

Title: The contribution of nitrogen deposition to the photosynthetic capacity of forests

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## Introduction

The auxiliary material includes 1 table with details of all included FLUXNET sites. The details include site ID (as in FLUXNET), their name and latitude, as well as forest type and climate zone, all these information was gathered through the FLUXNET website. The columns for N deposition and Amax are values that were derived during our analysis (further

information hereover is in de materials and methods of the paper), foliar N and LAI data was gathered through literature by the first author during the year 2011. The column (#yr) indicates how many years of fluxdata were included in the analysis per site. Citations for each site, and for the literature in which LAI and foliar N data was taken from are in the last 3 columns.

## Header of the Table

Table A1. Site characteristics of the 80 forest FLUXNET sites: Site abbreviation as in FLUXNET, site name (Site), Latitude (Lat), igpb- forest type (For) (DBF = Deciduous Broadleaf, EBF = Evergreen Broadleaf, ENF = Evergreen needleleaf, MF = Mixed Forest), climate group (Clim) (TE = Temperate, TR = Tropical, SM = Subtropical-Mediterranean, AR = Arctic, BO = Boreal, TC = Temperate-Continental), N deposition (Ndepo in kg N ha<sup>-1</sup> yr<sup>-1</sup>), Amax (Amax in μmol CO<sub>2</sub> m<sup>-2</sup> s<sup>-1</sup>), foliar N concentration (fol N in %N per gram dry weight), maximum tree LAI (LAI) in m<sup>2</sup> m<sup>-2</sup>, number of included data years (#yr), site citation, and citations for foliar N and LAI.

## Footnotes of the table

a LAI estimate includes understorey.

b Precipitation measurements were unavailable at fluxtower.

c Climate classification follows the Köppen-Geiger climate classification [Kottek et al., 2006].

d Name of Principal Investigator was given if no site reference was available.

e Sites were excluded due to unusually high leverage on regression results.

## References (references that are included in the Table of the auxiliary material

Anthoni, P. M., A. Knohl, C. Rebmann, A. Freibauer, M. Mund, W. Ziegler, O. Kolle, and E.-D. Schulze (2004), Forest and agricultural land-use-dependent CO<sub>2</sub> exchange in Thuringia, Germany, *Global Change Biol.*, 10(12), 2005-2019, doi:10.1111/j.1365-2486.2004.00863.x.

Arain, M. A., and N. Restrepo-Coupe (2005), Net ecosystem production in a temperate pine plantation in southeastern Canada, *Agr. Forest Meteorol.*, 128(3-4), 223-241.

Araújo, A. C., A. D. Nobre, B. Kruijt, J. A. Elbers, R. Dallarosa, P. Stefani, C. von Randow, A. O. Manzi, A. D. Culf, J. H. C. Gash, R. Valentini, and P. Kabat (2002), Comparative measurements of carbon dioxide fluxes from two nearby towers in a central Amazonian rainforest: The Manaus LBA site, *J. Geophys. Res.*, 107(D20), 8090, doi:10.1029/2001JD000676.

Aubinet, M., B. Chermanne, M. Vandenhaute, B. Longdoz, M. Yernaux, and E. Laitat (2001), Long term carbon dioxide exchange above a mixed forest in the Belgian Ardennes, *Agr. Forest Meteorol.*, 108(4), 293-315, doi:10.1016/S0168-1923(01)00244-1.

Beer, C., P. Ciais, M. Reichstein, D. Baldocchi, B. E. Law, D. Papale, J.-F. Soussana, C. Ammann, N. Buchmann, D. Frank, D. Gianelle, I. A. Janssens, A. Knohl, B. Köstner, E. Moors, O. Roupsard, H. Verbeeck, T. Vesala, C. A. Williams, and G. Wohlfahrt (2009), Temporal and among-site variability of inherent water use efficiency at the ecosystem level, *Global Biogeochem. Cycles*, 23(2), GB2018, doi:10.1029/2008GB003233.

Berbigier, P., J.-M. Bonnefond, and P. Mellmann (2001), CO<sub>2</sub> and water vapour fluxes for 2 years above Euroflux forest site, *Agr. Forest Meteorol.*, 108(3), 183-197, doi:10.1016/S0168-1923(01)00240-4.

