Detecting changes in essential ecosystem and biodiversity properties- towards a Biosphere Atmosphere Change Index: BACI

Deliverable 3.2: Synthesis data product of ecosystem parameters derived at Fluxnet sites, characterized by uncertainty estimation

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Summary

This deliverable describes the methods used for generating Ecosystem Functional Properties (EFPs) for the purpose of "upscaling" in WP4 and as reference test in WP5, providing an overview of results. The scientific focus is on providing site level time series of EFPs at daily time resolution useful for recognizing slow and/or suddenly changes in ecosystems health and functionality.

Aims

The functionality of land ecosystem can be summarized by array of features generally named Ecosystem Functional Properties (EFPs), most of them describing the capability of green ecosystems to optimize natural resource (e.g. light or water) for carbon uptake. Several studies have highlighted how EFPs, at the ecosystem scale, could change as a direct/indirect effects of global change (Keenan et al., 2013). In fact, EFPs are affected by many factors such as the ecosystem type (e.g. forest vs cropland plant functional types, boreal vs Mediterranean climate etc.), health of green vegetation, vegetation density or environmental (and climatic) stress factors. Changes in EFPs can be slow as consequence of the adaptation of natural ecosystem to the environmental conditions, or suddenly, such in the case of strong disturbances. For this reason EFPs should be continuously monitored by ecosystem scale measurements having fine time resolution. The FLUXNET network provides ecosystem scale estimation of carbon and energy exchange for the most relevant land ecosystem over the world. More than 400 study sites are continuously monitored in the context of the FLUXNET network. In addition, the high temporal resolution (30-60 minutes) of the measurements makes thee data unique and particularly suited for EFPs estimation. Thus, the FLUXNET records have been used for evaluating the EFPs by direct calculation and by model parameterization.

The main objective of "*Task 3.2 Synthesis of relevant ecosystem scale functional parameters (EFPs, cf. definitions) derived by Fluxnet sites records and ancillary information, characterized by uncertainty estimation"* is to provide a synthesis of the most relevant ecosystem functional properties using the FLUXNET dataset. We have estimated the following EFPs:

- Light Use Efficiency (LUE)
- Water Use Efficiency (WUE)
- Inherent WUE
- Bowen Ratio

The estimated EFPs have been provided at ecosystem scale and at daily time resolution. In addition direct estimation of the EFPs uncertainties have been provided day-by-day. Finally, ancillary information of the quality of the data and measurements conditions have been provided for the users.

Data

Data used for the task purpose are the half hourly time series of carbon and energy fluxes provided by FLUXNET2015 dataset TIER 1 (FULLSET). In particular, we used the estimated values of Gross Primary Production (GPP) as carbon fluxes (photosynthesis); Latent heat of evapotraspiration (LE) and sensible heat (H) among the energy fluxes. GPP has been estimated starting from Net Ecosystem Exchange (NEE) measurements by partitioning. Two different partitioning methods have been applied for estimating GPP: one based on nighttime respiration extrapolation as described in Reichstein et al. (2005) and the other based on daytime data for the parameterization of a NEE model as described in Lasslop et al. (2010). For each method, different GPPs have been derived by the use of 6 different versions of NEE, each one derived by different u* filtering setup (constant and variable u* threshold over the years and different selection of the reference threshold to be used, see FLUXNET webpage for details at http://fluxnet/fluxdata.org). We used all the derived GPP in order to get a consisten estimation of the uncertainties. LE is the energy used for the evapotraspiration of H_2O from land surface, it is responsible of the changing states of water (from liquid to air) and its transfer toward the atmosphere. LE is mediated by the photosynthetic activity by plants. Conversely H is associated with changing in temperature thus it is related to the warming/cooling of the environments. H and LE are provided in two different versions in the FLUXNET2015 dataset: raw measurements and corrected estimates for the energy balance closure. We used both versions for H and LE. Meteorological records were also provided by FLUXNET dataset. For the purpose of Task 3.2 we used the records for incoming global shortwave radiation (Rad), rain precipitation (P) and Vapor Pressure Deficit (VPD).

Data Use Agreements

EFPs have been derived by FLUXNET 2015 dataset FULLSET TIER1. EFPs can be only used in the context of BACI project and must not be directly re-distributed beyond BACI without respecting the original data policy. The policy for use of EFPs is the same of FLUXNET 2015 dataset FULLSET TIER1 that we reported at follow. More information can be found here: http://fluxnet.fluxdata.org/data/data-policy/.

"Tier One data are open and free for scientific and educational purposes and their use will follow the fair use policy, stated here. Data users describe the intended use of the data when they fill out the data-download form; this intended-use statement will be emailed to the data producer(s) and posted on the Fluxdata website (https://fluxnet.fluxdata.org). The fair use policy dictates that (1) data producers are informed of who uses the data and for what purpose (which can be satisfied by the aforementioned mechanism) and (2) that proper acknowledgment and citations are given to all data used in a peer reviewed publication, via the following protocols: The data citation will be either a per-site DOI that is provided with the data download or a citation of a publication for each site. Every publication should use the standard FLUXNET acknowledgment given below. It is requested that every publication specify each site used with the FLUXNET-ID, data-years used, data DOI (in preparation), and brief acknowledgment for funding (if provided by FLUXNET PI) in the text or supplementary material. Finally, all data providers should be informed of forthcoming publications."

Metadata, methods and processing

Before methods description, we provide an overview of the EFPs estimated by FLUXENT data in Task 3.2. LUE states for the capacity with which vegetation converts the incoming light to fixed carbon (Gitelson et al., 2015). It was derived by the work of Monteith (1972) and Monteith et al., (1977) and it is important because direct statement of the photosynthetic capacity of land ecosystems. In our dataset LUE has been calculated as the ratio between GPP and Rad. LUE varies with the ecosystem types, vegetation health, seasonality and environmental constraining factors. Water Use Efficiency (WUE) states the capability of an ecosystem to convert each unit of water loss (by evapotraspiration) in gross biomass production (Beer et al., 2009). In fact, photosynthetic rate is directly related to the water loss as transpiration trough stomata by plants (Cowan and Farquhar, 1977). WUE (at ecosystem scale) states the capability of green ecosystem to optimize the available water that moves from soil to atmosphere through plant canopies. WUE is affected by soil water availability and environmental conditions constraining evaporative demand (e.g. high vapour pressure deficit). WUE has been estimated as the ratio between GPP and ET. Inherent WUE, accounts for the evaporative demand by atmosphere and it has been estimated as (VPD*GPP)/ET. Finally, Bowen ratio is used to define the amount (as ratio) of energy used for warming in comparison with the one used for evapotraspiration. Bowen ratio has been estimated as the ratio between H and LE. In general it is higher in bare and dry soils and lower in dense forests.

Because we have different versions for the same flux (e.g. different GPP estimates), we have used each one version singularly, thus different versions of EFPs have been calculated. We started from half hourly measurements. LUE, WUE and Inherent WUE are strictly connected with photosynthetic activity, thus only daytime period has been used for these EFPs estimation.

Since eddy covariance data are affected by gap due to invalid measures for different bad features (acquisition failure, low turbulence, advection etc), data gap have been filled using the MDS method reported in Reichstein et al. (2005). We have used gap filled data for calculating the EFPs but the quality of the data has been considered and reported. Daily EFPs have been estimated as ratios of mean daily daytime values; daily daytime values have been calculated applying a bootstrap methods on the half hourly values, allowing to calculate the mean daily values and the mean daily uncertainty of the estimates. For the presence of gap-filled data, each daily estimates is complemented by quality flags information. In fact, each EFP variable is stored and provided as tables containing EFPs value, EFPs uncertainty, and the three fields for quality check: “QualityFlag”, “DaytimeRatio” and “OverallDayQuality” with values ranging between 0 and 1. “QualityFlag” reports the percentage of daytime half hourly value that are measured or high quality gap filled; “DaytimeRatio “ reports the fraction of daytime period over the day; “OverallDayQuality“, provides the same information that are in “QualityFlag” but for the whole day (considering also the nighttime period). In addition, because evapotraspiration can be affected by recent rain events, an additional ancillary information was derived by precipitation records: it is stored in the variable “Day After Rain events“ and reports the days after the last rain events (0 when a rain events occurred in the same day).

