Global trait-environment relationships revealed by sPlot, the global vegetation plot database

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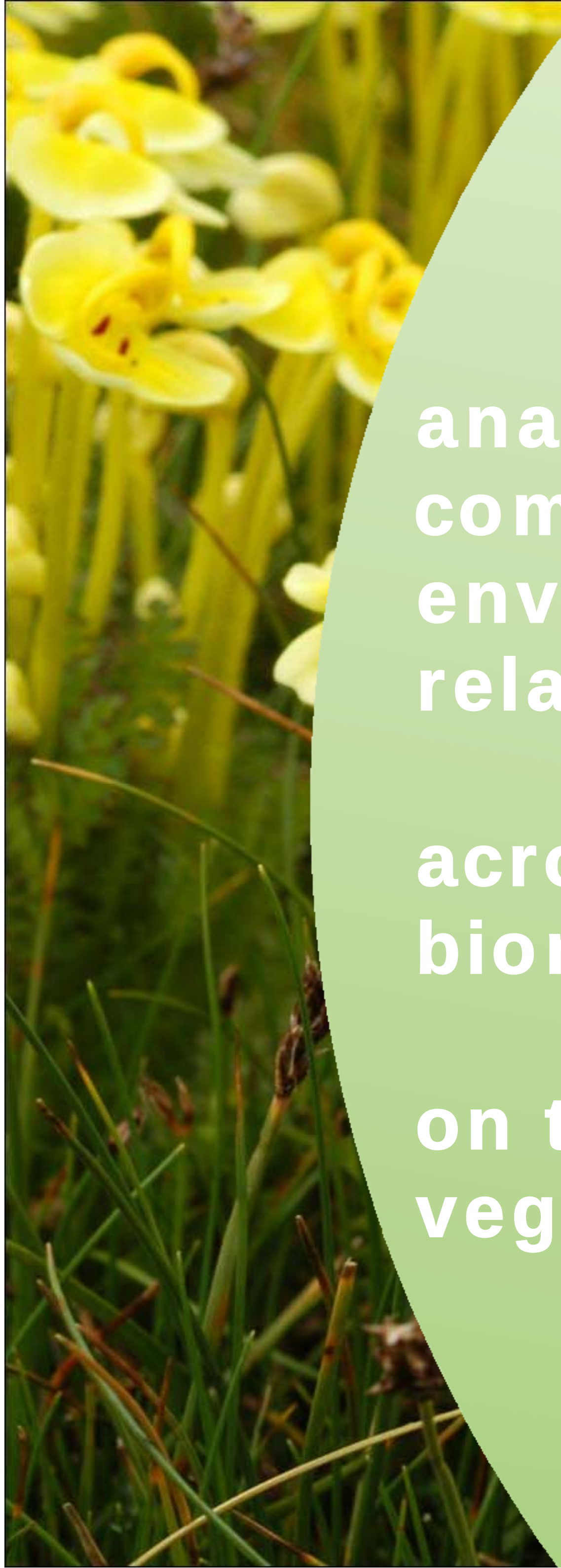


Aims of sPlot

analysis of plant community trait - environment relationships

across the world's biomes

on the basis of vegetation plot data.

The global trait spectrum

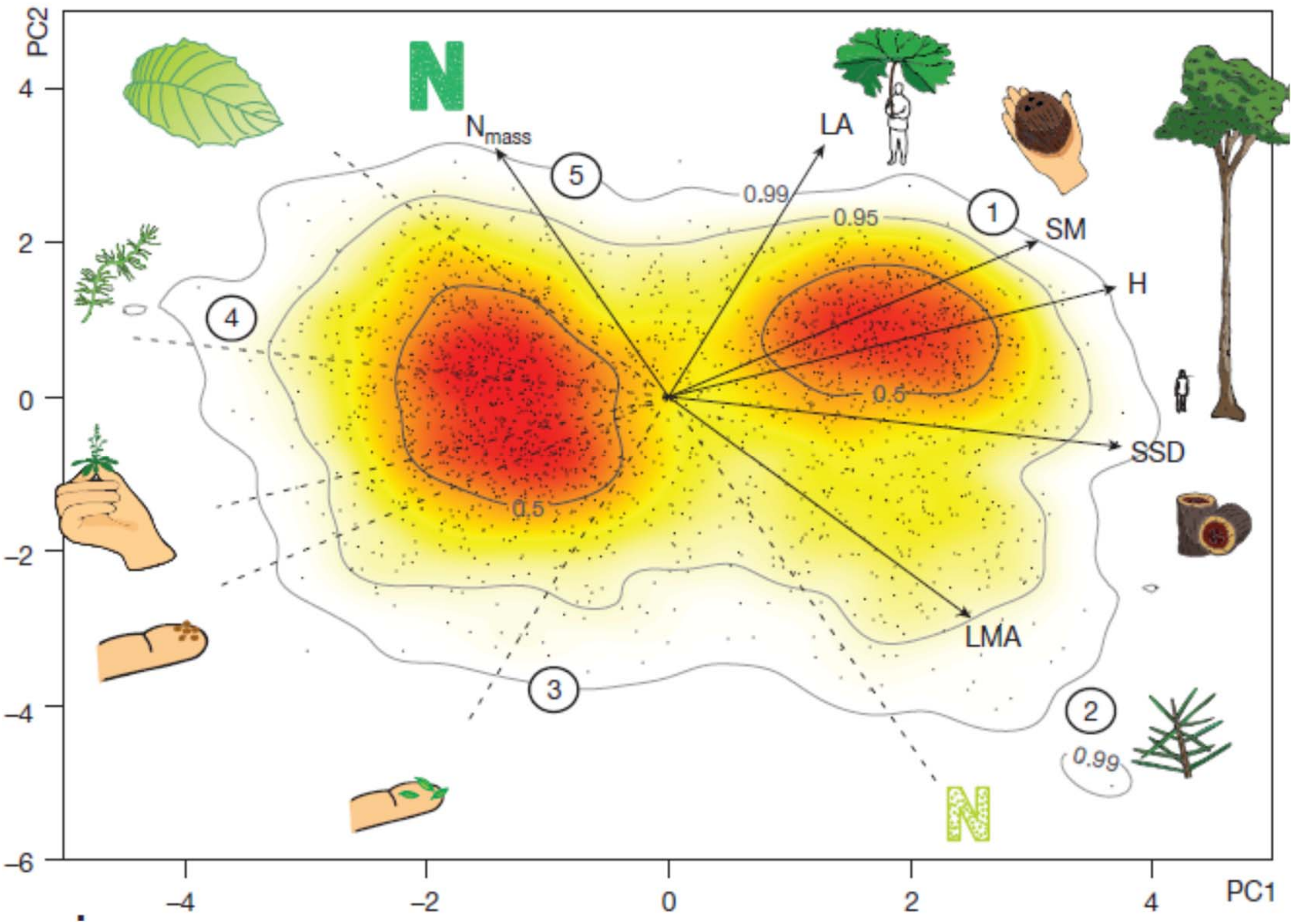


Fig. 2a from Díaz et al. (2016): The global spectrum of plant form and function. Nature 529: 167-171.

1st PCA axis:
Traits of plant height + diaspore size

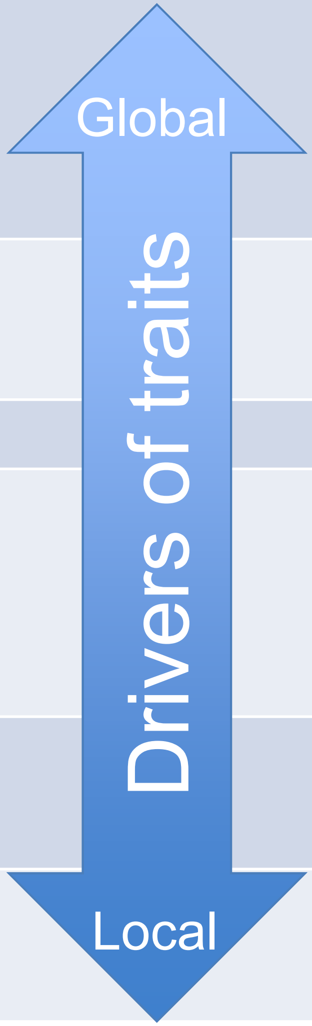
2nd PCA axis:
SLA + leaf area + leaf N content

Plot versus occurrence information

Information on...	Plot data	Occurrence data
Species	Species composition of the community	Species pool (per grid cell)
Diversity	α	γ
Environmental filtering by regional factors	+	+
Environmental filtering by local factors (soil, topography, disturbance etc.)	+	-
Biotic filtering	+ (Species interactions can be derived from co-occurrence)	-
Ecosystem functioning	Weighted by abundance (CWM, FD)	Unweighted, no abundance information

Traits studied

Trait	Description	Function	Expected relationship to climatic favorability
SLA, Leaf area, Leaf fresh mass, Leaf N, Leaf P ⇳ LDMC, Leaf N per area, Leaf C per dry mass	Leaf economics spectrum: Thin, N-rich leaves with high turnover ⇳ Thick, N-conservative, long-lived leaves	Productivity Competitive ability	+++
Wood vessel length ⇳ Stem conduit density	Effective water transport ⇳ Cavitation prevention	Water use efficiency	+
Plant height	Mean individual height of adult plants	Competitive ability	+/0
Seed number per reproduction unit ⇳ Seed mass, Seed length, Dispersal unit length,	Seed economics spectrum: Small, well dispersed seeds ⇳ Seeds with storage reserve to facilitate establishment	Dispersal	0
Leaf N to P ratio	P limitation (N:P >15) ⇳ N limitation (N:P <10)	Nutrient supply	0
Leaf nitrogen isotope ratio (delta 15N)	Access to N derived from N_2 fixation ⇳ N supply via mycorrhiza	Source, soil depth and form of N supply	0/-