Bergeron, O., H. A. Margolis, T. A. Black, C. Coursolle, A. L. Dunn, A. G. Barr, and S. C. Wofsy (2007), Comparison of carbon dioxide fluxes over three boreal black spruce forests in Canada, *Global Change Biol.*, 13(1), 89-107, doi:10.1111/j.1365-2486.2006.01281.x.

Bonal, D., A. Bosc, S. Ponton, J.-Y. Goret, B. Burban, P. Gross, J.-M. Bonnefond, J. Elbers, B. Longdoz, D. Epron, J.-M.

- Guehl, and A. Granier (2008), Impact of severe dry season on net ecosystem exchange in the Neotropical rainforest of French Guiana, *Global Change Biol.*, 14(8), 1917-1933, doi:10.1111/j.1365-2486.2008.01610.x.
- Bracho, R., T. L. Powell, S. Dore, J. Li, C. R. Hinkle, and B. G. Drake (2008), Environmental and biological controls on water and energy exchange in Florida scrub oak and pine flatwoods ecosystems, *J. Geophys. Res.*, 113(G2), G02004, doi:10.1029/2007JG000469.
- Carswell, F., A. Costa, M. Palheta, Y. Malhi, P. Meir, J. Costa, M. Ruivo, L. Leal, J. Costa, R. Clement, and J. Grace (2002), Seasonality in CO<sub>2</sub> and H<sub>2</sub>O flux at an eastern Amazonian rain forest, *J. Geophys. Res.*, 107(D20), 8076, doi:10.1029/2000JD00284.
- Chen, J., K. T. Paw U, S. L. Ustin, T. H. Suchanek, B. J. Bond, K. D. Brosofske, and M. Falk (2004), Net Ecosystem Exchanges of Carbon, Water, and Energy in Young and Old-growth Douglas-Fir Forests, *Ecosystems*, 7, 534-544, doi:10.1007/s10021-004-0143-.
- Chen, J. M., A. Govind, O. Sonnentag, Y. Zhang, A. Barr, and B. Amiro (2006), Leaf area index measurements at Fluxnet-Canada forest sites, *Agr. Forest Meteorol.*, 140(1-4), 257-268, doi:10.1016/j.agrformet.2006.08.005.
- Chiesi, M., F. Maselli, M. Bindi, L. Fibbi, P. Cherubini, E. Arlotta, G. Tirone, G. Matteucci, and G. Seufert (2005), Modelling carbon budget of Mediterranean forests using ground and remote sensing measurements, *Agr. Forest Meteorol.*, 135(1-4), 22-34, doi:10.1016/j.agrformet.2005.09.011.
- Clark, K. L., H. L. Gholz, and M. S. Castro (2004), Carbon dynamics along a chronosequence of slash pine plantations in North Florida, *Ecol. Appl.*, 14(4), 1154-1171, doi:10.1890/02-5391.
- David, T. S., M. I. Ferreira, S. Cohen, J. S. Pereira, and J. S. David (2004), Constraints on transpiration from an evergreen oak tree in southern Portugal, *Agr. Forest Meteorol.*, 122(3-4), 193-205, doi:10.1016/j.agrformet.2003.09.014.
- Davidson, E. A., K. E. Savage, S. E. Trumbore, and W. Borken (2006), Vertical partitioning of CO<sub>2</sub> production within a temperate forest soil, *Global Change Biol.*, 12(6), 944-956, doi:10.1111/j.1365-2486.2005.01142.x.
- Davis, K. J., P. S. Bakwin, C. Yi, B. W. Berger, C. Zhao, R. M. Teclaw, and J. G. Isebrands (2003), The annual cycles of CO<sub>2</sub> and H<sub>2</sub>O exchange over a northern mixed forest as observed from a very tall tower, *Global Change Biol.*, 9(9), 1278-1293, doi:10.1046/j.1365-2486.2003.00672.x.
- DeForest, J., A. Noormets, S. McNulty, G. Sun, G. Tenney, and J. Chen (2006), Phenophases alter the soil respiration-temperature relationship in an oak-dominated forest, *Int. J. Biometeorol.*, 51, 135-144, doi:10.1007/s00484-006-0046-7.
- Desai, A. R., P. V. Bolstad, B. D. Cook, K. J. Davis, and E. V. Carey (2005), Comparing net ecosystem exchange of carbon dioxide between an old-growth and mature forest in the upper Midwest, USA, *Agr. Forest Meteorol.*, 128(1-2), 33-55, doi:10.1016/j.agrformet.2004.09.005.
- Dolman, A. J., E. J. Moors, and J. A. Elbers (2002), The carbon uptake of a mid latitude pine forest growing on sandy soil, *Agr. Forest Meteorol.*, 111(3), 157-170, doi:10.1016/S0168-1923(02)00024-2.
- Dunn, A. L., C. C. Barford, S. C. Wofsy, M. L. Goulden, and B. C. Daube (2007), A long-term record of carbon exchange in a boreal black spruce forest: means, responses to interannual variability, and decadal trends, *Global Change Biol.*, 13(3), 577-590, doi:10.1111/j.1365-2486.2006.01221.x.
- Ellsworth, D. S., P. B. Reich, E. S. Naumburg, G. W. Koch, M. E. Kubiske, and S. D. Smith (2004), Photosynthesis, carboxylation and leaf nitrogen responses of 16 species to elevated pCO<sub>2</sub> across four free-air CO<sub>2</sub> enrichment experiments in forest, grassland and desert, *Global Change Biol.*, 10(12), 2121-2138, doi:10.1111/j.1365-2486.2004.00867.x.
- Flanagan, L. B., and K. H. Syed (2011), Stimulation of both photosynthesis and respiration in response to warmer and drier

