATERIALS AND METHODS

The survey was carried out in 2014. It covered a simple random sample of 395 households. Sample distribution between the seven localities of Khartoum State was done proportionally and the selection of households was by convenience (Fig. 1). The size of the simple random sample was decided using the following formula:

$$n = \frac{p(1-p)z^2}{e^2},$$

where p is the assumed prevalence of the event in the population under study (usually based on previous studies, field data or the literature), z is the critical value obtained from a standard normal distribution, and e is the maximum absolute error. The value for p was set to 0.50, as there are no previous similar data. The level of confidence was set at 95% and its corresponding z value 1.96 was used. The value for e was set at 0.05.

The questionnaire consisted of four sections designed to provide information about the following:

Demographic characteristics of the surveyed households (sex, age group, place of birth, education, and employment status).

House characteristics (e.g. building materials, source of drinking water, house ownership, type of sewage system used).

Climate change knowledge (knowledge of the basic term climate change, its meaning, its main causes, climate change topics that most interest them, and sources from which they obtained their knowledge).

Beliefs and thoughts about causes of climate change, including the role of government in relation to climate change and respondents' willingness to pay to mitigate it.

The sample had a balanced sex structure, with 52.2% of respondents being males and 47.8% females. The predominant age group, at 35% of the sample size, was 18–30 years old. While 51% of the respondents were born outside Khartoum, 21% of them had moved to Khartoum from other states during the 2000s. Fifty-two per cent of respondents had lived in their neighbourhoods for time periods ranging between 11 and 30 years. Marital status of the surveyed sample revealed that; 58% of the households were married while unmarried, widowed and divorced or separated households represented 42%, employed and apprentice households composed 77% of the sample, meanwhile, the workless households were 23%. A glimpse of the education level of the respondents showed that; 42.2% holds non-university degree, 55% carries bachelor or postgraduate degree, 2.5% were illiterate and 0.3% with no answer provided.

RESULTS

Frequency and percentage analyses were applied to the survey results. More than 75% of the respondents were aware of both the term "climate change" and its main causes. However, familiarity with its associated risks was less (25–75%), due in part to belief in divine will and destiny. Moreover, knowledge regarding the ongoing government efforts, leading institutions, and nongovernment organizations, as well as trust in the capability of Khartoum State authorities to adapt the city to the foreseen impacts were found to be at the lowest level of knowledge among the surveyed sample (<25%). Forty-nine per cent of respondents believed that both human activities and God are responsible for causing climate change (Fig. 2). Seventy-one per cent of respondents showed interest in reading, listening to, and watching information on topics about climate change, but only 55.3% frequently read, listened to, or watched such information. Television

was the main source from which the majority of respondents obtained climate change knowledge. Rainfall and floods are the topics that most interested the respondents. Although 79% of respondents agreed or strongly agreed they were willing to pay to mitigate climate change, 76.8% considered themselves as being inactive at the household level in adapting to climate change. Many respondents believed that nothing was being done by local (50.4%) and federal governments (48.4%), respectively, to mitigate climate change.

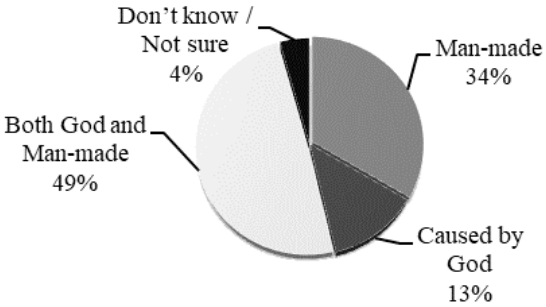

Fig. 2: *Responses to the question about who is causing climate change (Alhuseen 2015).*

DISCUSSION

The survey results showed that the study sample has significant knowledge about climate change, although there is still a knowledge gap in this area needing to be properly filled by effective means. Some major findings of the current study have been vindicated by a similar study carried out among farmers in Nigeria (n = 49 farmer households). Whereas 96% of those in the Nigerian sample had heard the term "climate change", their knowledge of risks associated with climate change was at a very low level (Terdoo & Adekola 2014). Similarly, that same study found that beliefs may affect perception and proactive actions in relation to climate change risks, and one-fifth of respondents hoped for a divine solution to the hazards associated with climate change (Terdoo & Adekola 2014). Bord et al. (2000) had argued that although acquiring good knowledge about the causes of climate change may indicate both stated intents to take voluntary actions and to vote to enact new government policies regarding climate change, this remains limited to individual action and intentions rather than to societal actions that bring about change. They further argued that despite increasing scientific knowledge on climate change, actions are slow to occur, particularly at the political level (Bord et al. 2000). On the other hand, a World Bank study (The World Bank 2009) showed high willingness to pay in 14 out of 15 developed and developing countries where a poll had been conducted, but this also reflected respondents' weak belief in the adequacy of the roles that their national governments were playing. The present study provides unprecedented insight into the knowledge and attitudes towards climate change among Khartoum State households. The results obtained can be used by city authorities and researchers to support ongoing adaptive procedures while building upon the strong tendency towards willingness to pay among respondents and to further bridge the knowledge gap regarding risks associated with climate change.

