Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-265
Manuscript under review for journal Biogeosciences
Discussion started: 20 July 2017

Biogeosciences Discussions

Ideas and perspectives: New research examples of autumnal climate change ecology

Ulf Büntgen[1,2,3], and Paul J. Krusic[1,4]

[1]Department of Geography, University of Cambridge, CB23EN Cambridge, UK

[2]Swiss Federal Research Institute WSL, Zürcherstrasse 111, 8903 Birmensdorf, Switzerland

[3]CzechGlobe and Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic

[4]Navarino Environmental Observatory, 24001 Messenia, Greece

Correspondence to: U. Büntgen (ulf.buentgen@geog.cam.ac.uk)

Abstract. Changes in autumnal climate affecting the diversity and productivity of the ecosphere are arguably as important as vernal climatic changes. Motivated by a recent call for more research on the biological and ecological consequences of autumnal climate change (Gallinat et al., 2015), we present three examples of innovative biogeoscience, employing novel datasets and methodologies, which refine our ability to monitor the physiological functioning and ecosystem performance during autumn. Drawn from recent research in wildlife biology (big-game hunting), wood anatomy (tree-ring formation) and mycology (mushroom inventory), these studies provide original insights that contribute to an improved understanding of how varying environmental and climatic conditions impact the phenology, productivity and diversity of different organisms in autumn.

1 Big-game hunting

Warming-induced range shifts along altitudinal and latitudinal gradients have been reported for many plant and animal species around the world (Parmesan and Yohe, 2003; Thomas et al., 2004; Lenoir et al., 2008; Harsch et al., 2009; Chen et al., 2011; Gottfried et al., 2012; Pauli et al., 2012). The mobility and behavioral plasticity of large animals, however, complicates detection of climate-induced population movements. Long-term, massively replicated and geographically detailed hunting records can supplement traditional animal tracking studies (Kays et al., 2015). For instance, the Swiss canton of Grisons has amassed >230,000 harvest locations of four ungulate species (Büntgen et al., 2017). Carefully collected since 1991, this inventory contains year-to-year and decadal niche tracking of free-ranging ibex, chamois, red deer and roe deer populations in higher elevations, late in the year. The significant upward trend in ranging habits over the last two decades coincides with warmer, snow-free and vegetation-rich, conditions in September and October. Such findings will help improve awareness of the interconnectivity of the full annual cycle, including the return to winter ranges (Rivrud et al., 2016).

2 Tree-ring formation

Though wood formation in many extra-tropical species occurs during most of the warm season, several plant physiological processes occur at the end of the growing season. Their precise assessment has greatly improved following recent advances in quantitative wood anatomy (Steppe et al., 2015). State-of-the-art studies combining high-resolution dendrometer measurements with micro-anatomy have found xylem lignification can persist through autumn (Cuny et al., 2015). Thus, autumnal conditions can stimulate and prolong woody biomass production, leaving a fingerprint on the intra-annual course of the global carbon cycle (Piao et al., 2008). The application of wood anatomical studies, particularly in environments with strong and regular summer droughts such as the Mediterranean, could help identify moisture-controlled metabolic processes and ecophysiological reactions during the formation of tree rings, thereby enabling the separation of different development stages from anatomical traits.

3 Mushroom inventories

Rapid emergence, short lifespans, and non-photoperiodic constraints (Körner and Basler, 2010), make mushroom fruiting bodies ideal indicators of changes in late growing season conditions. Inter-annual and multi-decadal variations in the abundance of autumnal sporocarps (productivity), as well as the intra-annual timing of their occurrence (phenology), and species abundance (diversity), are closely related to the multifaceted interplay of biotic (mycelium and host interaction) and abiotic (environment and climate) factors (Boddy et al., 2014). Experimental findings, local observations, national inventories and their continental-scale compilations allow autumnal mushroom 'fruit body' dynamics to be reconstructed. Over seven million sporocarp records, representing >10,000 fungal species from nine countries, have been drawn from various scientific and citizen-science projects (Andrew et al., 2017). In addition to providing evidence of warming-induced spatiotemporal shifts in autumn mushroom phenology (Kauserud et al., 2012), this pan-European mycological inventory offers unique macro-ecological opportunities to assess how fungal communities interact with their environment. Exploring how fungal fruit body productivity and diversity is linked to biotic and abiotic factors, including tree growth, as well as climate variation and nitrogen deposition (Büntgen and Egli, 2014; Andrew et al., 2016; Van Strien et al., 2017), respectively, will provide new biological and ecological insights during autumn.