conditions in a boreal peatland ecosystem, *Global Change Biol.*, 17(7), 2271-2287, doi:10.1111/j.1365-2486.2010.02378.x.

Garbulsky, M. F., J. Penuelas, D. Papale, and I. Filella (2008), Remote estimation of carbon dioxide uptake by a Mediterranean forest, *Global Change Biol.*, 14(12), 2860-2867, doi:10.1111/j.1365-2486.2008.01684.x.

Goulden, M. L., G. C. Winston, A. M. S. McMillan, M. E. Litvak, E. L. Read, A. V. Rocha, and J. R. Elliot (2006), An eddy covariance mesonet to measure the effect of forest age on land-atmosphere exchange, *Global Change Biol.*, 12(11), 2146-2162, doi:10.1111/j.1365-2486.2006.01251.x.

Granier, A., K. Pilegaard, and N. O. Jensen (2002), Similar net ecosystem exchange of beech stands located in France and Denmark, *Agr. Forest Meteorol.*, 114(1-2), 75-82, doi:10.1016/S0168-1923(02)00137-5.

Griffis, T. J., T. A. Black, K. Morgenstern, A. G. Barr, Z. Nestic, G. B. Drewitt, D. Gaumont-Guay, and J. H. McCaughey (2003), Ecophysiological controls on the carbon balances of three southern boreal forests, *Agr. Forest Meteorol.*, 117(1-2), 53-71, doi:10.1016/S0168-1923(03)00023-6.

Grünwald, T., and C. Bernhofer (2007), A decade of carbon, water and energy flux measurements of an old spruce forest at the Anchor Station Tharandt, *Tellus Ser. B*, 59(3), 387-396, doi:10.1111/j.1600-0889.2007.00259.x.

Grünzweig, J., T. Lin, E. Rotenberg, A. Schwartz, and D. Yakir (2003), Carbon sequestration in arid-land forest, *Global Change Biol.*, 9(5), 791-799.

Gu, L., T. Meyers, S. G. Pallardy, P. J. Hanson, B. Yang, M. Heuer, K. P. Hosman, Q. Liu, J. S. Riggs, D. Sluss, and S. D. Wullschlegel (2007), Influences of biomass heat and biochemical energy storages on the land surface fluxes and radiative temperature, *J. Geophys. Res.*, 112(D2), D02107, doi:10.1029/2006JD007425.

Gu, L., T. Meyers, S. G. Pallardy, P. J. Hanson, B. Yang, M. Heuer, K. P. Hosman, J. S. Riggs, D. Sluss, and S. D. Wullschlegel (2006), Direct and indirect effects of atmospheric conditions and soil moisture on surface energy partitioning revealed by a prolonged drought at a temperate forest site, *J. Geophys. Res.*, 111(D16), D16102, doi:10.1029/2006JD007161.