Results

Using the FLUXNET data TIER1 we obtained 12 versions of LUE, 24 versions of WUE and Inherent WUE and 2 versions of Bowen Ratio. Each EFP was estimated at daily time step for 166 FLUXNET sites, leading to roughly 400.000 daily records for each EFP version.

In figure 1 it is reported an example of the distribution of daily values for estimated EFPs in the case of FLUXNET site IT-Ro2 (Roccarespampani 2), a Mediterranean oak forest located in central Italy.

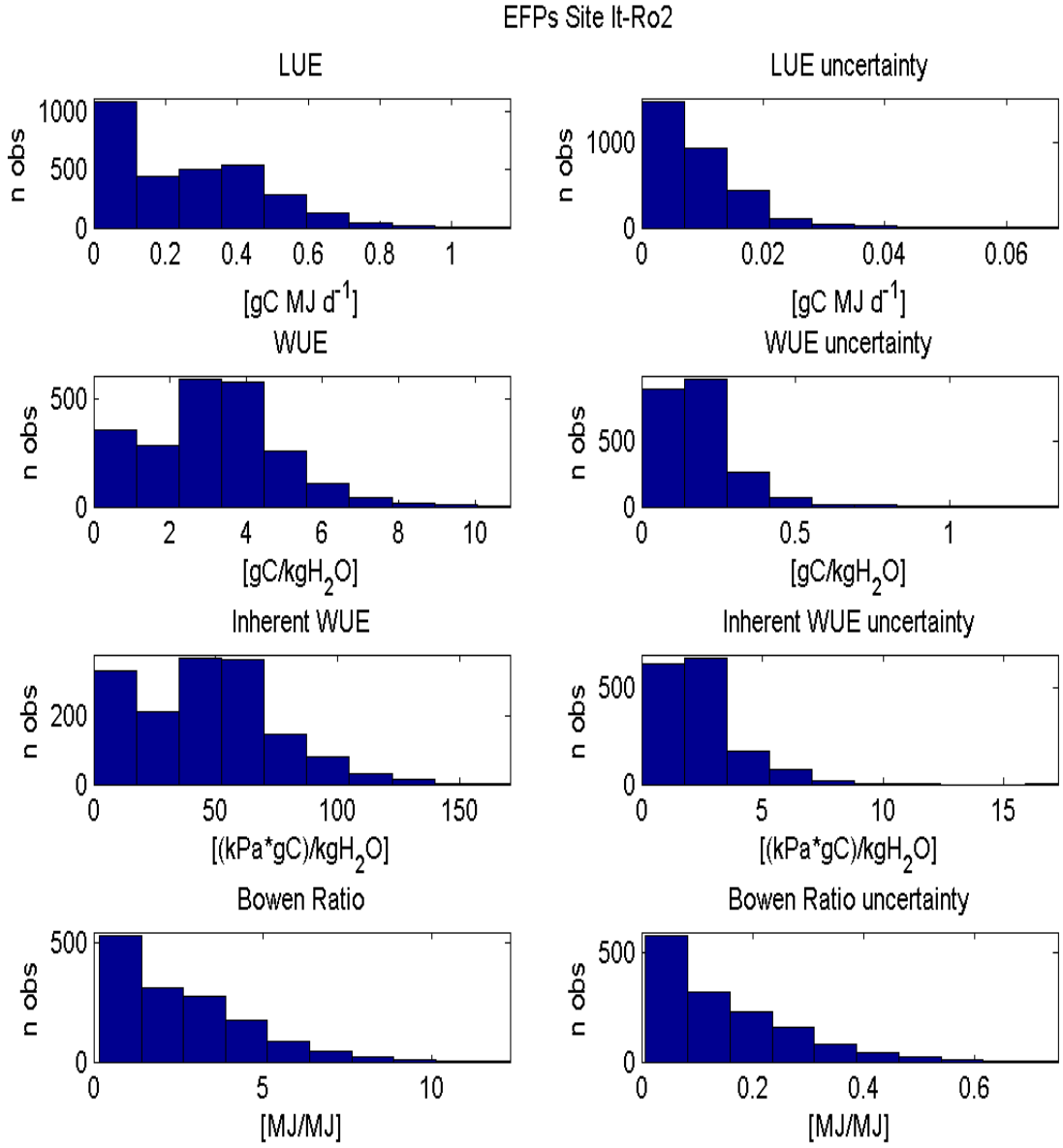

Figure 1: distribution of daily values of LUE, WUE, Inherent WUE and Bowen ratio calculated for the site IT-Ro2, a Mediterranean oak forest in central Italy. EFPs reported in the current figure have been estimated using GPP (Lasslop, Constant u*, USTAR50) and energy fluxes (H and LE) not corrected for the energy balance closure.