Global productivity

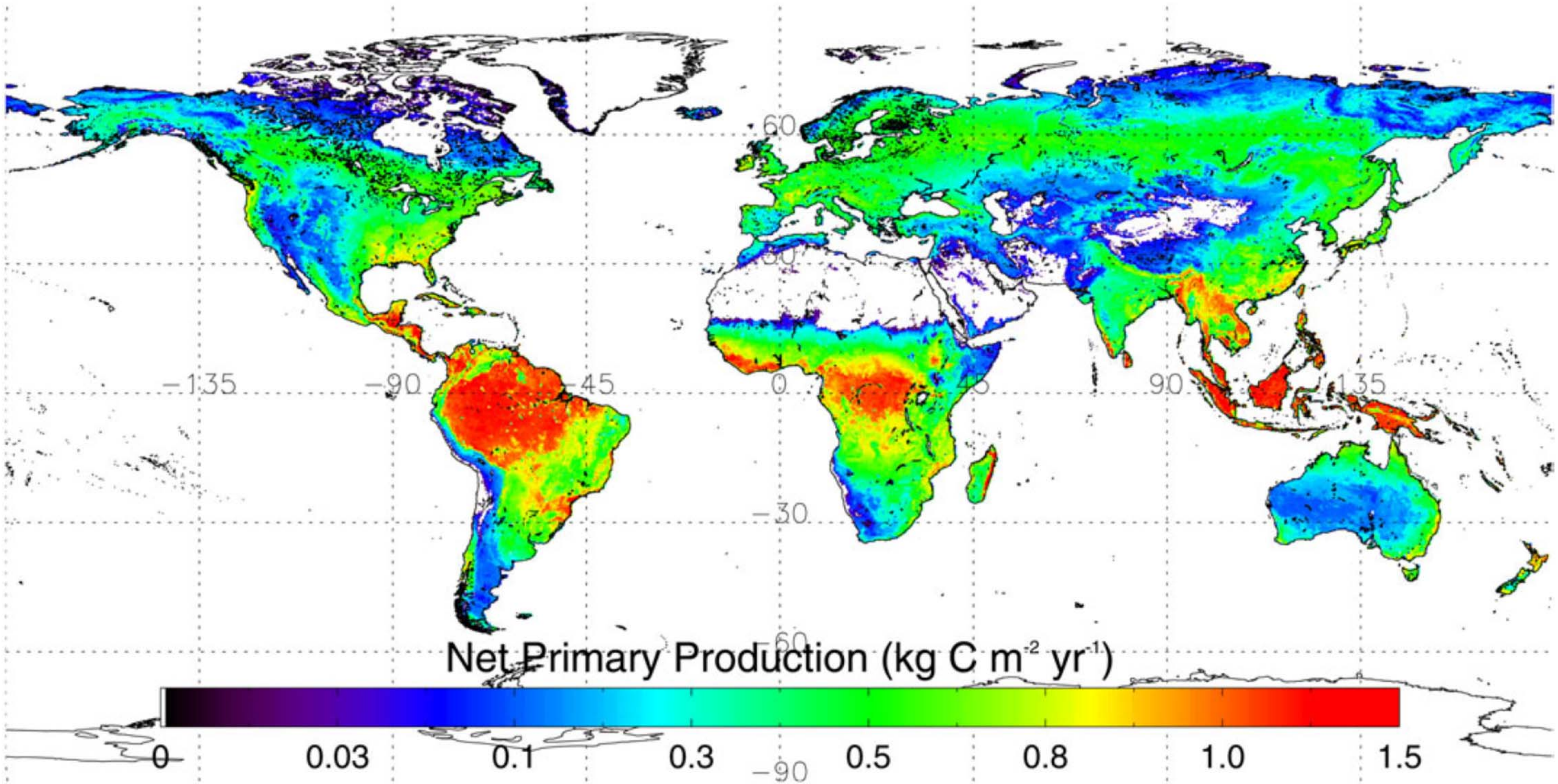
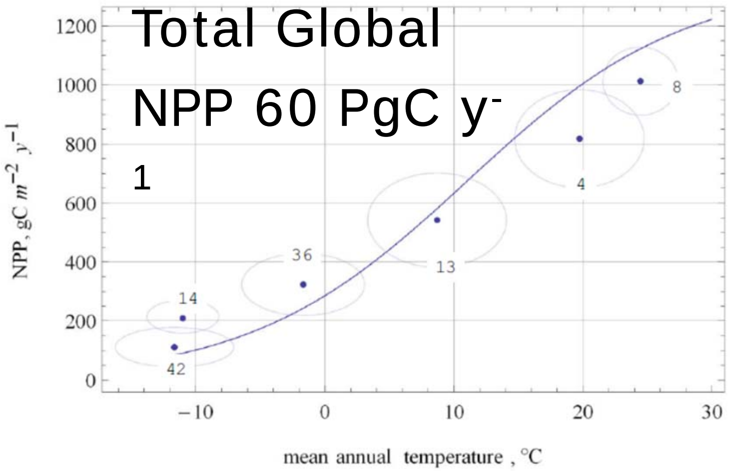


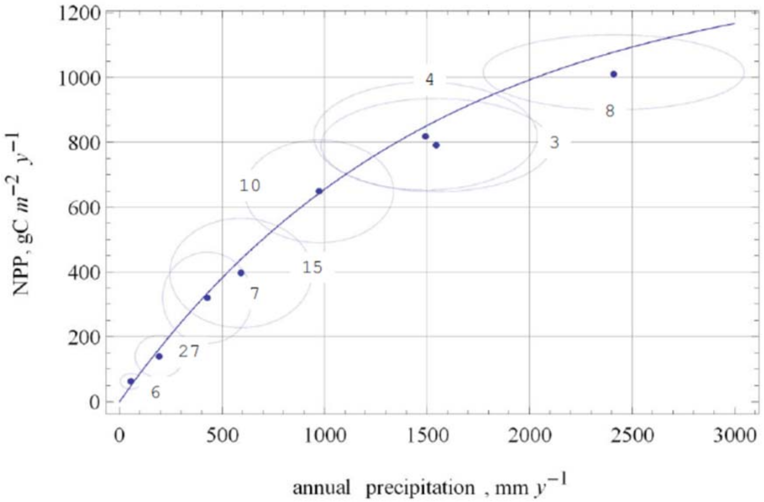
Fig. 2 from Friend, A.D. (2010): Terrestrial plant production and climate change. J. Exp. Bot. 61: 1293-1309.

Global net primary production (NPP)

NPP per biome as predicted by the Miami model (1972)

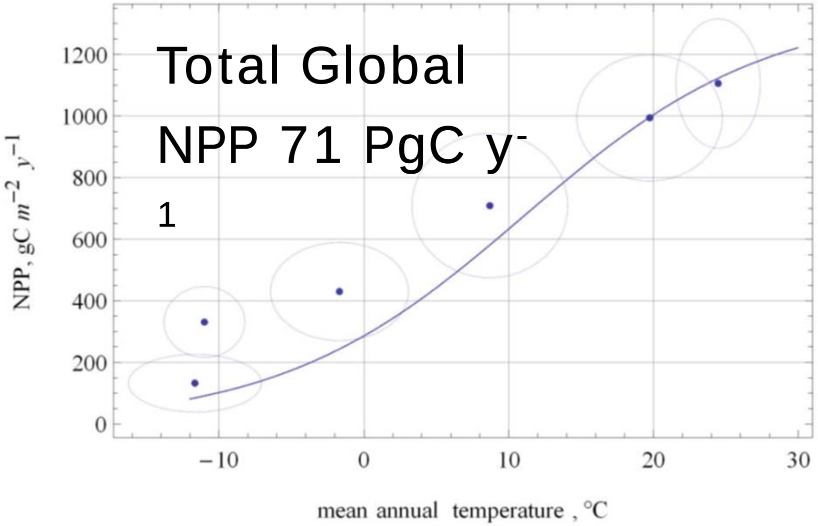
Total Global NPP 60 PgC y^{-1}

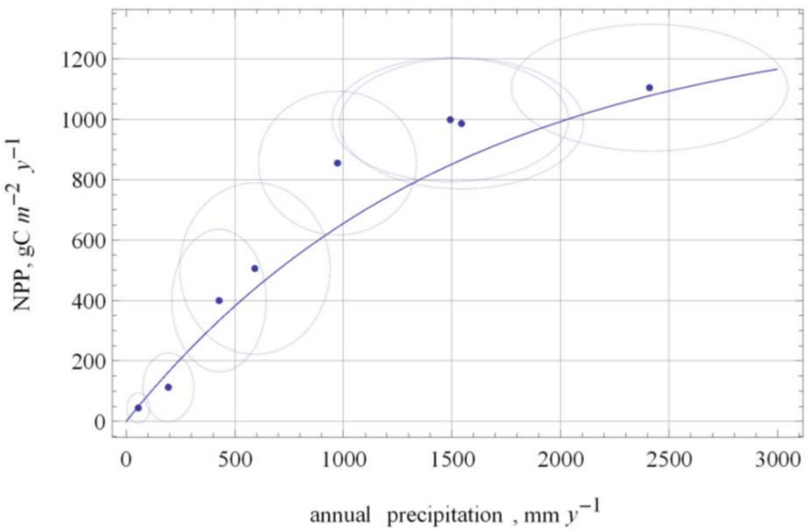




NPP per biome as predicted by the model of Alexandrov & Matsunaga (2008) (version 1.13.0)

Total Global NPP 71 PgC y^{-1}





Lieth H: Modeling the primary productivity of the world. Primary Productivity of the Biosphere 1975: 237-263.

Fig. 1 and 3 from Alexandrov, G.A. & Matsunaga, T. (2008): Normative productivity of the global vegetation. Carbon Balance & Managem. 3: 8.