Guan, D.-X., J.-B. Wu, X.-S. Zhao, S.-J. Han, G.-R. Yu, X.-M. Sun, and C.-J. Jin (2006), CO<sub>2</sub> fluxes over an old, temperate mixed forest in northeastern China, *Agr. Forest Meteorol.*, 137(3-4), 138-149.

Hadley, J. L., P. S. Kuzeja, M. J. Daley, N. G. Phillips, T. Mulcahy, and S. Singh (2008), Water use and carbon exchange of red oak- and eastern hemlock-dominated forests in the northeastern USA: implications for ecosystem-level effects of hemlock woolly adelgid, *Tree Phys.*, 28(4), 615-627, doi:10.1093/treephys/28.4.615.

Hanson, P. J., S. D. Wullschlegel, R. J. Norby, T. J. Tschaplinski, and C. A. Gunderson (2005), Importance of changing CO<sub>2</sub>, temperature, precipitation, and ozone on carbon and water cycles of an upland-oak forest: incorporating experimental results into model simulations, *Global Change Biol.*, 11(9), 1402-1423, doi:10.1111/j.1365-2486.2005.00991.x.

Hirano, T., R. Hirata, Y. Fujinuma, N. Saigusa, S. Yamamoto, Y. Harazono, M. Takada, K. Inukai, and G. Inoue (2003), CO<sub>2</sub> and water vapor exchange of a larch forest in northern Japan, *Tellus Ser. B*, 55(2), 244-257.

Hirano, T., H. Segah, T. Harada, S. Limin, T. June, R. Hirata, and M. Osaki (2007), Carbon dioxide balance of a tropical peat swamp forest in Kalimantan, Indonesia, *Global Change Biol.*, 13(2), 412-425, doi:10.1111/j.1365-2486.2006.01301.x.

Hollinger, D. Y., J. Aber, B. Dail, E. A. Davidson, S. M. Goltz, H. Hughes, M. Y. Leclerc, J. T. Lee, A. D. Richardson, C. Rodrigues, N. Scott, D. Achuatavarier, and J. Walsh (2004), Spatial and temporal variability in forest-atmosphere CO<sub>2</sub> exchange, *Global Change Biol.*, 10(10), 1689-1706, doi:10.1111/j.1365-2486.2004.00847.x.

Humphreys, E. R., T. A. Black, K. Morgenstern, T. Cai, G. B. Drewitt, Z. Nestic, and J. Trofymow (2006), Carbon dioxide fluxes in coastal Douglas-fir stands at different stages of development after clearcut harvesting, *Agr. Forest Meteorol.*, 140(1-4), 6-22, doi:10.1016/j.agrformet.2006.03.018.

Janssens, I. A., D. A. Sampson, J. Cermak, L. Meiresonne, F. Riguzzi, S. Overloop, and R. Ceulemans (1999), Above- and belowground phytomass and carbon storage in a Belgian Scots pine stand, *Ann. For. Sci.*, 56(2), 81-90, doi:10.1051/forest:19990201.

Kergoat, L., S. Lafont, A. Arneth, V. Le Dantec, and B. Saugier (2008), Nitrogen controls plant canopy light-use efficiency in temperate and boreal ecosystems, *J. Geophys. Res. Biogeosci.*, 113(G4), G04017, doi:10.1029/2007JG000676.

Knohl, A., E.-D. Schulze, O. Kolle, and N. Buchmann (2003), Large carbon uptake by an unmanaged 250-year-old deciduous forest in Central Germany, *Agr. Forest Meteorol.*, 118(3-4), 151-167.

Kowalski, A. S., D. Loustau, P. Berbigier, G. Manca, V. Tedeschi, M. Borghetti, R. Valentini, P. Kolari, F. Berninger, Å. Rannik, P. Hari, M. Rayment, M. Mencuccini, J. Moncrieff, and J. Grace (2004), Paired comparisons of carbon exchange between undisturbed and regenerating stands in four managed forests in Europe, *Global Change Biol.*, 10(10), 1707--1723, doi:10.1111/j.1365-2486.2004.00846.x.

Law, B., P. Thornton, J. Irvine, P. Anthoni, and S. Van Tuyl (2001), Carbon storage and fluxes in ponderosa pine forests at different developmental stages, *Global Change Biol.*, 7(7), 755-777.