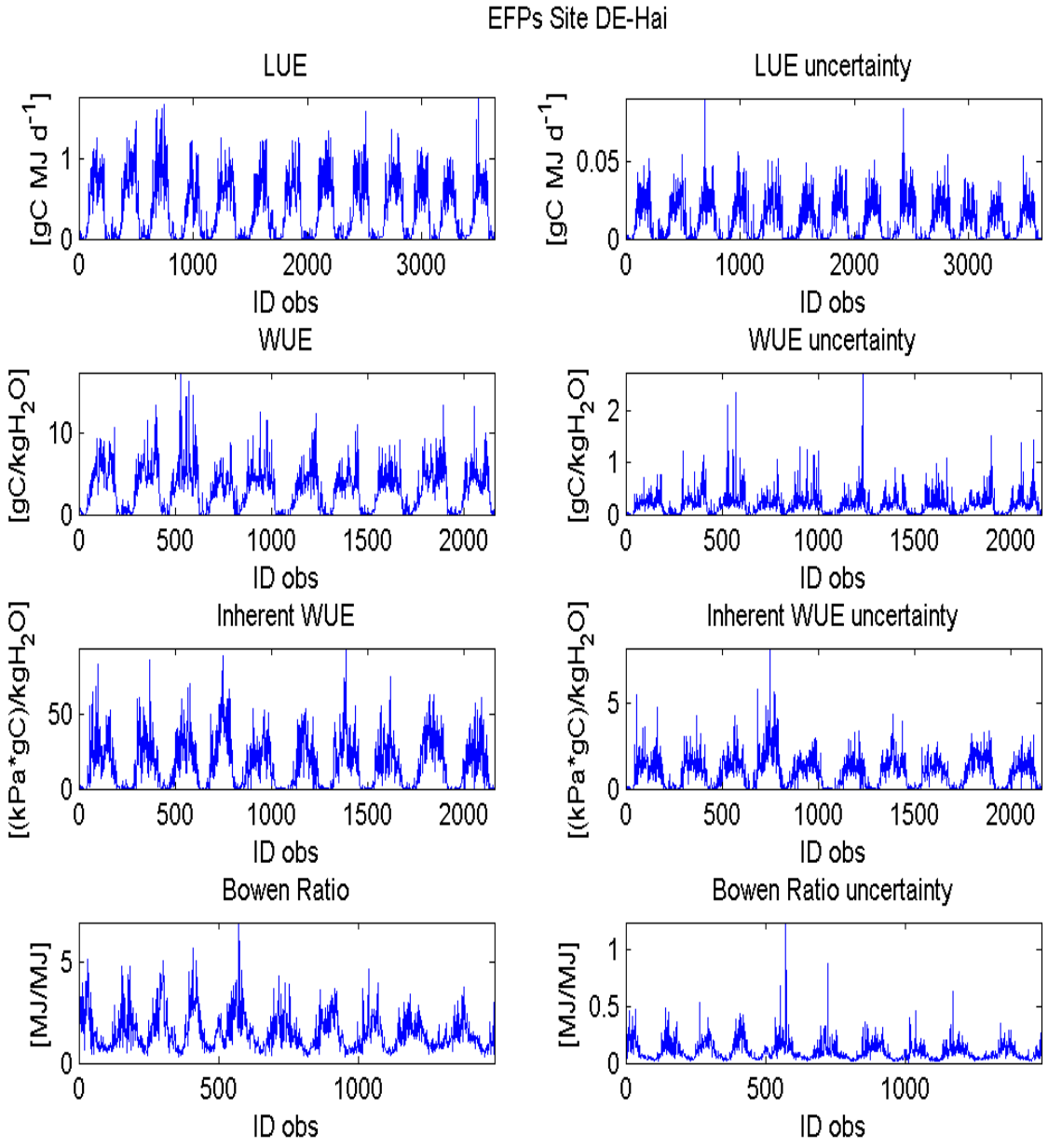

Figure 2: example of the seasonal dynamics of LUE, WUE, Inherent WUE and Bowen ratio calculated for the site DE-Hai, a deciduous broadleaved forest in Germany. EFPs reported in the current figure have been estimated using GPP (Lasslop, Constant u*, USTAR50) and energy fluxes (H and LE) not corrected for the energy balance closure.

The seasonal dynamics of GPP and energy fluxes is also mirrored in EFPs dynamics (figure 2). The mean site value of daily LUE, derived from daily estimates, ranged between 0.02-0.69 gC MJ^{-1}, while the corresponding value in the case of WUE, Inherent WUE and Bowen Ratio ranged

respectively between 0.76-7.8 gC/kgH_2O, 4-194 (kPa gC)/kgH_2O and 0.32-5.26 MJ/MJ. For all EFPs, the mean value of daily uncertainty are generally lower than 10% of the mean site values (excluding few outlier sites in which the mean value of daily uncertainty is greater). The spread among different versions of EFPs, due to different versions of GPP and LE in input, resulted lower than 20% of the mean site values, used as reference. In Appendix 1-4 of this document there are summarized the mean site values of the estimated EFPs for a subsample of study sites accomplished by the mean values of estimated daily uncertainties and the spread among versions.

Long term time series of estimated EFPs could be useful for understanding changing of ecosystem functionality in the context of climate changes. In figure 3 it is shown an example of the changing over the time of estimated EFP for the evergreen forest FR-Pue. Due to the fact that EFPs change seasonally, we evaluated the trend over the years for two seasons: spring and summer. We found a general decrease of LUE, WUE and Inherent WUE in both seasons, that could be due to a reduction of ecosystem photosynthetic activity across the years. In figure 4 it is reported the distribution of correlation coefficients between time (years) and seasonal EFPs for a subset of study sites in North hemisphere, then grouped per PFT. It is possible to note a general increase of WUE in spring and summer in the case of DBF sites, while a general decrease of WUE was found in the case of EBF.

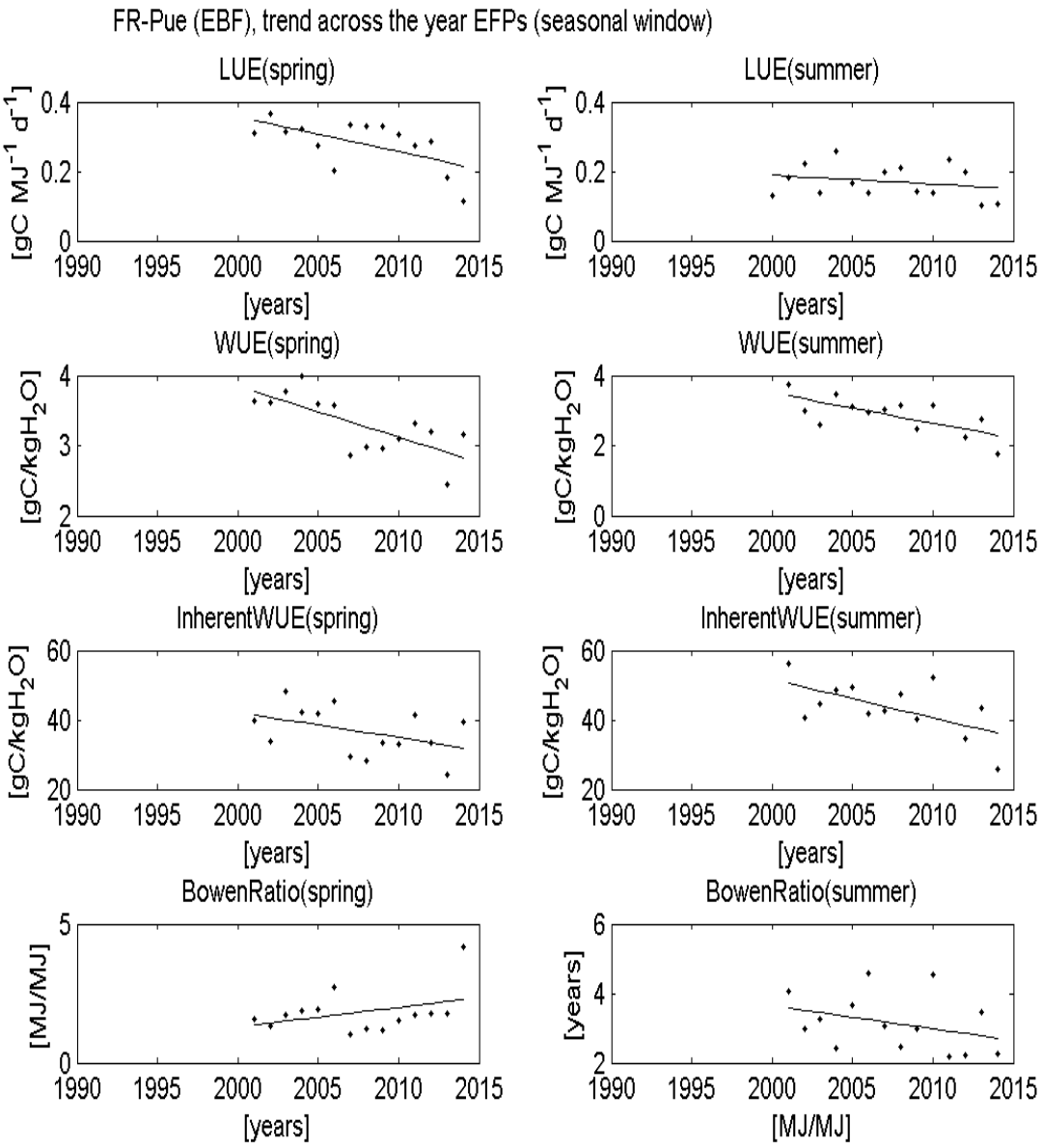

Figure 3: an example of changing across the year of LUE, WUE, Inherent WUE and Bowen Ratio in the spring (left) and summer period (right) in the study site of FR-Pue.