All current global NPP models show monotonous increase of NPP with MAT and MAP

Macroclimate as driver for functional identity

Mean trait values of grid cells (SLA)

- SLA ($\log_{10}$ transformed)
- Based on species occurrence data on 1° grid cells.
- Spearman correlation coefficient

Trait	Lat	Alt	MAT
Maximum height	0.25	–0.05	–0.10
Leaf %N	–0.01	0.18	0.23
Leaf %P	0.62	0.07	–0.54
Seed mass	–0.26	–0.20	0.47
Specific leaf area	–0.48	–0.19	0.33
Wood density	–0.61	–0.24	0.62

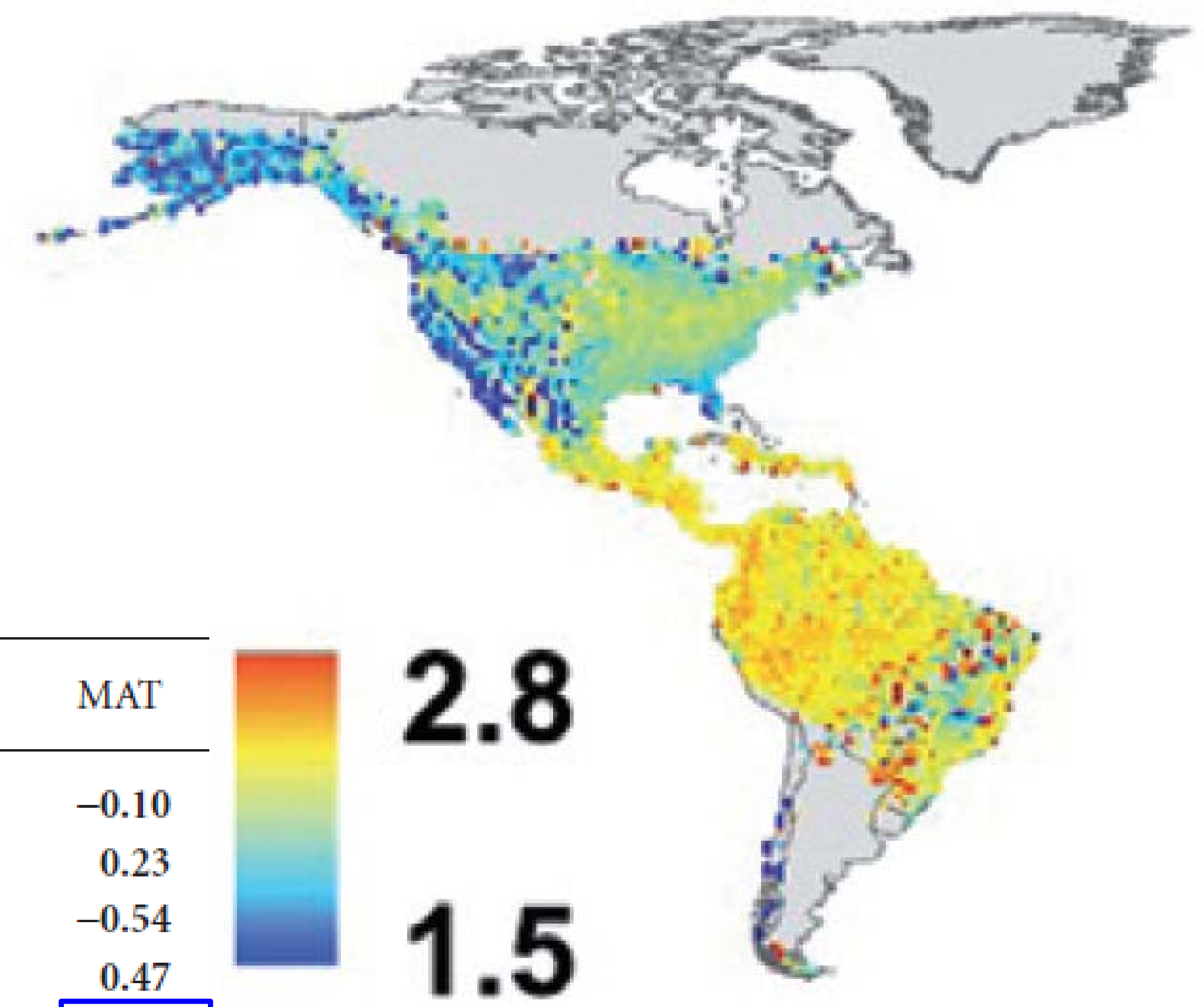
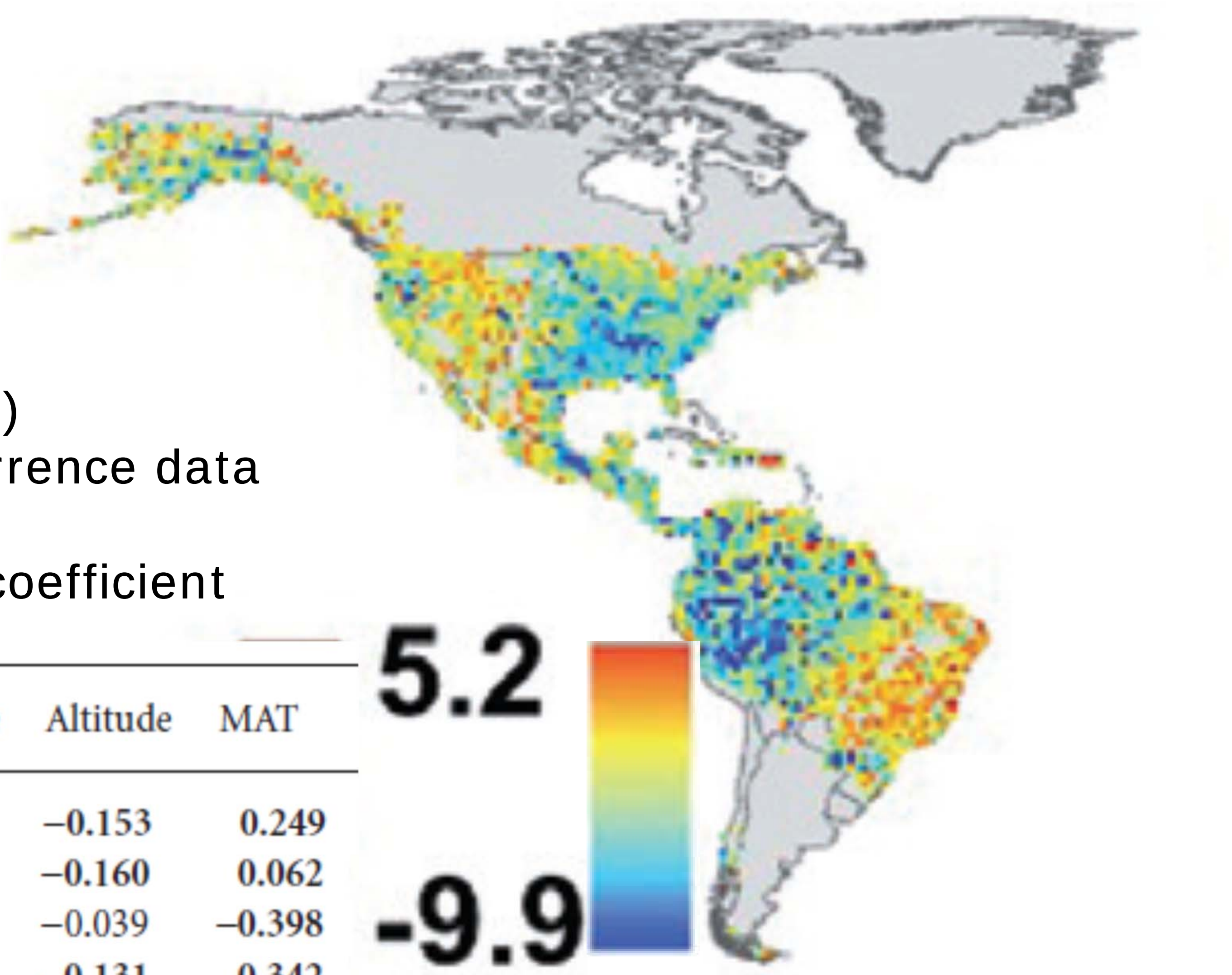


Fig. 1 and Table 1 from Swenson et al. 2012, Global Ecol. Biogeogr. 21: 798-808.

Macroclimate as driver for functional diversity

Standardized effect sizes (SES) of functional diversity (FD) of grid cells (SLA)

- SLA (log_{10} transformed)
- Based on species occurrence data on 1° grid cells.
- Spearman correlation coefficient



Trait	Metric	Latitude	Altitude	MAT
Maximum height	SES FD	–0.132	–0.153	0.249
Leaf % N	SES FD	0.107	–0.160	0.062
Leaf % P	SES FD	0.428	–0.039	–0.398
Seed mass	SES FD	–0.350	–0.131	0.342
Specific leaf area	SES FD	–0.121	–0.149	0.107
Wood density	SES FD	–0.543	–0.112	0.546

Fig. 1 and Table 2 from Swenson et al. 2012, Global Ecol. Biogeogr. 21: 798-808.

Objectives

1. To provide the first global maps of functional identity (CWM) and functional diversity (FD)
2. To identify the main macrocimatic drivers of CWM and FD
3. To compare the amount of overall variation explained by macroclimate between CWM and FD.

Hypotheses

1. Community weighted mean trait values reflect the same trade-offs as species mean trait values (tall vs. small, fast vs. slow growth)
2. The strongest response to global macroclimatic drivers have traits that are related to productivity, such as SLA, leaf N, leaf P, LDMC.
3. The amount of variation explained by macroclimate is similarly high for FD than CWM.