A non-traditional resource that can provide important mushroom-related data for autumnal climate change research, are governmental emergency services. Poison centers, such as the Swiss National Poisons Information Centre delivers 24-hour/7-days-a-week nationwide free medical advice. Since its establishment in 1966, the center has registered over one million poison-related inquiries with around one percent of all cases attributed to mushrooms (Schenk-Jäger et al., 2016). Comparison between these >12,000 mushroom-related calls with survey information from the Swiss National Data Centre for Biodiversity demonstrates the ability of poison center data to capture spatiotemporal patterns of fungal phenology, productivity and diversity (Schenk-Jäger et al., 2016).

4 What's next?

By providing timely examples of research initiatives that further a better understanding of biological and ecological responses to autumnal conditions (Gallinat et al., 2015), we hope to encourage diversity and creativity in future studies. For instance, there is a multitude of aquatic organisms that have life histories stored in distinct seasonal increments (Cole and Fairbanks, 1990; Morrongiello, et al., 2012; Black et al., 2014; Reynolds, et al., 2016). Complementary to terrestrial plant growth, information recorded in long-lived fish, bivalve and coral species can reflect autumnal and even winter signals at high temporal resolution (Black et al., 2017).

Moreover, we agree with Williams et al. (2015) about the biological and ecological importance of winter climate change. Knowledge of the intensity and duration of climate variability during winter is particularly critical for higher latitude and altitude ecosystems, where the impacts of winter temperature and precipitation on snow cover persist through most of the year. Although varying between organisms and habitats, cold season trends and extremes may alter chilling requirements, frost injury, energy and water balance, phenology and community interactions. At the same time, winter warming generally exceeds that during other months, with implications not only on the annual temperature cycle (Duan et al., 2017) and the Earth's carbon balance (Piao et al., 2008; Friend et al., 2014), but also by creating a temporal mismatch between the biological requirements of different ecosystem components and climate (Williams et al., 2015; Marra et al., 2016).

Future research on climate change ecology should consider the effects of changing temperature and hydroclimate (precipitation and drought) in autumn and winter. Emphasis should be given to investigations of the temporal synchronization of climate variability and species-specific biological demands. Future efforts should also consider mining the whole range of non-traditional, environmental inventories and metrics that exist today. The application of (process-based) mechanistic models (Friend et al., 2014; Yang et al., 2017), capable of detecting interactive influences and nonlinear factors affecting physiological alternations, and diversity in organisms throughout the year, are still in their infancy.

Author contributions. U. Büntgen developed the idea and wrote the paper together with P.J. Krusic.

Acknowledgements. Dr. Jeff Diez (University of Riverside, USA), Dr. Andrew Friend (University of Cambridge), Dr. Amanda Gallinat (Boston University), Prof. Christian Körner (University of Basel), and Dr. Andrew Liebhold (USDA Forest Service, USA), kindly commented on earlier versions of this paper. U.B. received funding from the Ministry of Education, Youth and Sports of CR within the National Sustainability Program I (NPU I; GN LO1415), and additional support was provided by NSF grant 0909541. We are particularly thankful to all colleagues that made their data available.

References

Andrew, C., Heegaard, E., Halvorsen, R., Martinez-Pena, F., Egli, S., Kirk, P.M., Bässler, C., Büntgen, U., Aldea, J., Høiland, K., Boddy, L. and Kauserud, H.: Climate impacts on fungal community and trait dynamics. Fungal Ecol., 22, 17–25, 2016.