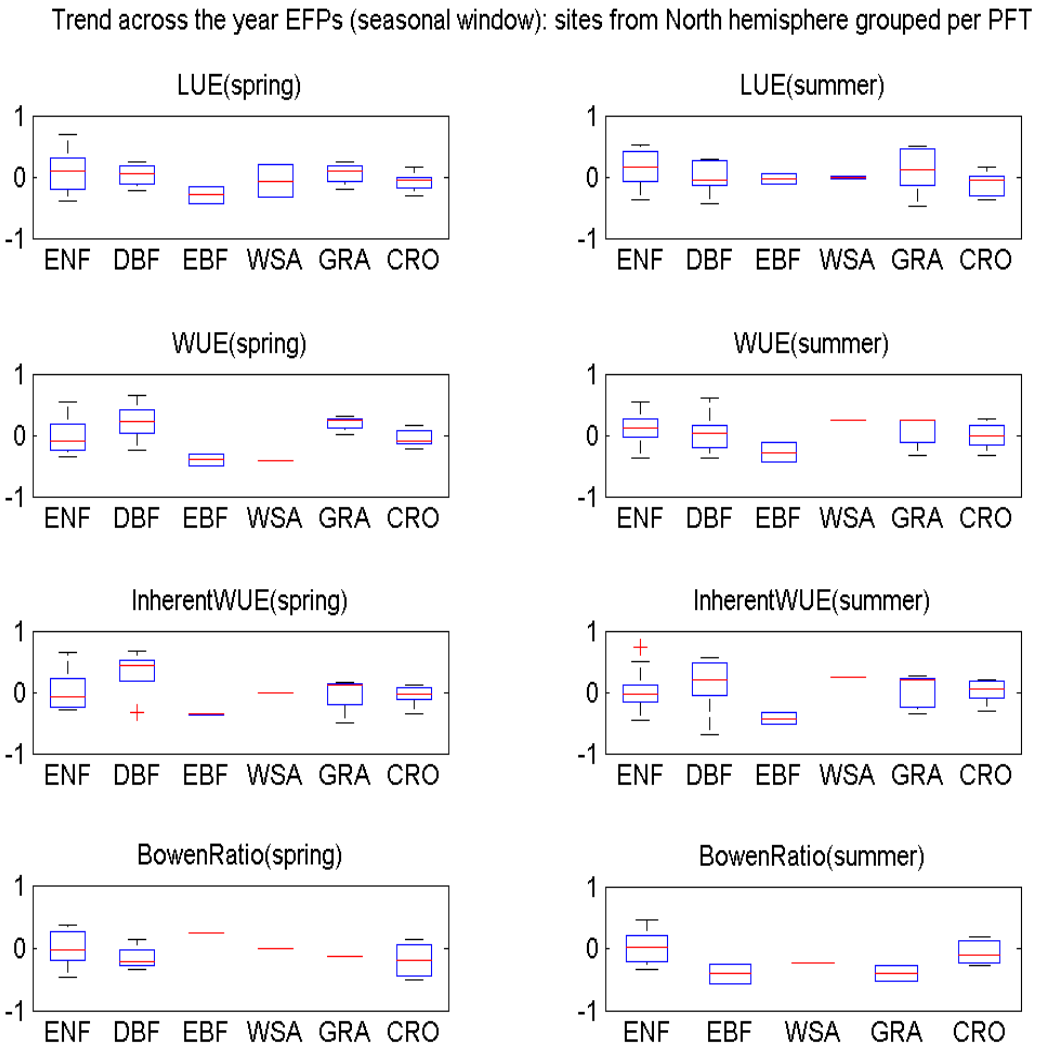

Figure 4: distribution of correlation coefficients between years and seasonal (spring and summer) values of EFPs, estimated for a subset of study sites in North hemisphere, then grouped per PFT.

Conclusions

Site levels EFPs products derived in Task 3.2 provide detailed overview of the ecosystem functionality dynamics derived by carbon and energy fluxes. We provided EFPs daily time series with uncertainty of daily values. At the same time, different versions of EFPs have been derived by different fluxes estimates. In general, we recommend to use each EFPs version singularly for the analysis, and filtering the time series by the use of the quality flag of the estimates; our preference is avoiding the use of data when the ratio of daytime good quality data ("QualityFlag"), used for the estimates, is lower than 0.8.

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Appendix 1 mean estimated LUE [gC MJ^{-1}]. Mean site value and mean site uncertainty reported as reference in the table have been estimated using GPP(Lasslop,Costant u*, USTAR50).

SiteCode	PFT	Mean value	Mean Uncertainty	Spread Among data	Period	n points
AR-SLu	MF	0.354005	0.003925	0.00815	2010-2011	362
AT-Neu	GRA	0.469284	0.017511	0.071335	2002-2012	2462
AU-Ade	WSA	0.052988	0.002488	0.00153	2010-2013	781
AU-ASM	ENF	0.31597	0.012033	0.007127	2007-2009	532
AU-Cpr	SAV	0.088925	0.00359	0.002012	2010-2014	1192
AU-Cum	EBF	0.229403	0.01194	0.005763	2012-2014	647
AU-DaP	GRA	0.280821	0.008683	0.007021	2007-2013	1108
AU-DaS	SAV	0.213909	0.007743	0.005148	2008-2014	1813
AU-Dry	SAV	0.155513	0.007096	0.006767	2008-2014	1438
AU-Emr	GRA	0.085765	0.003164	0.004901	2011-2013	614
AU-Fog	WET	0.145699	0.005955	0.005924	2006-2008	689
AU-Gin	WSA	0.169366	0.006603	0.002825	2011-2014	867
AU-How	WSA	0.290406	0.011152	0.005686	2001-2014	3593
AU-RDF	WSA	0.18919	0.007215	0.00573	2011-2013	232
AU-Rig	GRA	0.307902	0.010962	0.005788	2011-2014	947
AU-Stp	GRA	0.095331	0.003822	0.002675	2008-2014	975
AU-Tum	EBF	0.535593	0.013277	0.029004	2001-2014	3217
AU-Wac	EBF	0.563809	0.0194	0.033192	2005-2008	920
AU-Whr	EBF	0.227875	0.006378	0.006824	2012-2014	849
AU-Wom	EBF	0.525224	0.014777	0.011099	2010-2012	625
AU-Ync	GRA	0.094176	0.004022	0.010703	2013-2013	194
BE-Bra	MF	0.433499	0.012372	0.015288	1999-2014	3933
BE-Lon	CRO	0.406946	0.0115	0.004952	2004-2014	2199
BE-Vie	MF	0.547	0.019247	0.007398	1996-2014	4343
BR-Sa3	EBF	0.643309	0.025361	0.034047	2000-2004	1163

CA-Qfo	ENF	0.221966	0.00853	0.004205	2003-2010	1521
CA-SF1	ENF	0.359899	0.011784	0.012748	2003-2006	490
CA-SF2	ENF	0.39222	0.012734	0.013895	2001-2005	604
CA-SF3	OSH	0.164759	0.005369	0.011197	2002-2006	588
CH-Cha	GRA	0.686014	0.024574	0.033035	2005-2014	2652
CH-Dav	ENF	0.286889	0.012668	0.02178	1997-2014	3141
CH-Fru	GRA	0.53854	0.018132	0.021509	2005-2014	1397
CN-Cng	GRA	0.141032	0.005364	0.010559	2007-2010	969
CN-Du2	GRA	0.063189	0.003101	0.009294	2007-2008	390
CN-HaM	GRA	0.219994	0.008019	0.018852	2002-2004	460
CZ-wet	WET	0.268992	0.009641	0.008443	2006-2014	2126
DE-Geb	CRO	0.309849	0.009055	0.004794	2001-2014	3125
DE-Gri	GRA	0.424686	0.013896	0.014448	2004-2014	2806
DE-Hai	DBF	0.457483	0.014692	0.008522	2000-2012	2051
DE-Kli	CRO	0.28255	0.007471	0.00706	2004-2014	2251
DE-Lkb	ENF	0.147713	0.005061	0.007755	2009-2013	276
DE-Obe	ENF	0.472597	0.013758	0.010288	2008-2014	1467
DE-Seh	CRO	0.385947	0.011074	0.006032	2007-2010	796
DE-SfN	WET	0.240415	0.008738	0.016123	2012-2014	688
DE-Tha	ENF	0.520877	0.01755	0.008448	1996-2014	5267
DK-Sor	DBF	0.511063	0.016017	0.012095	1996-2014	5035
ES-LgS	OSH	0.079188	0.002987	0.001494	2007-2009	666
FI-Hyy	ENF	0.401646	0.011505	0.006441	1996-2014	4097
FI-Lom	WET	0.250282	0.008273	0.007491	2007-2009	404
FI-Sod	ENF	0.30225	0.008574	0.00981	2001-2014	2153
FR-Gri	CRO	0.46243	0.011232	0.008963	2004-2013	1513
FR-LBr	ENF	0.440151	0.012172	0.010805	1996-2008	2677
FR-Pue	EBF	0.288783	0.009999	0.004668	2000-2014	3637