Traits from TRY 3.0

Gap-filled data through matrix factorization

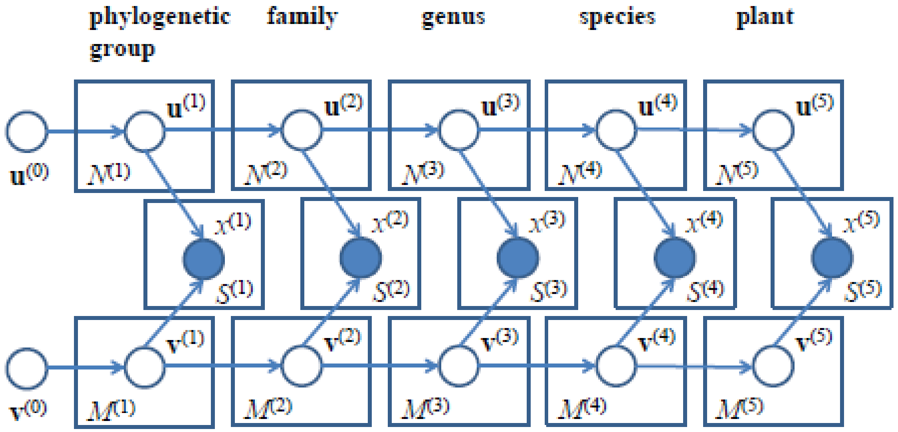


Fig. 1 from Shan, H. et al. (2012): Gap Filling in the Plant Kingdom—Trait Prediction Using Hierarchical Probabilistic Matrix Factorization. Proceedings of the 29 th International Conference on Machine Learning, Edinburgh, Scotland,

Total number of species with gap-filled species in TRY: **40,790**

Of these are in sPlot **36,832** (**60.47 % of all species in sPlot 2**)

18 Traits: SLA, PlantHeight, SeedMass, LDMC, StemDens, LeafArea, LeafN, LeafP, LeafNperArea, Leaffreshmass, LeafNPratio, LeafC.perdrymass, Leaf.delta.15N, Stem.cond.dens, Seed.num.rep.unit, Wood.vessel.length, Seed.length, Disp.unit.leng

Calculations

$$CWM = \sum_{i=1}^{s} p_i * x_i$$

Community weighted mean

p_i = relative cover of species *i* in each vegetation record, calculated from the cover, abundance or bhd measures provided in the database

x_i = trait value of species *i*, $\log_e$ transformed

$$FD_Q = \sum_{i=1}^{s} \sum_{j=i+1}^{s-1} D_{ij} * p_i * p_j$$

Quadratic entropy, Rao's (1982) Q

D_{ij} = Euclidean distance in trait values x_i between all species *i* and *j* in one plot

- calculated for 18 traits and for 1,111,307 plots (99.41% of all plots in sPlot)

Macroclimatic predictors

Bioclim variables

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3 = Isothermality (BIO2/BIO7) (100)*
*BIO4 = Temperature Seasonality (standard deviation *100)*
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter
T_Jan...T_Dec = Mean monthly temperature January....December
P_Jan...P_Dec = Mean monthly precipitation January....December

Length of vegetation period

GDD5 = Grow degree days above 5° C temperature

Synes, N.W. & Osborne, P.E. (2011). Choice of predictor variables as a source of uncertainty in continental-scale species distribution modelling under climate change. Glob. Ecol. Biogeogr. 20, 904–914.

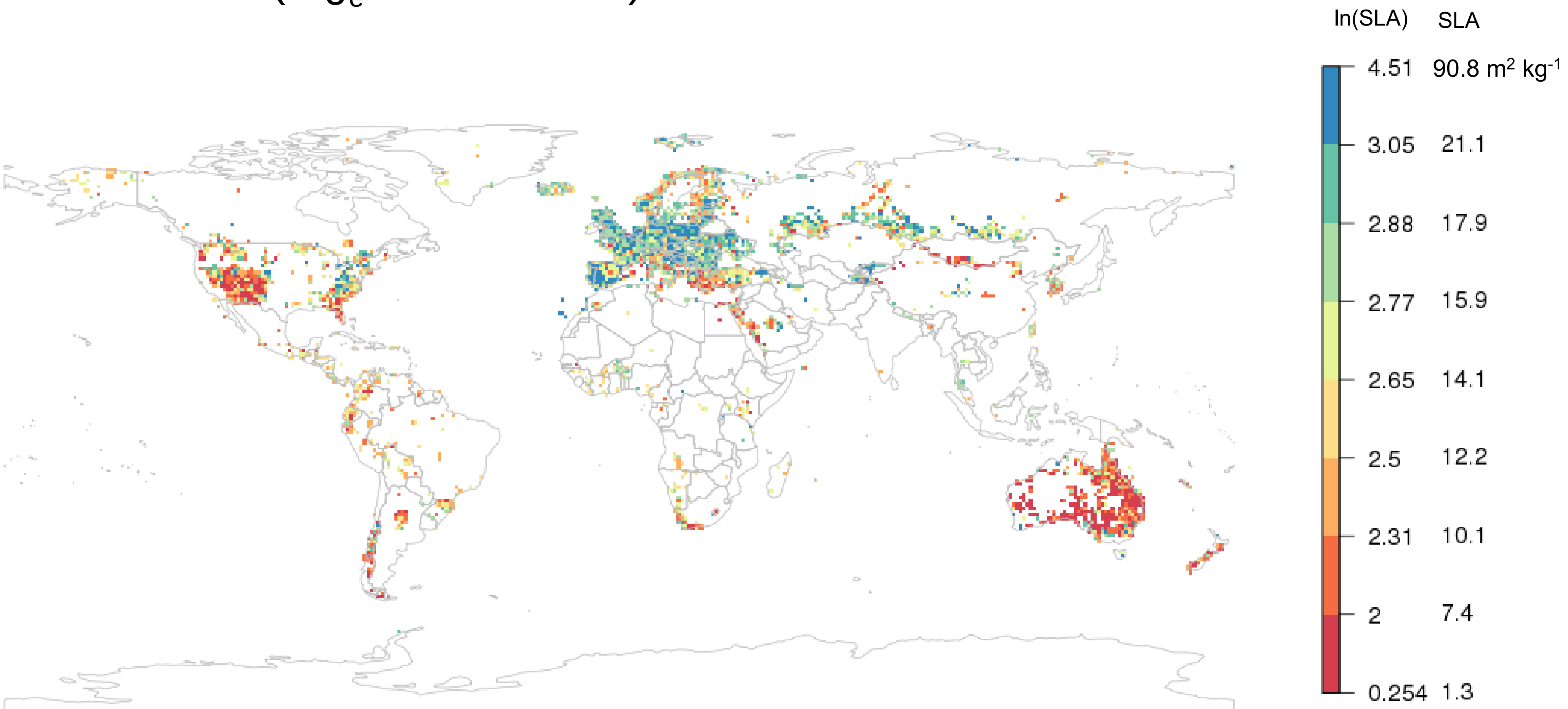
Drought indices

AR = Aridity = MAP/MAE (mean annual precipitation/mean annual potential evapo-transpiration)
PET = Potential evapotranspiration

http://www.cgiar-csi.org/data/global-aridity-and-pet-database

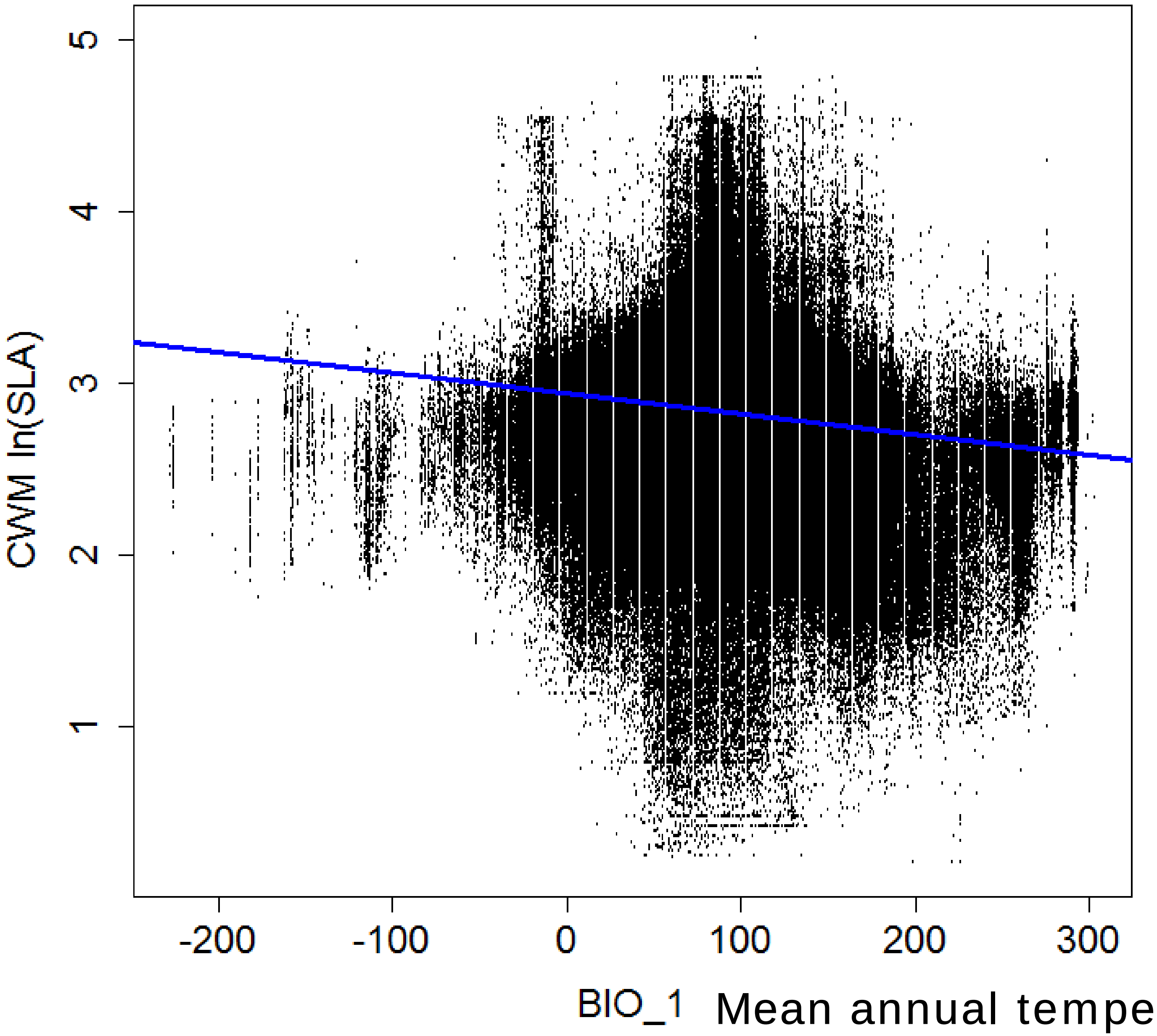
Community weighted mean trait values of specific leaf area (CWM SLA)

- Based on 1,111,307 plots (99.41% of all plots)
- SLA (log_e transformed)