Law, B. E., O. J. Sun, J. Campbell, S. van Tuyl, and P. E. Thornton (2003), Changes in carbon storage and fluxes in a chronosequence of ponderosa pine, *Global Change Biol.*, 9(4), 510-524, doi:10.1046/j.1365-2486.2003.00624.x.

Leuning, R., H. A. Cleugh, S. J. Zegelin, and D. Hughes (2005), Carbon and water fluxes over a temperate Eucalyptus forest and a tropical wet/dry savanna in Australia: measurements and comparison with MODIS remote sensing estimates, *Agr. Forest Meteorol.*, 129(3-4), 151-173, doi:DOI: 10.1016/j.agrformet.2004.12.004.

Lindroth, A., A. Grelle, and A.-S. Morén (1998), Long-term measurements of boreal forest carbon balance reveal large temperature sensitivity, *Global Change Biol.*, 4(4), 443-450, doi:10.1046/j.1365-2486.1998.00165.x.

Lindroth, A., F. Lagergren, M. Aurela, B. Bjarnadottir, T. Christensen, E. Dellwik, A. Grelle, A. Ibrom, T. Johansson, H. Lankreijer, S. Launiainen, T. Laurila, M. Molder, E. Nikinmaa, K. Pilegaard, B. D. Sigurdsson, and T. Vesala (2008), Leaf area index is the principal scaling parameter for both gross photosynthesis and ecosystem respiration of Northern deciduous and coniferous forests, *Tellus Ser. B*, 60(2), 129-142, doi:10.1111/j.1600-0889.2007.00330.x.

Liu, H., J. T. Randerson, J. Lindfors, I. Chapin, and F. Stuart (2005), Changes in the surface energy budget after fire in boreal ecosystems of interior Alaska: An annual perspective, *J. Geophys. Res.*, 110(D13), D13101, doi:10.1029/2004JD005158.

Marcolla, B., A. Pitacco, and A. Cescatti (2003), Canopy architecture and turbulence structure in a coniferous forest, *Boundary Layer Meteorol.*, 108(1), 39-59.

McCaughey, J., M. Pejam, M. Arain, and D. Cameron (2006), Carbon dioxide and energy fluxes from a boreal mixedwood forest ecosystem in Ontario, Canada, *Agr. Forest Meteorol.*, 140(1-4), 79-96, doi:10.1016/j.agrformet.2006.08.010.

Medlyn, B. E., P. Berbigier, R. Clement, A. Grelle, D. Loustau, S. Linder, L. Wingate, P. G. Jarvis, B. D. Sigurdsson, and R. E. McMurtrie (2005), Carbon balance of coniferous forests growing in contrasting climates: Model-based analysis, *Agr. Forest Meteorol.*, 131(1-2), 97-124, doi:10.1016/j.agrformet.2005.05.004.

Michelot, A., Eglin, Thomas, Dufrene, Eric, C. Lelarge-Trouverie, and C. Damesin (2011), Comparison of seasonal variations in water-use efficiency calculated from the carbon isotope composition of tree rings and flux data in a temperate forest, *Plant Cell Environ.*, 34(2), 230-244, doi:10.1111/j.1365-3040.2010.02238.x.

Milyukova, I., O. Kolle, A. Varlagin, N. Vygodskaya, E. Schulze, and J. Lloyd (2002), Carbon balance of a southern taiga spruce stand in European Russia, *Tellus Ser. B*, 54(5), 429-442.