IT-BCi	CRO	0.429574	0.012187	0.010292	2004-2014	2523
IT-CA1	DBF	0.228261	0.008463	0.004303	2011-2014	867
IT-CA2	CRO	0.285758	0.008687	0.013415	2011-2014	739
IT-CA3	DBF	0.239648	0.00893	0.004178	2011-2014	662
IT-Col	DBF	0.31015	0.011735	0.00755	1996-2014	2109
IT-Cp2	EBF	0.488653	0.019087	0.005739	2012-2014	753
IT-Cpz	EBF	0.422461	0.014036	0.0105	2000-2008	2443
IT-Lav	ENF	0.516634	0.018005	0.022456	2003-2014	3192
IT-MBo	GRA	0.29461	0.010509	0.011667	2003-2013	2727
IT-Noe	CSH	0.250482	0.009335	0.006217	2004-2014	2553
IT-PT1	DBF	0.372667	0.013544	0.008856	2002-2004	622
IT-Ren	ENF	0.345852	0.012216	0.011545	1999-2013	1462
IT-Ro2	DBF	0.318806	0.010408	0.011002	2002-2012	2029
IT-SRo	ENF	0.431467	0.014024	0.009872	1999-2012	3669
IT-Tor	GRA	0.283518	0.008634	0.009464	2008-2014	957
NL-Hor	GRA	0.307178	0.010489	0.024029	2004-2011	1971
NL-Loo	ENF	0.533263	0.014878	0.012609	1996-2013	4491
RU-Cok	OSH	0.246901	0.008179	0.027685	2003-2013	877
RU-Fyo	ENF	0.475073	0.016434	0.01413	1998-2014	3205
RU-Ha1	GRA	0.177741	0.007404	0.007719	2002-2004	473
SD-Dem	SAV	0.11527	0.004332	0.003935	2007-2009	622
SN-Dhr	SAV	0.203922	0.005931	0.003566	2011-2013	315
US-AR1	GRA	0.094701	0.002732	0.006486	2009-2012	732
US-AR2	GRA	0.071147	0.002606	0.004147	2009-2012	708
US-ARM	CRO	0.186965	0.005934	0.007605	2003-2012	1355
US-Blo	ENF	0.293487	0.009188	0.028804	1998-2007	1343
US-Cop	GRA	0.022012	0.000885	0.001199	2002-2007	383
US-GBT	ENF	0.171247	0.005498	0.007266	2002-2003	243

US-GLE	ENF	0.119656	0.003175	0.004582	2005-2014	891
US-KS2	CSH	0.328105	0.009913	0.003625	2003-2006	1257
US-Los	WET	0.246353	0.007756	0.015801	2001-2014	1533
US-Me2	ENF	0.378648	0.011874	0.017631	1999-2014	1517
US-MMS	DBF	0.312129	0.010263	0.010918	2002-2014	2111
US-Ne1	CRO	0.20356	0.00917	0.004652	1999-2014	2507
US-Ne2	CRO	0.51372	0.008013	0.006014	2001-2012	1574
US-Ne3	CRO	0.463702	0.008344	0.00961	2001-2012	1477
US-NR1	ENF	0.405703	0.008248	0.010263	2001-2012	1457
US-Prr	ENF	0.184983	0.007875	0.00514	2011-2013	286
US-SRG	GRA	0.06717	0.002548	0.001731	2008-2014	1683
US-SRM	WSA	0.05521	0.002707	0.002725	2004-2014	1584
US-Syv	MF	0.242349	0.007863	0.025144	2001-2014	1490
US-Ton	WSA	0.157222	0.005975	0.011447	2001-2014	2725
US-Twt	CRO	0.265726	0.005718	0.017701	2009-2014	887
US-Var	GRA	0.249089	0.008744	0.013701	2000-2014	2354
US-WCr	DBF	0.390103	0.014156	0.010002	1999-2014	1421
US-Whs	OSH	0.060907	0.003838	0.005498	2007-2014	833
US-Wi3	DBF	0.354849	0.012056	0.027949	2002-2004	282
US-Wi4	ENF	0.4387	0.014915	0.017598	2002-2005	491
US-Wkg	GRA	0.062956	0.002403	0.006177	2004-2014	1617
ZA-Kru	SAV	0.188169	0.006797	0.011648	2000-2010	1171
ZM-Mon	DBF	0.267918	0.010656	0.003532	2007-2009	483

Appendix 2 mean estimated WUE [gC/kgH_2O]. Mean site value and mean site uncertainty reported as reference in the table have been estimated using GPP(Lasslop,Costant u*, USTAR50) and LE fluxes not corrected for the energy balance closure.

SiteCode	PFT	Mean value	Mean Uncertainty	Spread Among data	Period	n points
AR-SLu	MF	7.811724	0.37621	0.919906	2010-2011	198
AT-Neu	GRA	4.701723	0.307681	0.992933	2002-2012	1895
AU-Ade	WSA	1.177193	0.051853	0.145465	2010-2013	392
AU-ASM	ENF	1.941889	0.106249	0.089224	2007-2009	525
AU-Cpr	SAV	1.787331	0.116194	0.096709	2010-2014	924
AU-Cum	EBF	2.174983	0.137298	0.367367	2012-2014	586
AU-DaP	GRA	2.038918	0.083275	0.157787	2007-2013	1029
AU-DaS	SAV	1.962451	0.116722	0.164465	2008-2014	1683
AU-Dry	SAV	1.801505	0.110727	0.201726	2008-2014	1357
AU-Emr	GRA	1.74268	0.105126	0.326289	2011-2013	549
AU-Fog	WET	0.887931	0.043037	0.057719	2006-2008	594
AU-Gin	WSA	2.225859	0.120843	0.146772	2011-2014	799
AU-How	WSA	1.901324	0.120701	0.150066	2001-2014	3278
AU-RDF	WSA	1.444104	0.084729	0.11847	2011-2013	188
AU-Rig	GRA	3.213816	0.151065	0.366532	2011-2014	852
AU-Stp	GRA	1.039206	0.043808	0.036798	2009-2014	855
AU-Tum	EBF	4.589992	0.283573	0.683046	2001-2014	2792
AU-Wac	EBF	4.139165	0.707799	22.2799	2005-2008	745
AU-Whr	EBF	2.958818	0.201591	0.277517	2012-2014	733
AU-Wom	EBF	4.291419	0.220905	0.453741	2010-2012	592
AU-Ync	GRA	2.026866	0.126534	0.309528	2013-2013	120
BE-Bra	MF	5.096664	0.307015	0.643439	1999-2014	2330
BE-Lon	CRO	4.705395	0.330755	0.711062	2004-2014	1174
BE-Vie	MF	5.782833	0.380407	0.389193	1996-2014	2359
BR-Sa3	EBF	3.154702	0.226093	0.250471	2000-2004	1137