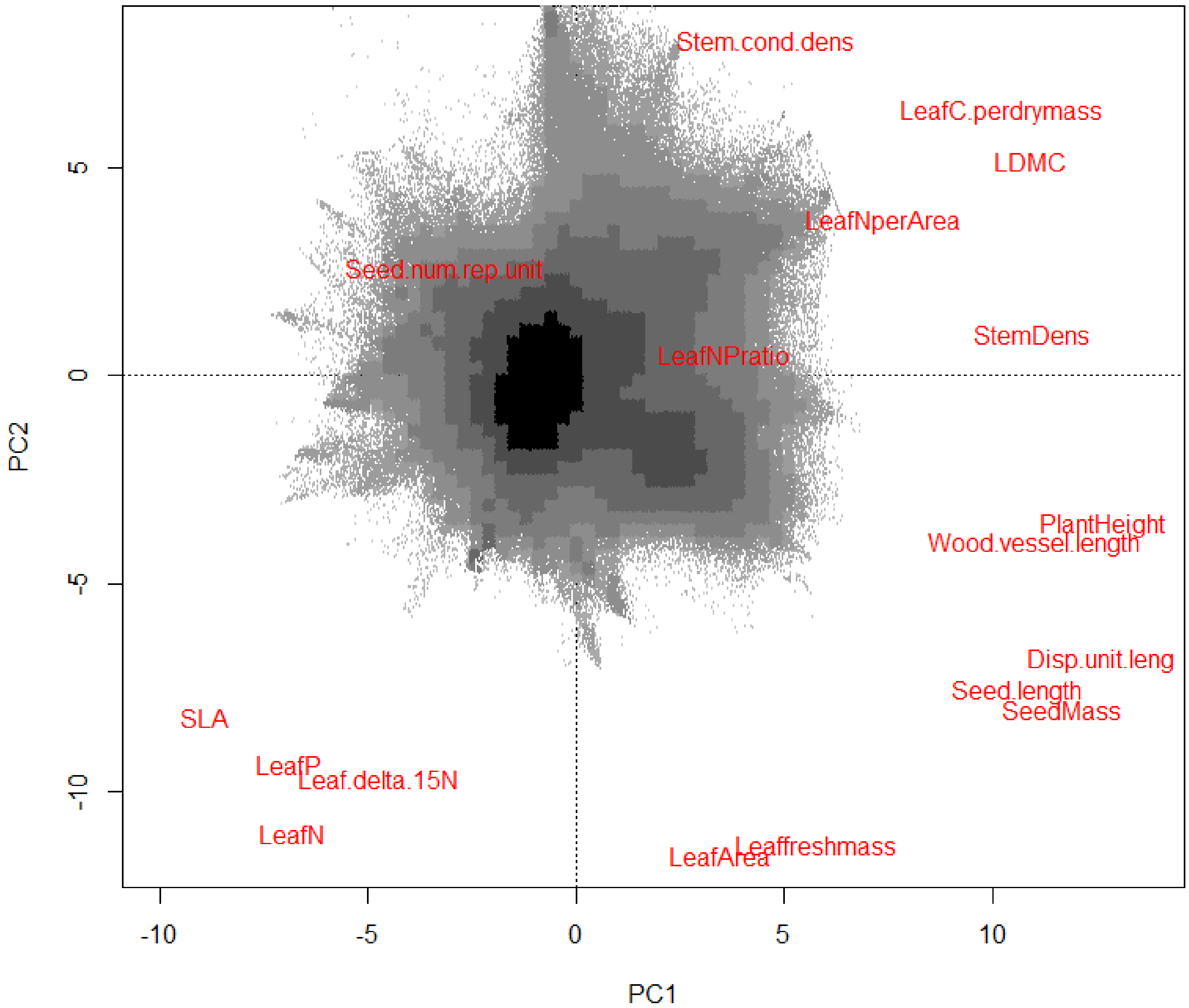
CWM of SLA

versus mean annual temperature (MAT), $r^2 = 0.0156$



Mean annual temperature [*10 ° C]

PCA of all CWMs

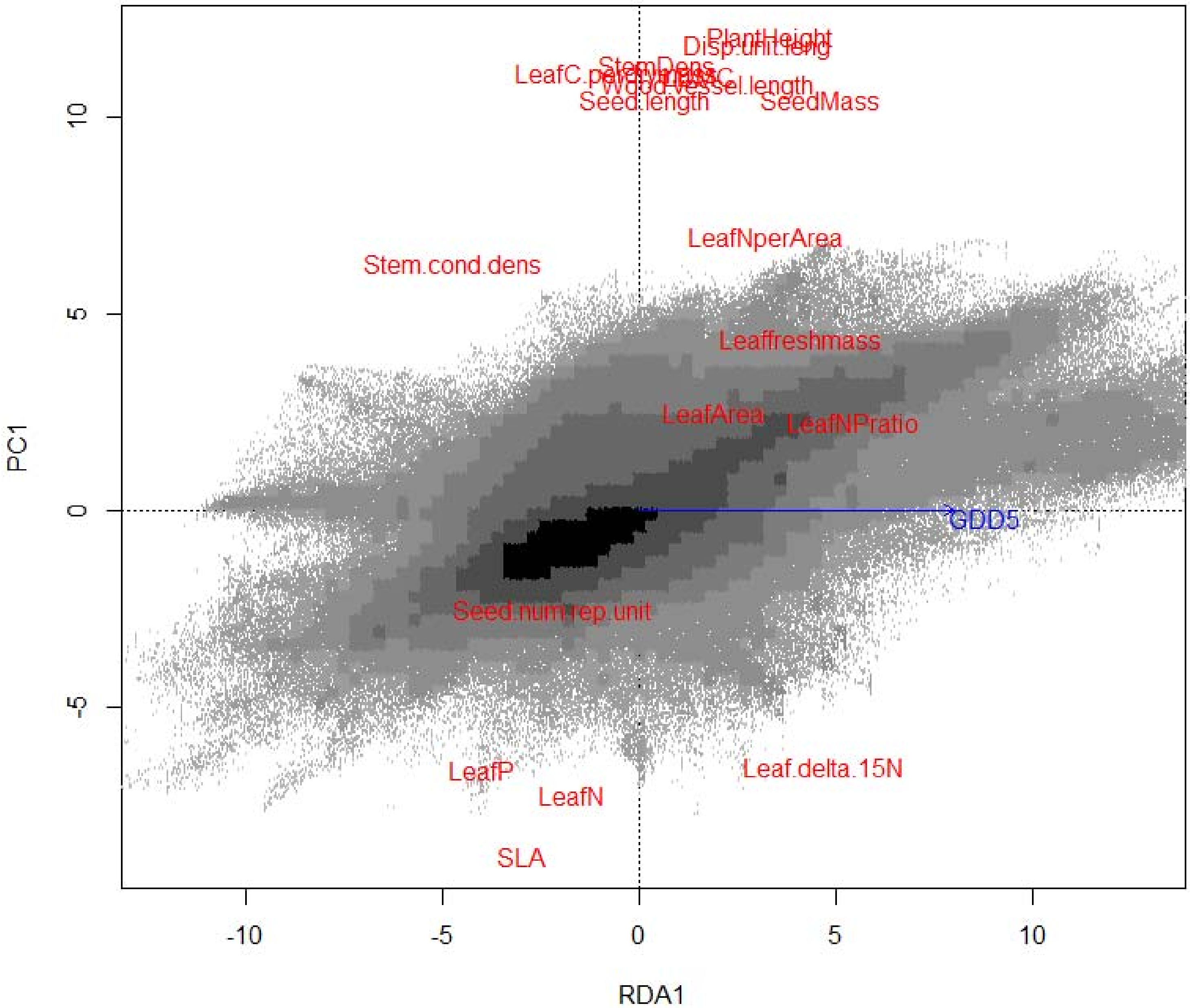


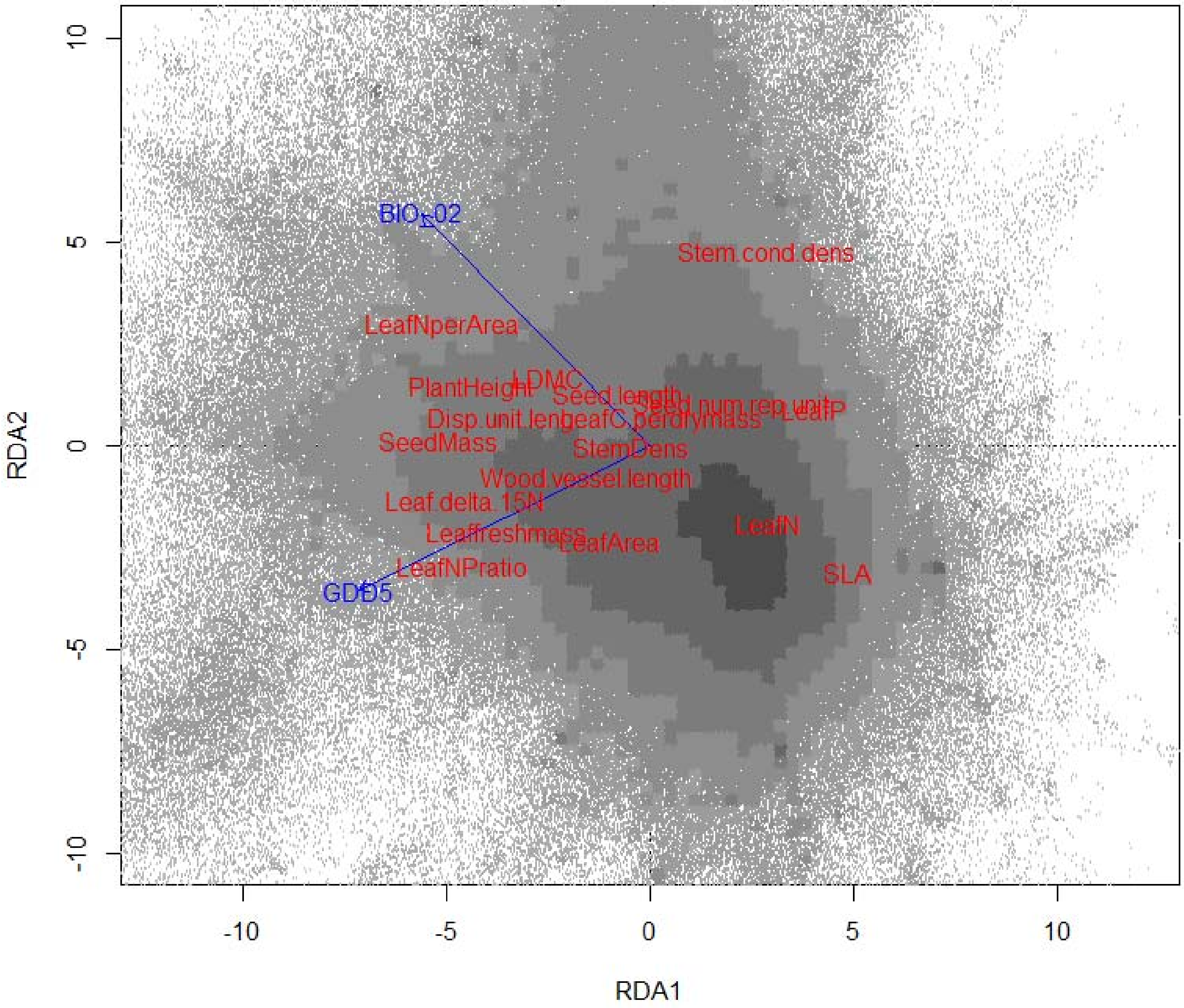
Variance in CWM explained by the first two axes = 52.41%