- Monson, R. K., A. A. Turnipseed, J. P. Sparks, P. C. Harley, L. E. Scott-Denton, K. Sparks, and T. E. Huxman (2002), Carbon sequestration in a high-elevation, subalpine forest, *Global Change Biol.*, 8(5), 459-478, doi:10.1046/j.1365-2486.2002.00480.x.
- Montagnani, L., G. Manca, E. Canepa, E. Georgieva, M. Acosta, C. Feigenwinter, D. Janous, G. Kerschbaumer, A. Lindroth, L. Minach, S. Minerbi, M. Molder, M. Pavelka, G. Seufert, M. Zeri, and W. Ziegler (2009), A new mass conservation approach to the study of CO<sub>2</sub> advection in an alpine forest, *J. Geophys. Res. Atmos.*, 114, doi:10.1029/2008JD010650.
- Nave, L. E., C. S. Vogel, C. M. Gough, and P. S. Curtis (2009), Contribution of atmospheric nitrogen deposition to net primary productivity in a northern hardwood forest, *Can. J. For. Res.*, 39(6), 1108-1118, doi:10.1139/X09-038.
- NitroEuropeIP, coordinated by the Centre for Ecology and Hydrology.
- Noormets, A., J. Chen, and T. Crow (2007), Age-Dependent Changes in Ecosystem Carbon Fluxes in Managed Forests in Northern Wisconsin, USA, *Ecosystems*, 10, 187-203, doi:10.1007/s10021-007-9018-y.
- Ollinger, S. V., A. D. Richardson, M. E. Martin, D. Y. Hollinger, S. E. Frohking, P. B. Reich, L. C. Plourde, G. G. Katul, J. W. Munger, R. Oren, M.-L. Smith, K. T. Paw U, P. V. Bolstad, B. D. Cook, M. C. Day, T. A. Martin, R. K. Monson, and H. P. Schmid (2008), Canopy nitrogen, carbon assimilation, and albedo in temperate and boreal forests: Functional relations and potential climate feedbacks, *PNAS*, 105(49), 19336-19341, doi:10.1073/pnas.0810021105.
- Ollinger, S., and M.-L. Smith (2005), Net Primary Production and Canopy Nitrogen in a Temperate Forest Landscape: An Analysis Using Imaging Spectroscopy, Modeling and Field Data, *Ecosystems*, 8, 760-778, doi:10.1007/s10021-005-0079-5.
- Op de Beeck, M., B. Gielen, I. Jonckheere, R. Samson, I. A. Janssens, and R. Ceulemans (2010), Needle age-related and seasonal photosynthetic capacity variation is negligible for modelling yearly gas exchange of a sparse temperate Scots pine forest, *Biogeosc.*, 7(1), 199-215, doi:10.5194/bg-7-199-2010.
- Palmroth, S., and P. Hari (2001), Evaluation of the importance of acclimation of needle structure, photosynthesis, and respiration to available photosynthetically active radiation in a Scots pine canopy, *Can. J. For. Res.*, 31(7), 1235-1243, doi:10.1139/x01-051.
- Peltoniemi, M., M. Pulkkinen, P. Kolari, R. Duursma, L. Montagnani, S. Wharton, F. Lagergren, K. Takagi, H. Verbeeck, T. Christensen, T. Vesala, M. Falk, D. Loustau, and A. Mäkelä (2012), Does canopy mean N concentration explain differences in light use efficiencies of canopies in 14 contrasting forest sites? *Tree Phys.* 32(2), 200-218, doi:10.1093/treephys/tpr140.
- Pilegaard, K., T. Mikkelsen, C. Beier, N. Jensen, P. Ambus, and H. Ro-Poulsen (2003), Field measurements of atmosphere-biosphere interactions in a Danish beech forest, *Boreal Environ. Res.*, 8(4), 315-333.
- Powell, T. L., H. L. Gholz, K. L. Clark, G. Starr, W. P. Cropper, and T. A. Martin (2008), Carbon exchange of a mature, naturally regenerated pine forest in north Florida, *Global Change Biol.*, 14(11), 2523-2538, doi:10.1111/j.1365-2486.2008.01675.x.
- Rambal, S., R. Joffre, J. M. Ourcival, J. Cavender-Bares, and A. Rocheteau (2004), The growth respiration component in eddy CO<sub>2</sub> flux from a *Quercus ilex* mediterranean forest, *Global Change Biol.*, 10(9), 1460-1469, doi:10.1111/j.1365-2486.2004.00819.x.
- von Randow, C., A. O. Manzi, B. Kruijt, P. J. de Oliveira, F. B. Zanchi, R. L. Silva, M. G. Hodnett, J. H. C. Gash, J. A. Elbers, M. J. Waterloo, F. L. Cardoso, and P. Kabat (2004), Comparative measurements and seasonal variations in energy and carbon exchange over forest and pasture in South West Amazonia, *Theor. Appl. Climatol.*, 78, 5-26, doi:10.1007/s00704-004-0041-z.
- Read, D.J., P.H. Freer-Smith, J.I.L. Morison, N. Hanley, C.C. West, and P. Snowdon, (Eds) (2009), Combating climate change – a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change. The synthesis report, The Stationery Office, Edinburgh.