CA-Qfo	ENF	2.764128	0.175572	0.441367	2003-2010	1148
CA-SF1	ENF	2.610618	0.123278	0.223185	2003-2006	469
CA-SF2	ENF	3.145096	0.139106	0.331213	2001-2005	552
CA-SF3	OSH	1.607918	0.095981	0.218735	2002-2006	524
CH-Cha	GRA	5.359071	0.304067	0.744531	2005-2014	2396
CH-Dav	ENF	3.242968	0.291408	0.804167	1997-2013	1771
CH-Fru	GRA	3.868733	0.213061	0.441013	2006-2014	1204
CN-Cng	GRA	1.680451	0.078644	0.271618	2007-2010	689
CN-Du2	GRA	0.760317	0.046317	0.223174	2007-2008	246
CN-HaM	GRA	2.523549	0.129564	0.494108	2002-2004	393
CZ-wet	WET	2.553749	0.131132	0.302369	2009-2014	974
DE-Geb	CRO	3.313329	0.172382	0.348659	2001-2014	1867
DE-Gri	GRA	4.902947	0.268186	1.053539	2004-2014	1917
DE-Hai	DBF	4.122943	0.255363	0.223923	2000-2009	1130
DE-Kli	CRO	3.565195	0.178117	0.632249	2004-2014	1370
DE-Lkb	ENF	1.322952	0.069527	0.093391	2009-2012	212
DE-Obe	ENF	5.30854	0.308856	0.674771	2008-2014	846
DE-Seh	CRO	2.89058	0.119268	0.184615	2007-2010	719
DE-SfN	WET	2.353023	0.14229	0.379437	2012-2014	471
DE-Tha	ENF	5.742984	0.409665	0.694621	1996-2014	3812
DK-Sor	DBF	4.16955	0.260028	0.214434	2001-2014	2425
ES-LgS	OSH	1.606024	0.093101	0.095445	2007-2009	468
FI-Hyy	ENF	4.088364	0.235088	0.422376	2003-2014	1929
FI-Lom	WET	2.215094	0.084428	0.245677	2007-2009	328
FI-Sod	ENF	2.8895	0.125043	0.156042	2001-2010	1318
FR-Gri	CRO	3.695823	0.163455	0.543332	2004-2013	1312
FR-LBr	ENF	3.603539	0.239928	0.358756	1996-2008	2171
FR-Pue	EBF	3.57841	0.210523	0.505956	2002-2014	1949

IT-BCi	CRO	3.210245	0.127214	0.363231	2008-2012	970
IT-CA1	DBF	2.083075	0.088477	0.165288	2011-2014	581
IT-CA2	CRO	2.963637	0.13838	0.449539	2011-2014	666
IT-CA3	DBF	2.532627	0.112713	0.135782	2012-2014	591
IT-Col	DBF	4.553256	0.291	0.618046	1996-2014	1312
IT-Cp2	EBF	5.233811	0.3589	0.17174	2012-2014	431
IT-Cpz	EBF	4.791849	0.243588	0.325877	2000-2008	2217
IT-Lav	ENF	5.481843	0.369844	0.546865	2003-2014	2847
IT-MBo	GRA	3.107401	0.17987	0.252372	2003-2013	2125
IT-Noe	CSH	3.495124	0.186933	0.16465	2004-2014	2259
IT-PT1	DBF	3.69844	0.242694	0.684046	2002-2004	349
IT-Ren	ENF	3.05134	0.220004	0.176933	2002-2013	928
IT-Ro2	DBF	3.665795	0.212669	0.544816	2002-2012	1571
IT-SRo	ENF	4.62487	0.273353	0.615486	1999-2010	2172
IT-Tor	GRA	2.39063	0.135185	0.220758	2008-2014	880
NL-Hor	GRA	2.30335	0.158895	0.18281	2004-2011	1090
NL-Loo	ENF	3.848369	0.253127	0.226442	1997-2013	3719
RU-Cok	OSH	2.768128	0.132471	0.316001	2003-2012	687
RU-Fyo	ENF	4.255176	0.257073	0.230701	1998-2014	1929
RU-Ha1	GRA	1.829388	0.091417	0.231628	2002-2004	377
SD-Dem	SAV	1.571002	0.07028	0.250677	2007-2009	444
SN-Dhr	SAV	2.200125	0.09074	0.071111	2011-2013	238
US-AR1	GRA	1.299097	0.056499	0.122385	2009-2012	591
US-AR2	GRA	1.14135	0.051848	0.104232	2009-2012	570
US-ARM	CRO	1.903009	0.10043	0.174655	2003-2012	1112
US-Blo	ENF	2.985321	0.149798	0.380566	1999-2007	855
US-Cop	GRA	1.07761	0.039577	0.212435	2003-2007	143
US-GBT	ENF	2.252965	0.112703	0.283965	2002-2003	222

US-GLE	ENF	1.874655	0.097402	0.211013	2005-2014	705
US-KS2	CSH	2.491603	0.116068	0.197619	2003-2006	1208
US-Los	WET	3.669635	0.190122	0.758721	2001-2010	781
US-Me2	ENF	3.598696	0.221922	0.691595	1999-2014	843
US-MMS	DBF	3.533395	0.218336	0.408694	2002-2014	1673
US-Ne1	CRO	2.304137	0.12417	0.258337	1999-2014	2067
US-Ne2	CRO	3.036549	0.094186	0.289896	2001-2012	1425
US-Ne3	CRO	2.829492	0.086104	0.274362	2001-2012	1358
US-NR1	ENF	2.717747	0.08892	0.223881	2001-2012	1304
US-Prr	ENF	2.669324	0.172137	0.465678	2011-2012	144
US-SRG	GRA	1.209198	0.053323	0.147942	2008-2014	1234
US-SRM	WSA	1.32839	0.075327	0.155158	2004-2014	959
US-Syv	MF	2.940741	0.170068	0.443972	2002-2007	492
US-Ton	WSA	2.57803	0.16332	0.446026	2001-2014	1493
US-Twt	CRO	1.563445	0.060858	0.246861	2009-2014	845
US-Var	GRA	2.946123	0.159665	0.419023	2000-2014	2138
US-WCr	DBF	3.898556	0.249078	0.603555	1999-2014	794
US-Whs	OSH	1.09	0.065016	0.117814	2007-2014	633
US-Wi3	DBF	3.495465	0.310548	0.721895	2002-2004	218
US-Wi4	ENF	4.09991	0.240257	0.839235	2002-2005	426
US-Wkg	GRA	1.521639	0.078367	0.231569	2004-2014	967
ZA-Kru	SAV	2.40112	0.147457	0.269624	2000-2010	694
ZM-Mon	DBF	2.472104	0.130167	0.355461	2007-2009	453

Appendix 3 mean estimated Inherent WUE [(kPa*gC)/kgH_2O]. Mean site value and mean site uncertainty reported as reference in the table have been estimated using GPP(Lasslop,Costant u*, USTAR50) and LE fluxes not corrected for the energy balance closure.

SiteCode	PFT	Mean value	Mean Uncertainty	Spread Among data	Period	n points
AR-SLu	MF	194.2883	14.19766	21.51082	2010-2011	198
AT-Neu	GRA	31.37587	1.537243	7.031098	2002-2012	1892
AU-Ade	WSA	26.70578	1.282154	3.719587	2010-2013	392
AU-ASM	ENF	37.45767	1.927936	1.827346	2007-2009	525
AU-Cpr	SAV	24.58194	1.598308	1.697682	2010-2014	924
AU-Cum	EBF	25.74502	1.434162	4.338435	2012-2014	586
AU-DaP	GRA	36.18242	1.592765	3.121454	2007-2013	1029
AU-DaS	SAV	44.10305	2.706674	4.015725	2008-2014	1683
AU-Dry	SAV	43.49853	2.400826	5.029992	2008-2014	1361
AU-Emr	GRA	27.47648	1.755195	5.381888	2011-2013	549
AU-Fog	WET	14.14384	0.629125	1.063284	2006-2008	564
AU-Gin	WSA	37.8223	1.991513	2.272027	2011-2014	799
AU-How	WSA	34.11613	1.890579	2.732283	2001-2014	3281
AU-RDF	WSA	29.12252	1.395614	2.243038	2011-2013	189
AU-Rig	GRA	22.94313	1.042374	2.638303	2011-2014	853
AU-Stp	GRA	24.52778	0.982558	1.015602	2009-2014	855
AU-Tum	EBF	22.04294	1.23835	3.556738	2001-2014	2823
AU-Wac	EBF	16.15936	1.481811	0.953973	2005-2008	746
AU-Whr	EBF	32.92866	2.470145	3.199783	2012-2014	733
AU-Wom	EBF	13.29556	0.757119	1.426707	2010-2012	592
AU-Ync	GRA	19.83964	0.909326	3.662474	2013-2013	121
BE-Bra	MF	32.46335	1.966597	4.213614	1999-2014	2231
BE-Lon	CRO	29.72868	1.225628	4.488134	2004-2014	1124
BE-Vie	MF	29.57081	1.593669	2.400198	1996-2014	2354
BR-Sa3	EBF	33.17164	1.927368	3.173132	2000-2003	1078