RDA of all CWMs

Step forward selection of all Bioclim variables.

Variance in CWM explained by GDD5 as first RDA axis = 4.12%

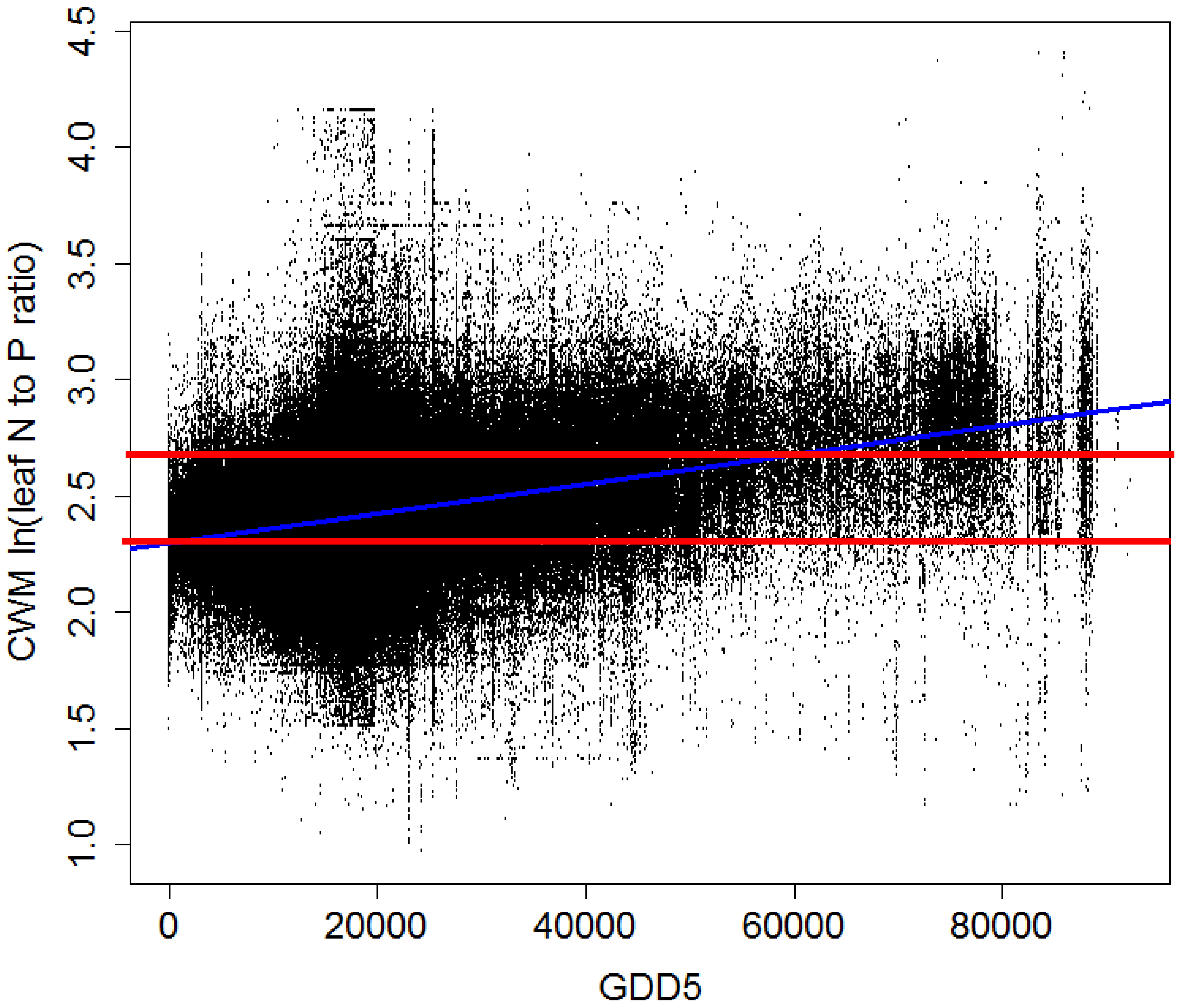




RDA of all CWMs

Step forward selection of all Bioclim variables. Variance in CWM explained by GDD5 and BIO_02 as first two RDA axes = 6.40%.

BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))



CWM of leaf N to P ratio

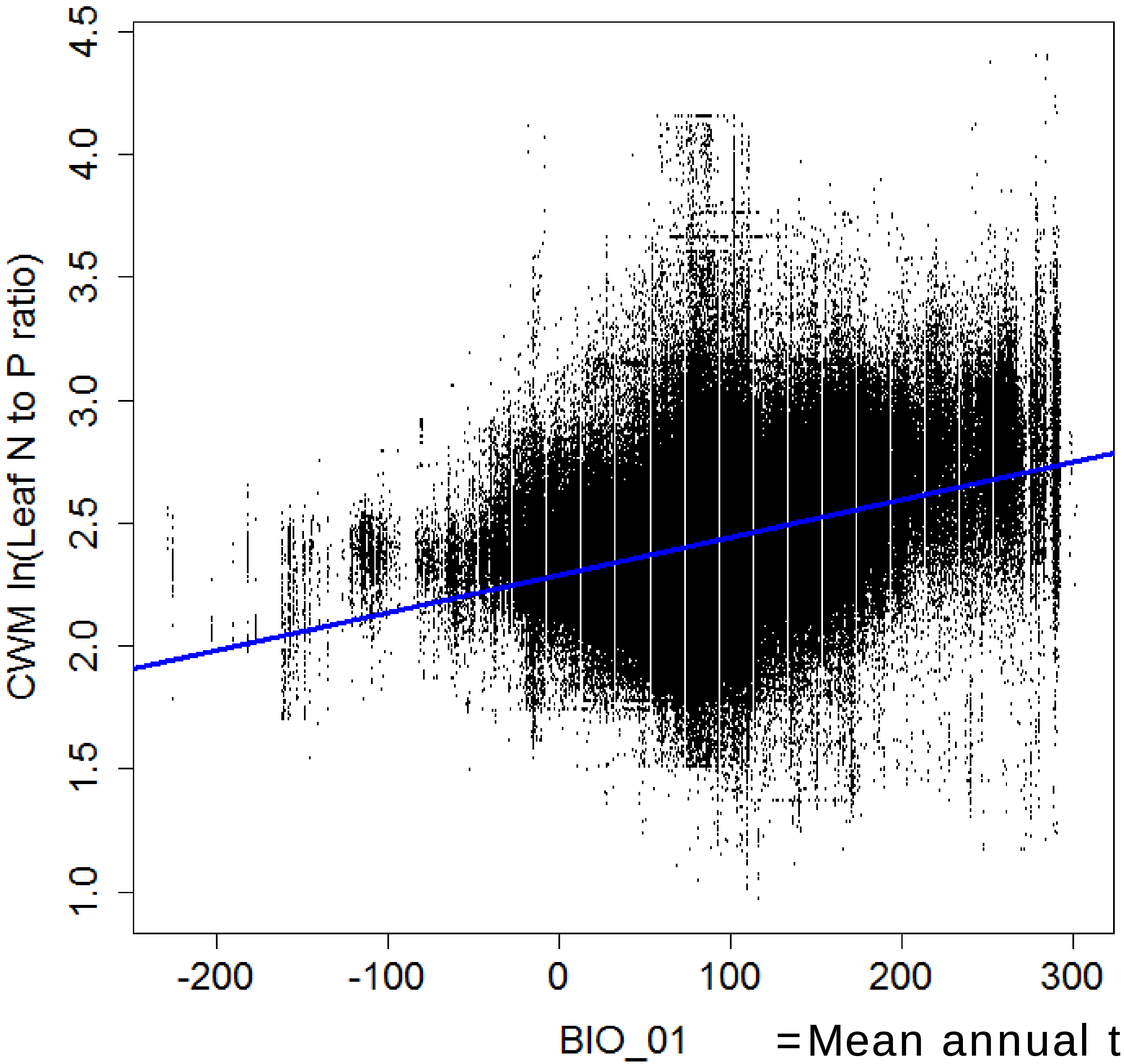
versus GDD5, $r^2 = 0.1193$

-> ln(15)

-> ln(10)

N:P ratios above and below which productivity is strongly limited by P or N

Güsewell, S., 2004. N:P ratios in terrestrial plants: variation and functional significance. New Phytol. 164, 243–266.