Andrew, C., Heegaard, E., Kirk, P., Bässler, C., Heilmann-Clausen, J., Krisai-Greilhuber, I., Kuyper, T., Senn, B., Büntgen, U., Diez, J., Egli, S., Gange, A., Halvorsen, R., Høiland,

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-265
Manuscript under review for journal Biogeosciences
Discussion started: 20 July 2017

K., Nordén, J., Rustøen, F., Boddy, L. and Kauserud, H.: Big data integration: Pan-European fungal species observations' assembly for addressing contemporary questions in ecology and global change biology. Fungal Biol. Rev., 31, 88–98, 2017.

Black, B.A., Sydeman, W.J., Frank, D.C., Griffin, D., Stahle, D.W., García-Reyes, M., Rykaczewski, R.R., Bograd, S.J. and Peterson, W.T.: Six centuries of variability and extremes in a coupled marine-terrestrial ecosystem. Science 345, 1498–1502, 2014.

Black, B.A., Griffin, D., van der Sleen, P., Wanamaker, Jr. A.D., Speer, J.H., Frank, D.C., Stahle, D.W., Pederson, N., Copenhaever, C.A., Trouet, V., Griffin, S. and Gillanders, B.M.: The value of crossdating to retain high-frequency variability, climate signals, and extreme events in environmental proxies. Global Change Biol., 22, 2582–2595, 2016.

Boddy, L., Büntgen, U., Egli, S., Gange, A., Heegaard, E., Kirk, P., Mohammad, A. and Kauserud, H.: Climate variation effects on fungal fruiting. Fungal Ecol., 10, 20–33, 2014.

Büntgen, U. and Egli, S.: Breaking new ground at the interface of dendroecology and mycology. Trends Plant Sci., 19, 613–614, 2014.

Büntgen, U., Greuter, L., Bollmann, K., Jenny, H., Liebhold, A., Galvan, J.D., Stenseth, N.C., Andrew, C. and Mysterud, A.: Elevational range shifts in four mountain ungulate species from the Swiss Alps. Ecosphere 8(4), e01761. 10.1002/ecs2.1761, 2017.

Chen, I.C., Hill, J.K., Ohlemüller, R., Roy, D.B. and Thomas, C.D.: Rapid range shifts of species associated with high levels of climate warming. Science, 333, 1024–1026, 2011.

Cole, J.E. and Fairbanks, R.G.: The southern oscillation recorded in the $\delta^{18}O$ of corals from Tarawa atoll. Paleoceanograpy, 5, 669–683, 1990.

Cuny, H.E., Rathgeber, C.B.K., Frank, D.C., Fonti, P., Mäkinen, H., Prislan, P., Rossi, S., Martinez del Castillo, E., Campelo, F. et al.: Woody biomass production lags stem-girth increase by over one month in coniferous forests. Nature Plants 1, 1–6, 2015.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-265
Manuscript under review for journal Biogeosciences
Discussion started: 20 July 2017

Duan, J., Esper, J., Büntgen, U., Li, L., Xoplaki, E., Zhang, H., Wang, L., Fang, Y. and Luterbacher, J.: Weakening of annual temperature cycle over the Tibetan Plateau since the 1870s. Nature Com., 8, 14008, 2017.

Friend, A.D., Lucht, W., Rademacher, T.T., Keribin, R., Betts, R., Cadule, P., Ciais, P., Clark, D.B., Dankers, R., Falloon, P.D. et al.: Carbon residence time dominates uncertainty in terrestrial vegetation responses to future climate and atmospheric CO2. Proc. Natl. Acad. Sci. USA, 111, 3280–3285, 2014.

Gallinat, A.S., Primack, R.B. and Wagner, D.L.: Autumn, the neglected season in climate change research. Trends Ecol. Evol., 30, 169–176, 2015.

Gottfried, M., et al.: Continent-wide response of mountain vegetation to climate change. Nature Clim. Change, 2, 111–115. 2012.

Harsch, M.A., Hulme, P.E., McGlone, M.S. and R. P. Duncane, R.P.: Are treelines advancing? A global meta-analysis of treeline response to climate warming. Ecol. Lett., 12, 1040–1049, 2009.