Reichstein, M., E. Falge, D. Baldocchi, D. Papale, M. Aubinet, P. Berbigier, C. Bernhofer, N. Buchmann, T. Gilmanov, A. Granier, T. Grünwald, K. Havránková, H. Ilvesniemi, D. Janous, A. Knohl, T. Laurila, A. Lohila, D. Loustau, G. Matteucci, T. Meyers, F. Miglietta, J.-M. Ourcival, J. Pumpanen, S. Rambal, E. Rotenberg, M. Sanz, J. Tenhunen, G. Seufert, F. Vaccari, T. Vesala, D. Yakir, and R. Valentini (2005), On the separation of net ecosystem exchange into assimilation and ecosystem respiration: review and improved algorithm, *Global Change Biol.*, 11(9), 1424-1439, doi:10.1111/j.1365-2486.2005.001002.x.

Roberntz, P. (2001), Atmospheric carbon dioxide concentration, nitrogen availability, temperature and the photosynthetic capacity of current-year Norway spruce shoots, *Tree Phys.*, 21(12-13), 931-940, doi:10.1093/treephys/21.12-13.931.

da Rocha, H. R., A. O. Manzi, O. M. Cabral, S. D. Miller, M. L. Goulden, S. R. Saleska, N. R.-Coupe, S. C. Wofsy, L. S. Borma, P. Artaxo, G. Vourlitis, J. S. Nogueira, F. L. Cardoso, A. D. Nobre, B. Kruijt, H. C. Freitas, C. von Randow, R. G. Aguiar, and J. F. Maia (2009), Patterns of water and heat flux across a biome gradient from tropical forest to savanna in Brazil, *J. Geophys. Res.*, 114(G1), G00B12, doi:10.1029/2007JG000640.

Roupsard, O., J.-M. Bonnefond, M. Irvine, P. Berbigier, Y. Nouvellon, J. Dautzat, S. Taga, O. Hamel, C. Jourdan, L. Saint-André, I. Mialet-Serra, J.-P. Labrousse, D. Epron, R. Joffre, S. Braconnier, A. Rouzière, M. Navarro, and J.-P. Bouillet (2006), Partitioning energy and evapo-transpiration above and below a tropical palm canopy, *Agr. Forest Meteorol.*, 139(3-4), 252-268, doi:10.1016/j.agrformet.2006.07.006.

Saigusa, N., S. Yamamoto, S. Murayama, H. Kondo, and N. Nishimura (2002), Gross primary production and net ecosystem exchange of a cool-temperate deciduous forest estimated by the eddy covariance method, *Agr. Forest Meteorol.*, 112(3-4), 203-215, doi:10.1016/S0168-1923(02)00082-5.

Saleska, S. R., S. D. Miller, D. M. Matross, M. L. Goulden, S. C. Wofsy, H. R. da Rocha, P. B. de Camargo, P. Crill, B. C. Daube, H. C. de Freitas, L. Huttyra, M. Keller, V. Kirchhoff, M. Menton, J. W. Munger, E. H. Pyle, A. H. Rice, and H. Silva (2003), Carbon in Amazon Forests: Unexpected Seasonal Fluxes and Disturbance-Induced Losses, *Science*, 302(5650), 1554-1557, doi:10.1126/science.1091165.

Sanz, M., A. Carrara, C. Gimeno, A. Bucher, and R. López (2004), Effects of a dry and warm summer conditions on CO<sub>2</sub> and energy fluxes from three Mediterranean ecosystems, *Geophys. Res. Abstr.*, 6, 03239.

Scartazza, A., C. Mata, G. Matteucci, D. Yakir, S. Moscatello, and E. Brugnoli (2004), Comparisons of δ<sup>13</sup>C of photosynthetic products and ecosystem respiratory CO<sub>2</sub> and their responses to seasonal climate variability, *Oecol.*, 140, 340-351, doi:10.1007/s00442-004-1588-1.

Schindler, D., M. Türk, and H. Mayer (2006), CO<sub>2</sub> fluxes of a Scots pine forest growing in the warm and dry southern upper Rhine plain, SW Germany, *Eur. J. Forest Res.*, 125, 201-212, doi:10.1007/s10342-005-0107-1.