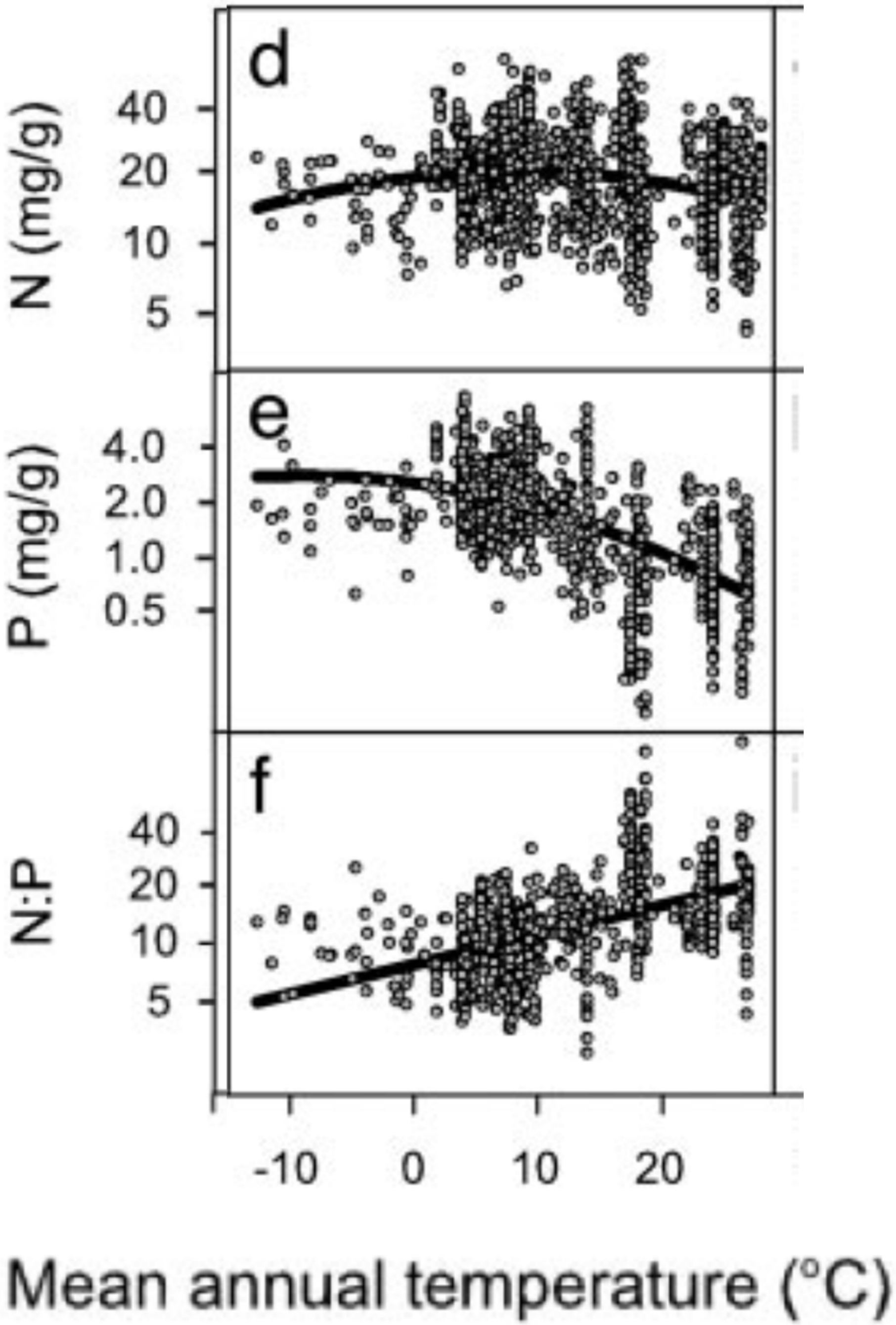


=Mean annual temperature [*10 ° C]

CWM of leaf N to P ratio

versus mean annual temperature (MAT),

r^2 = 0.103



N:P ratios increase with MAT

based on observations on single species

Fig. 1 d, e, f from Reich, P.B. & Oleksyn, J. (2004) Global patterns of plant leaf N and P in relation to temperature and latitude, P. Natl. A. Sci. USA, 101: 11001-11006.

Growth rates decrease with the N:P ratio

Correlation of N, P and N:P with maximal growth rates

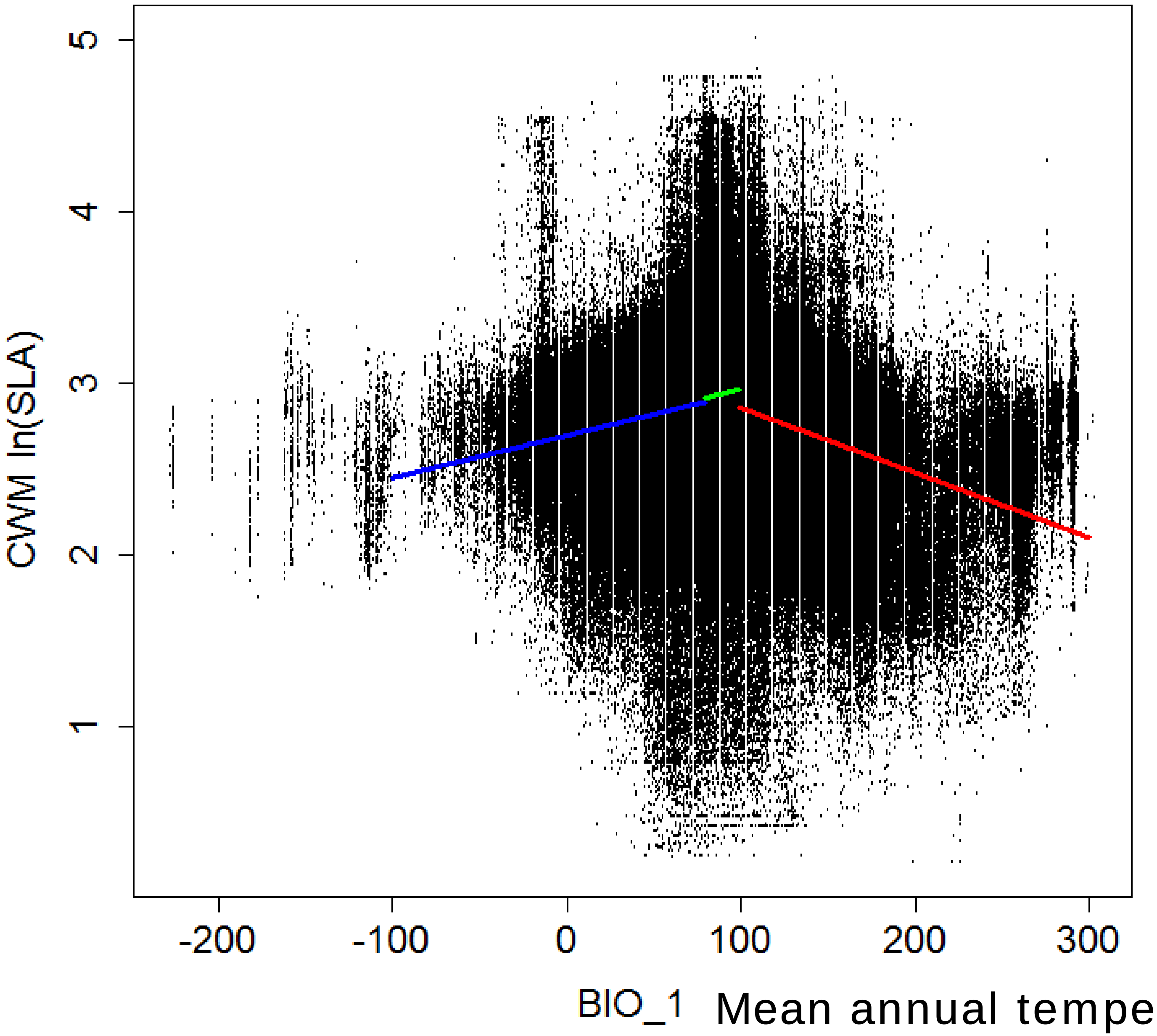
	n	[N]	[P]	N : P ratio
(a) Correlations with RGR				
Forest floor forbs[1]	17	0.69**	0.79***	na
Forest floor graminoids[1]	16	0.48	0.41	na
Herbaceous species[2]	67	0.33*	0.51***	–0.50***
Vascular plants[3]	250	0.62***	0.56***	na
Woody plants[4]	79	0.52***	0.50***	–0.17

-> reduced growth rates at high N:P ratios

Table 1 from Güsewell, S., 2004. N:P ratios in terrestrial plants: variation and functional significance. New Phytol. 164, 243–266.

CWM of SLA

versus mean annual temperature (MAT), divided by 33% und 66% percentiles.