Kauserud, H., Heegaard, E., Büntgen, U., Halvorsen, R., Egli, S., Boddy, L., Senn-Irlet, B., Greilhuber, I., Dämon, W., Sparks, T., Nordén, J., Høiland, K., Kirk, P., Semenov, M. and Stenseth, N.C.: Warming-induced shift in European mushroom fruiting phenology. Natl. Acad. Sci. USA, 109, 14488–14493, 2012.

Kays, R., Crofoot, M.C., Jetz, W. and Wikelski, M.: Terrestrial animal tracking as an eye on life and planet. Science, 343, 24781–24788, 2015.

Körner, C. and Basler, D.: Phenology under global warming. Science, 327, 1461–1462, 2010.

Lenoir, J., Gégout, J.C., Marquet, P.A., de Ruffray, P. and Brisse, H.: A significant upward shift in plant species optimum elevation during the 20th century. Science, 320, 1768–1771, 2008.

Marra, P.P., Cohen, E.B., Loss, S.R., Rutter, J.E. and Tonra, C.M.: A call for full annual cycle research in animal ecology. Biol. Lett., 11, 20150552, 2016.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-265
Manuscript under review for journal Biogeosciences
Discussion started: 20 July 2017

Morrongiello, J.R., Thresher, R.E. and Smith, D.C.: Aquatic biochronologies and climate change. Nature Clim. Change, 2, 849 – 857, 2012.

Parmesan, C. and Yohe, G.: A globally coherent fingerprint of climate change impacts across natural systems. Nature, 421, 37–42, 2003.

Pauli, H., et al.: Recent plant diversity changes on Europe's mountain summits. Science, 336, 353–355, 2012.

Piao, S., Ciais, P., Friedlingstein, P., Peylin, P., Reichstein, M., Luyssaert, S., Margolis, H., Fang, J., Barr, A. et al.: Net carbon dioxide losses of northern ecosystems in response to autumn warming. Nature, 451, 49–52, 2008.

Reynolds, D.J., Scourse, J.D., Halloran, P.R., Nederbragt, A.J., Wanamaker, A.D., Butler, P.G., Richardson, C.A., Heinemeier, J., Eirıksson, J., Knudsen, K.L. and Hall, I.R.: Annually resolved North Atlantic marine climate over the last millennium. Nature Commun., 7, 13502, 2016.

Rivrud, I.M., Bischof, R., Meisingset, E.L., Zimmermann, B., Egil Loe, L. and Mysterud, A.: Leave before it's too late: anthropogenic and environmental triggers of autumn migration in a hunted ungulate population. Ecol., 97, 1058–1068, 2016.

Schenk-Jäger, K.M., Egli, S., Hanimann, D., Senn-Irlet, B., Kupferschmidt, H. and Büntgen, U.: Introducing mushroom fruiting patterns from the Swiss National Poisons Information Centre. PLOS ONE, 11(9), e0162314, 2016.

Steppe, K., Sterck, F. and Deslauriers, A.: Diel growth dynamics in tree stems: linking anatomy and ecophysiology. Trends Plant Sci., 20, 335–343, 2015.

Thomas, C.D., et al.: Extinction risk from climate change. Nature, 427, 145–148, 2004.

Van Strien, A.J., Boomsluiter, M., Noordeloos, M.E., Verweij, R.J.T. and Kuyper, T.W.: Woodland ectomycorrhizal fungi benefit from large-scale reduction in nitrogen deposition in the Netherlands. J. Ecol., doi:10.1111/1365-2664.12944, 2017.

Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-265
Manuscript under review for journal Biogeosciences
Discussion started: 20 July 2017

Williams, C.M., Henry, H.A.L. and Sinclair, B.J.: Cold truths: how winter drives responses of terrestrial organisms to climate change. Biol. Rev., 90, 214–235, 2015.

Yang, B., He, M., Shishov, V., Tychkov, I., Vaganov, E., Rossi, S., Ljungqvist, F.C., Bräuning, A. and Grießinger, J.: New perspective on spring vegetation phenology and global climate change based on Tibetan Plateau tree-ring data. Proc. Natl. Acad. Sci. USA, doi:10.1073/pnas.1616608114, 2017.