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Renewable energy sources evaluation: Regional Impact Assessment Framework (RegioIAF)

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ABSTRACT

A European Union directive set as a goal that renewable energy sources have a 20% share in final energy consumption by 2020. The Czech Republic has committed to fulfil the goal of 13%. This aim increases the demand for renewable energy, which means construction of more renewable sources is necessary. This is associated with both positive and negative externalities, however. Mayors of the municipalities face a decision whether or not to support any given renewable energy source and they need to consider all the possible impacts. Impact assessment methodologies currently in use focus on particular areas of evaluation but their evaluations are not comprehensive. This study presents an overall framework designed to help the mayors or potential renewable energy source investors with the decision-making process. The Regional Impact Assessment Framework (RegioIAF) includes all important effects connected to the operation of renewables: employment, regional gross domestic product, costs and revenues for the municipality, environmental impacts, and secondary impacts (e.g. energy prices, business environment). Based on the framework, each mayor can decide whether a given energy source is or is not suitable and efficient for the municipality.

INTRODUCTION

In reaction to climate change, the European Union issued a directive setting as a goal that renewable energy sources (RESs) will have a 20% share in final energy consumption by 2020 in order to reduce CO_2 emissions. The Czech Republic has committed to a goal of 13%, which imposes important requirements on decision makers. Based on the Czech National Action Plan (Ministry of Industry and Trade 2015), there is a suggestion to reach a 15.3% share of energy from renewables in final consumption. According to the Paris Agreement signed in 2015, the climate policy sets the goal to maintain the limit of rise in global temperature below 2°C (Ač 2017). In view of these aims, it is necessary to decide which RESs are suitable for different locations. Renewables' development is often associated with negative externalities, and these may be taken into account when deciding whether or not to support a given project.

Mayors of towns and villages in the Czech Republic lack information essential to making these decisions optimally. They also have no comprehensive evaluation methodology for examining impacts of various RESs and which would help them to decide whether given types of RESs should be built in their municipalities. A proper decision process should encompass all the different effects and externalities (both positive and negative). Currently, the regulatory impact assessment (RIA) is often used at state level and ultimately environmental impacts are evaluated using environmental impact assessment (EIA) at project realization level. Within RIA, the financial impacts (such as an impact on the state budget) are primarily evaluated. In addition, macroeconomic assessments (such as Next Finance 2012) are mainly carried out to analyse the impact on the state.

This paper focuses on a newly prepared framework for comprehensive impact assessment of RESs on the local level. A review of the relevant literature shows that it is almost impossible to calculate the impacts of renewables (e.g. Vezmar et al. 2014), and quantitative monetary evaluation is usually replaced by a qualitative impact assessment. Another option is to apply a multi-criteria analysis, which is the case in this paper. The methodology presented here will help mayors to include all the important aspects that should be taken into account during their decision-making processes.

The structure of the paper is as follows: The next section describes the information sources drawn upon and regional- or local-level impacts to be evaluated. The following section briefly presents the resulting Regional Impact Assessment Framework (RegioIAF), and the final section discusses how RegioIAF can be used by mayors or potential investors.

BASIS FOR THE FRAMEWORK

This paper introduces a different approach to evaluating RES impacts. Unlike the commonly used macroeconomic point of view, the authors focus at regional level. The RegioIAF is designed based on extensive literature research and connects different kinds of impacts of particular RESs. The renewables addressed by this study are biogas (e.g. McCombie & Jefferson 2016), photovoltaic (e.g. García et al. 2017), wind (e.g. Kazak et al. 2017), water, and geothermal energy (e.g. Vezmar et al. 2014) sources.

One of three methods usually is used for impact assessment and decision-making support: RIA, EIA, or LIA (local impact assessment). LIA evaluates the effects in the region or at a specific location. Those concepts can be regarded as too general for present purposes. The paper aims to develop the RegioIAF, which strictly defines what needs to be monitored. It is a combination of methods and key aspects, which makes it a local impact assessment focused on renewable energy sources in the particular location (village, city, region).

RegioIAF is developed based on a literature review and current evaluation methods (RIA, EIA and LIA). The study shows the categories of impacts regarding which the mayor should take account. There are primary and secondary impacts. The group of primary impacts includes (i) employment (long-term and short-term), (ii) gross domestic product at regional level, (iii) revenues for the municipality, (iv) costs for the municipality, and (v) environmental impacts (set of indicators). The secondary impacts can be defined as energy prices, business environment, technology and infrastructure level, education and human capital, and municipality development.

THE ASSESSMENT FRAMEWORK

The following table is one of RegioIAF's key tools useful for RES evaluation. Positive and/or negative impacts are evaluated for each category. Positive and negative impacts are divided into three degrees: significant, medium, and low. The mayor (or potential investor) will go through the table and evaluate the impacts based on the situation within the municipality (which may differ greatly from one municipality to another because of regional disparities), thereby creating a summary of the overall impact. To facilitate evaluation, a description of each category and its significance is included into the methodology. For example, the category "environmental impacts" is divided into several subcategories, such as land use, air quality, erosion, and biodiversity.

Table 1: Regional Impact Assessment Framework for examining primary impacts of renewable energy sources.

Regional Impact Type	Degree of impact							Criterion weight	Overall impact
	NEGATIVE (-)			No	POSITIVE (+)				
	significant	medium	low		low	medium	significant		
	-3	-2	-1	0	+1	+2	+3		
Long-term employment									
Short-term employment									
Regional gross domestic product									
Revenues for the municipality									
Costs for the municipality									
Environmental impacts									
Overall impact								**100 %**	

DISCUSSION

The main user of the RegioIAF will be a municipality's mayor, who deals with the decision whether to build a renewable energy source or not. The methodology could also be a useful guide for potential investors. It can serve for structuring the main arguments to receive financial support for renewables development within the region.

The presented framework avoids monetary evaluation, which is an inaccurate way of analysing the impacts. Alternatively, one could use cost-benefit analysis, but that method is costly and time-consuming. Therefore, the RegioIAF introduces a comprehensive overview of positive and negative impacts of renewables and serves as a user-friendly guide for decision makers.

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