CA-Qfo	ENF	17.11855	0.984836	2.708116	2003-2010	1150
CA-SF1	ENF	20.01558	0.94263	1.952165	2003-2006	467
CA-SF2	ENF	28.8764	1.363034	3.129051	2001-2005	523
CA-SF3	OSH	13.94924	0.77023	2.106883	2002-2006	469
CH-Cha	GRA	19.66395	1.429373	2.453961	2005-2014	1601
CH-Dav	ENF	20.95816	1.743789	5.37552	1997-2013	1771
CH-Fru	GRA	13.71498	0.828426	1.51981	2006-2014	1158
CN-Cng	GRA	21.09112	1.020785	3.42526	2007-2010	689
CN-Du2	GRA	8.117932	0.431911	3.040606	2007-2008	246
CN-HaM	GRA	14.12196	0.672003	2.682435	2002-2003	262
CZ-wet	WET	14.6513	0.697637	1.788427	2009-2014	982
DE-Geb	CRO	24.78338	1.123545	2.87142	2001-2014	1869
DE-Gri	GRA	33.48815	1.311555	7.242326	2004-2014	1915
DE-Hai	DBF	19.01866	1.161358	1.102285	2000-2009	1137
DE-Kli	CRO	23.00204	0.817877	4.196227	2004-2014	1371
DE-Lkb	ENF	4.472809	0.244309	0.454939	2009-2012	212
DE-Obe	ENF	25.41006	1.397523	3.484002	2008-2014	786
DE-Seh	CRO	16.17948	0.611514	0.938107	2007-2010	702
DE-SfN	WET	14.37718	0.8359	2.113566	2012-2014	475
DE-Tha	ENF	35.13418	2.263483	4.657372	1996-2014	3805
DK-Sor	DBF	23.81511	1.382288	1.313148	2001-2014	2431
ES-LgS	OSH	12.20543	0.638108	0.860731	2007-2009	471
FI-Hyy	ENF	22.40857	1.102557	2.506714	2003-2013	1612
FI-Lom	WET	9.459867	0.391123	1.179815	2007-2009	328
FI-Sod	ENF	14.31525	0.800739	0.871348	2001-2010	1310
FR-Gri	CRO	18.94294	0.794274	2.559304	2004-2013	1260
FR-LBr	ENF	24.4411	1.329073	2.867481	1996-2008	2171
FR-Pue	EBF	32.46809	1.765925	5.148553	2002-2014	1949

IT-BCi	CRO	23.70636	0.902404	2.671607	2008-2011	668
IT-CA1	DBF	20.88104	0.910047	1.707778	2011-2014	577
IT-CA2	CRO	18.14224	0.754871	3.08801	2011-2014	580
IT-CA3	DBF	25.37267	1.000275	1.666238	2012-2014	590
IT-Col	DBF	36.40648	2.128222	5.042619	1996-2014	1282
IT-Cp2	EBF	33.53404	2.095231	1.226915	2012-2014	431
IT-Cpz	EBF	39.65576	1.98498	2.788849	2000-2008	2042
IT-Lav	ENF	24.32892	1.473543	2.502102	2003-2014	2772
IT-MBo	GRA	11.1158	0.598159	0.935319	2003-2013	2122
IT-Noe	CSH	22.58596	1.190165	1.190286	2004-2014	1466
IT-PT1	DBF	38.34234	2.20589	6.504948	2003-2004	226
IT-Ren	ENF	16.57404	1.159113	1.04373	2002-2013	930
IT-Ro2	DBF	50.39452	2.605723	8.143156	2004-2012	1035
IT-SRo	ENF	29.02543	1.821195	4.550332	2001-2010	1723
IT-Tor	GRA	11.39827	0.559714	1.100945	2008-2014	879
NL-Hor	GRA	15.09608	0.903276	3.106236	2011-2011	106
NL-Loo	ENF	18.00094	1.155544	1.496793	1997-2013	3711
RU-Cok	OSH	12.30164	0.605579	0.65064	2005-2005	51
RU-Fyo	ENF	22.54919	1.310093	1.605401	1998-2014	1928
RU-Ha1	GRA	14.72298	0.693159	1.864253	2002-2004	377
SD-Dem	SAV	41.65054	2.158988	7.436306	2007-2009	444
SN-Dhr	SAV	57.08307	2.836969	2.639606	2011-2013	238
US-AR1	GRA	17.42262	0.812183	2.058042	2009-2012	600
US-AR2	GRA	15.63129	0.758898	1.778319	2009-2012	578
US-ARM	CRO	19.81271	0.87521	2.094897	2003-2012	1095
US-Blo	ENF	28.94339	1.143053	3.861289	1999-2007	858
US-Cop	GRA	27.99971	0.892209	5.566436	2003-2007	143
US-GBT	ENF	17.57848	0.801469	2.30121	2002-2003	222

US-GLE	ENF	13.11423	0.610598	1.460025	2005-2014	705
US-KS2	CSH	24.89103	0.891312	1.926146	2003-2006	1160
US-Los	WET	41.17414	1.668795	9.128269	2001-2010	786
US-Me2	ENF	30.77918	1.52175	5.950083	1999-2014	794
US-MMS	DBF	22.39218	1.343989	2.7625	2002-2014	1620
US-Ne1	CRO	19.95487	0.969061	2.235308	1999-2014	2067
US-Ne2	CRO	36.46101	1.326749	3.411839	2001-2012	1460
US-Ne3	CRO	33.40666	1.26092	3.18674	2001-2012	1400
US-NR1	ENF	36.77978	1.264326	3.049154	2001-2012	1319
US-Prr	ENF	16.82865	0.811227	2.936942	2011-2012	144
US-SRG	GRA	27.60959	1.09367	3.341138	2008-2014	1234
US-SRM	WSA	30.92189	1.547587	3.609481	2004-2014	951
US-Syv	MF	26.2447	1.267394	4.315471	2002-2007	493
US-Ton	WSA	28.77628	1.794772	5.408832	2001-2014	1497
US-Twt	CRO	22.86871	0.854605	3.815185	2009-2014	845
US-Var	GRA	20.53872	1.074648	3.145171	2000-2014	2145
US-WCr	DBF	21.82002	1.064554	3.381383	1999-2014	801
US-Whs	OSH	22.07425	1.161339	2.455177	2007-2014	633
US-Wi3	DBF	26.10649	1.295197	6.024848	2002-2004	219
US-Wi4	ENF	39.24699	2.098816	8.62993	2002-2005	429
US-Wkg	GRA	30.2131	1.500085	4.695927	2004-2014	967
ZA-Kru	SAV	30.03421	1.926905	3.794722	2000-2010	693
ZM-Mon	DBF	36.30195	1.911673	5.341118	2007-2009	453

Appendix 4 mean estimated Bowen Ratio [MJ/MJ]. Because only two version of Bowen ratio have been provided, the spread among products is not reported. Mean site value and mean site uncertainty reported as reference in the table have been estimated using energy fluxes (LE and H) not corrected for the energy balance closure.