Schmid, H. P., C. S. B. Grimmond, F. Copley, B. Offerle, and H.-B. Su (2000), Measurements of CO<sub>2</sub> and energy fluxes over a mixed hardwood forest in the mid-western United States, *Agr. Forest Meteorol.*, 103(4), 357-374, doi:10.1016/S0168-1923(00)00140-4.

Schwarz, P. A., B. E. Law, M. Williams, J. Irvine, M. Kurpius, and D. Moore (2004), Climatic versus biotic constraints on carbon and water fluxes in seasonally drought-affected ponderosa pine ecosystems, *Global Biogeochem. Cycles*, 18(4), GB4007, doi:10.1029/2004GB002234.

Staudt, K., and Foken, T. (2007), Documentation of reference data for the experimental areas of the Bayreuth Centre for Ecology and Environmental Research (BayCEER) at the Waldstein site, in *Arbeitsergebnisse, Universität Bayreuth, Abt. Mikrometeorologie* (ISSN 1614-8916), 35, pp. 1-35.

Suni, T., F. Berninger, T. Vesala, T. Markkanen, P. Hari, A. Mäkelä, H. Ilvesniemi, H. Hänninen, E. Nikinmaa, T. Huttula, T. Laurila, M. Aurela, A. Grelle, A. Lindroth, A. Arneth, O. Shibistova, and J. Lloyd (2003), Air temperature triggers the recovery of evergreen boreal forest photosynthesis in spring, *Global Change Biol.*, 9(10), 1410-1426, doi:10.1046/j.1365-2486.2003.00597.x.

Syed, K. H., L. B. Flanagan, P. J. Carlson, A. J. Glenn, and K. E. Van Gaalen (2006), Environmental control of net ecosystem CO<sub>2</sub> exchange in a treed, moderately rich fen in northern Alberta, *Agr. Forest Meteorol.*, 140(1-4), 97-114.

Takagi, K., K. Fukuzawa, N. Liang, M. Kayama, M. Nomura, H. Hojyo, S. Sugata, H. Shibata, T. Fukuzawa, Y. Takahashi, T. Nakaji, H. Oguma, M. Mano, Y. Akibayashi, T. Murayama, T. Koike, K. Sasa, and Y. Fujinuma (2009), Change in CO<sub>2</sub> balance under a series of forestry activities in a cool-temperate mixed forest with dense undergrowth, *Global Change Biol.*, 15(5), 1275-1288, doi:10.1111/j.1365-2486.2008.01795.x.

Thomas, C., and T. Foken (2007), Flux contribution of coherent structures and its implications for the exchange of energy and matter in a tall spruce canopy, *Boundary Layer Meteorol.*, 123, 317-337, doi:10.1007/s10546-006-9144-7.

Thomas, V., P. Treitz, J. H. McCaughey, T. Noland, and L. Rich (2008), Canopy chlorophyll concentration estimation using hyperspectral and lidar data for a boreal mixedwood forest in northern Ontario, Canada, *Int. J. Rem. Sens.*, 29(4), 1029-1052, doi:10.1080/01431160701281023.

Urbanski, S., C. Barford, S. Wofsy, C. Kucharik, E. Pyle, J. Budney, K. McKain, D. Fitzjarrald, M. Czikowsky, and J. W. Munger (2007), Factors controlling CO<sub>2</sub> exchange on timescales from hourly to decadal at Harvard Forest, *J. Geophys. Res.*, 112(G2), doi:10.1029/2006JG000293.

Vesala, T., T. Suni, Ü. Rannik, P. Keronen, T. Markkanen, S. Sevanto, T. Grönholm, S. Smolander, M. Kulmala, H. Ilvesniemi, R. Ojansuu, A. Uotila, J. Levula, A. Mäkelä, J. Pumpanen, P. Kolari, L. Kulmala, N. Altimir, F. Berninger, E. Nikinmaa, and P. Hari (2005), Effect of thinning on surface fluxes in a boreal forest, *Global Biogeochem. Cycles*, 19(2), GB2001, doi:10.1029/2004GB002316.

Zenone, T. (2007), Measuring Terrestrial CO<sub>2</sub> Uptake in a Short Rotation Forestry of Poplar for Bioenergy Production: Comparison between Biometric and Micrometeorological Techniques, PhD Thesis, University of Padova.