SiteCode	PFT	Mean value	Mean Uncertainty	Period	n points
AR-SLu	MF	3.418154	0.218824	2010-2011	194
AT-Neu	GRA	0.681383	0.040964	2002-2012	438
AU-Ade	WSA	4.308295	0.263226	2010-2013	425
AU-ASM	ENF	1.046872	0.078508	2007-2009	407
AU-Cpr	SAV	3.655871	0.262603	2010-2014	879
AU-Cum	EBF	1.47321	0.093926	2012-2014	358
AU-DaP	GRA	4.202571	0.301793	2007-2013	1093
AU-DaS	SAV	1.324006	0.107338	2008-2014	1493
AU-Dry	SAV	1.996876	0.157692	2008-2014	1214
AU-Emr	GRA	2.764362	0.205463	2011-2013	703
AU-Fog	WET	0.773566	0.052563	2006-2008	234
AU-Gin	WSA	2.473443	0.170374	2011-2014	685
AU-How	WSA	1.058526	0.081166	2001-2014	2088
AU-RDF	WSA	3.024816	0.196618	2012-2013	345
AU-Rig	GRA	2.965699	0.192264	2011-2014	558
AU-Stp	GRA	3.131076	0.155377	2008-2014	1296
AU-Tum	EBF	1.091589	0.072174	2001-2014	1924
AU-Wac	EBF	1.222481	0.140849	2005-2008	375
AU-Whr	EBF	2.422742	0.16795	2012-2014	640
AU-Wom	EBF	1.02786	0.063223	2010-2012	409
AU-Ync	GRA	5.260599	0.218742	2012-2014	325
BE-Bra	MF	2.031635	0.125837	1997-2014	1094
BE-Lon	CRO	1.030037	0.05276	2004-2014	611
BE-Vie	MF	1.652489	0.099353	1996-2014	1888

BR-Sa3	EBF	0.32462	0.023708	2000-2003	326
CA-Qfo	ENF	2.558401	0.146076	2004-2010	779
CA-SF1	ENF	2.473795	0.152509	2003-2006	395
CA-SF2	ENF	2.957351	0.15739	2002-2005	309
CA-SF3	OSH	1.787853	0.096375	2001-2006	661
CH-Cha	GRA	0.562548	0.0344	2006-2014	630
CH-Dav	ENF	1.431854	0.136444	1997-2013	1281
CH-Fru	GRA	0.542065	0.030113	2006-2014	896
CN-Cng	GRA	2.199219	0.099621	2007-2010	483
CN-Du2	GRA	2.188911	0.107672	2006-2008	412
CN-HaM	GRA	1.414849	0.084249	2002-2004	356
CZ-wet	WET	1.401222	0.082818	2009-2014	456
DE-Geb	CRO	1.676349	0.095965	2001-2014	1119
DE-Gri	GRA	0.688306	0.038656	2004-2006	117
DE-Hai	DBF	1.541861	0.102553	2000-2009	1414
DE-Kli	CRO	1.46255	0.077019	2005-2014	609
DE-Lkb	ENF	1.22707	0.065521	2009-2013	813
DE-Obe	ENF	1.635148	0.117668	2008-2014	749
DE-Seh	CRO	1.456868	0.09672	2008-2010	160
DE-SfN	WET	1.146085	0.061192	2012-2014	315
DE-Tha	ENF	1.850793	0.151953	1997-2014	2065
DK-Sor	DBF	1.78177	0.112729	2001-2014	820
ES-LgS	OSH	2.35547	0.138531	2007-2009	477
FI-Hyy	ENF	1.947335	0.122628	2003-2014	964
FI-Lom	WET	0.912579	0.038438	2007-2009	282
FI-Sod	ENF	2.307333	0.136471	2001-2010	831
FR-Gri	CRO	1.297709	0.084895	2004-2013	406
FR-LBr	ENF	1.273093	0.081877	1996-2008	1053

FR-Pue	EBF	2.215113	0.145019	2002-2014	1658
IT-BCi	CRO	1.199233	0.069121	2008-2012	597
IT-CA1	DBF	1.426323	0.09444	2011-2014	375
IT-CA2	CRO	2.345489	0.128131	2011-2014	431
IT-CA3	DBF	1.290541	0.072034	2012-2014	396
IT-Col	DBF	2.375697	0.196032	1996-2014	1288
IT-Cp2	EBF	2.167155	0.116805	2013-2014	323
IT-Cpz	EBF	2.207203	0.128509	2000-2008	1541
IT-Lav	ENF	2.107337	0.167597	2003-2014	2391
IT-MBo	GRA	0.735821	0.03151	2003-2013	1363
IT-Noe	CSH	3.485268	0.214071	2004-2014	2053
IT-PT1	DBF	1.590514	0.100155	2002-2004	151
IT-Ren	ENF	2.110092	0.152301	2002-2013	1859
IT-Ro2	DBF	2.572054	0.146694	2002-2012	1440
IT-SRo	ENF	1.9386	0.115564	1999-2009	1386
IT-Tor	GRA	0.87226	0.037295	2008-2014	887
NL-Hor	GRA	0.870481	0.047453	2005-2011	69
NL-Loo	ENF	1.580672	0.105242	1996-2013	1780
RU-Cok	OSH	1.286495	0.060987	2003-2013	303
RU-Fyo	ENF	1.910315	0.123406	1998-2014	1311
RU-Ha1	GRA	1.03237	0.058132	2002-2004	264
SD-Dem	SAV	3.123215	0.182285	2007-2009	403
SN-Dhr	SAV	2.46918	0.143094	2011-2013	364
US-AR1	GRA	2.450982	0.138312	2009-2012	743
US-AR2	GRA	2.301715	2.609707	2009-2012	682
US-ARM	CRO	2.358414	0.129051	2003-2012	1646
US-Blo	ENF	1.385926	0.080549	1997-2007	1213
US-Cop	GRA	4.389036	0.221157	2002-2007	344

US-GBT	ENF	2.92803	0.211434	2000-2005	863
US-GLE	ENF	2.994667	0.229168	2005-2014	2030
US-KS2	CSH	0.976063	0.046131	2003-2006	742
US-Los	WET	2.231779	0.10153	2001-2010	326
US-Me2	ENF	2.595989	0.167971	1999-2014	1062
US-MMS	DBF	2.245201	0.159551	2002-2014	2077
US-Ne1	CRO	2.923441	0.267359	1998-2014	2839
US-Ne2	CRO	2.127054	0.140707	2001-2013	1437
US-Ne3	CRO	2.098246	0.138407	2001-2013	1612
US-NR1	ENF	2.238732	0.151513	2001-2013	1699
US-Prr	ENF	1.644343	0.064681	2011-2013	161
US-SRG	GRA	3.72735	0.197427	2008-2014	1325
US-SRM	WSA	4.284763	0.296322	2004-2014	2109
US-Syv	MF	2.404089	0.150241	2002-2007	268
US-Ton	WSA	2.471417	0.168306	2001-2014	1701
US-Twt	CRO	1.381468	0.074251	2009-2014	458
US-Var	GRA	2.09509	0.131038	2000-2014	1769
US-WCr	DBF	2.565566	0.139031	1999-2014	542
US-Whs	OSH	3.238355	0.220383	2007-2014	1120
US-Wi3	DBF	1.606366	0.124291	2002-2004	91
US-Wi4	ENF	1.432573	0.086877	2002-2005	262
US-Wkg	GRA	3.07901	0.1833	2004-2014	1572
ZA-Kru	SAV	2.085587	0.170019	2000-2010	855
ZM-Mon	DBF	1.790647	0.12216	2007-2009	489