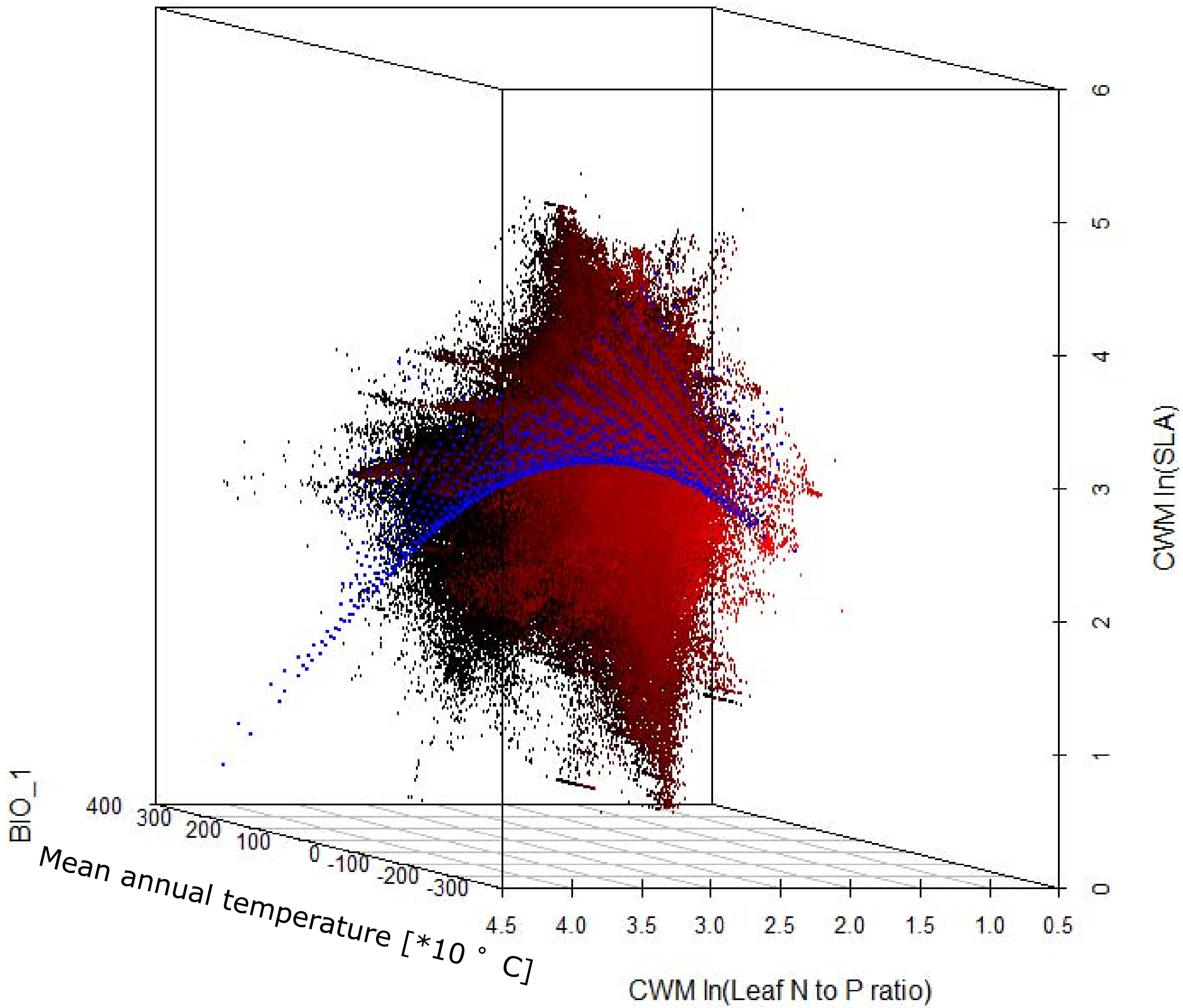


$r^2 = 0.0252$

$r^2 = 0.0422$

$r^2 = 0.1028$

Mean annual temperature [*10 ° C]



CWM of SLA

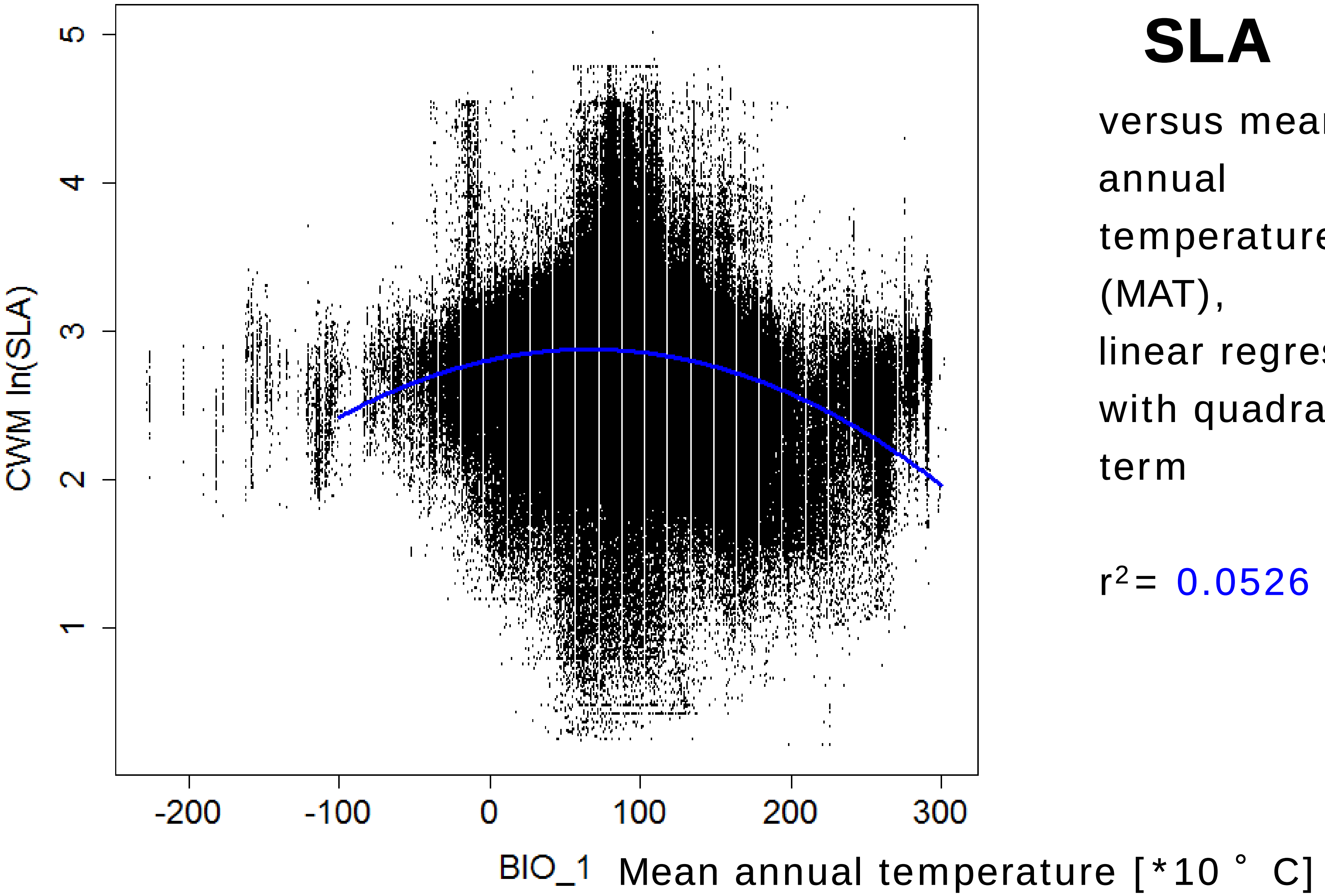
versus mean annual temperature (MAT) and CWM of leaf N to P ratio, linear multiple regression

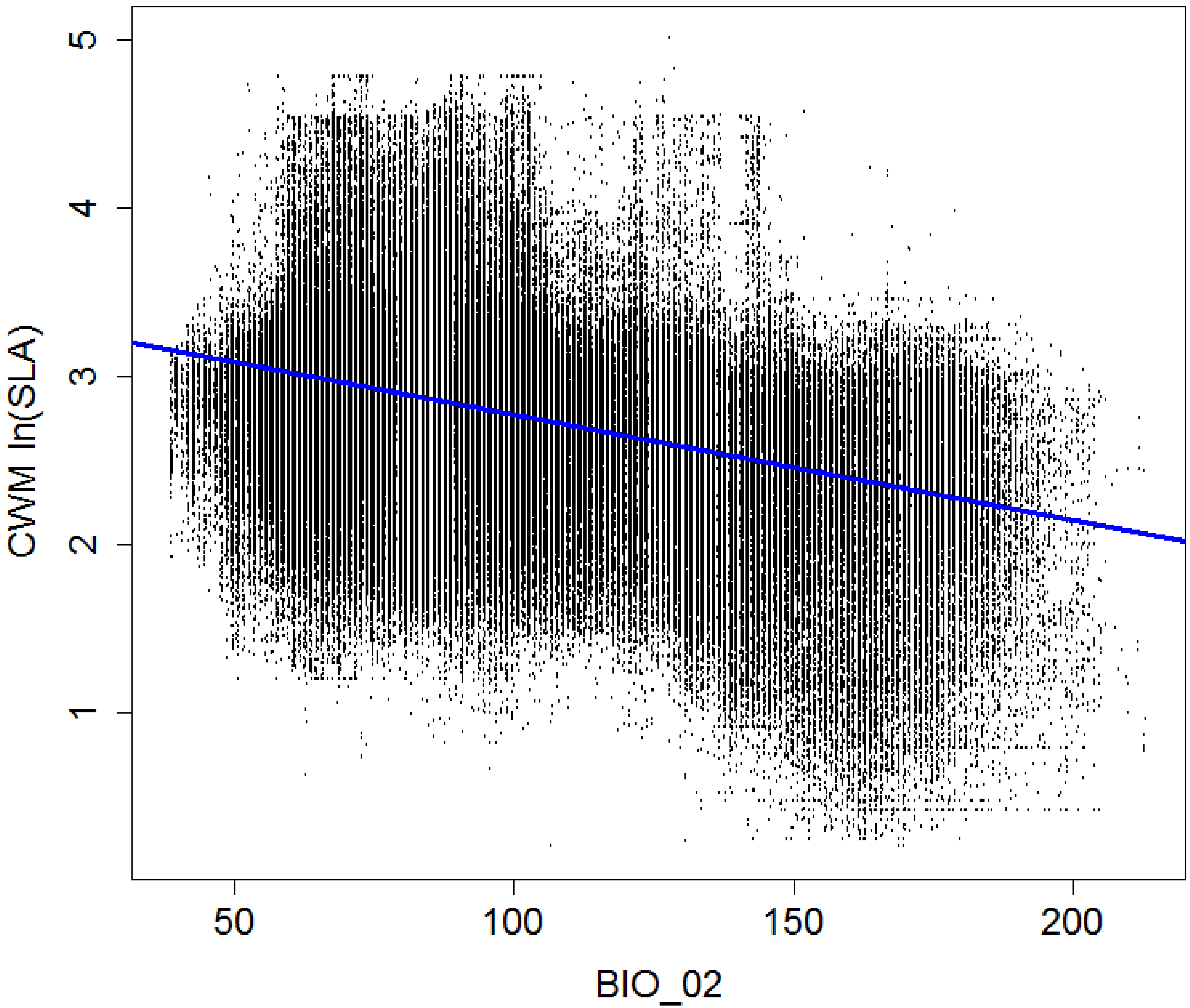
$r^2 = 0.0484$

CWM of SLA

versus mean annual temperature (MAT), linear regression with quadratic term

r^2= 0.0526





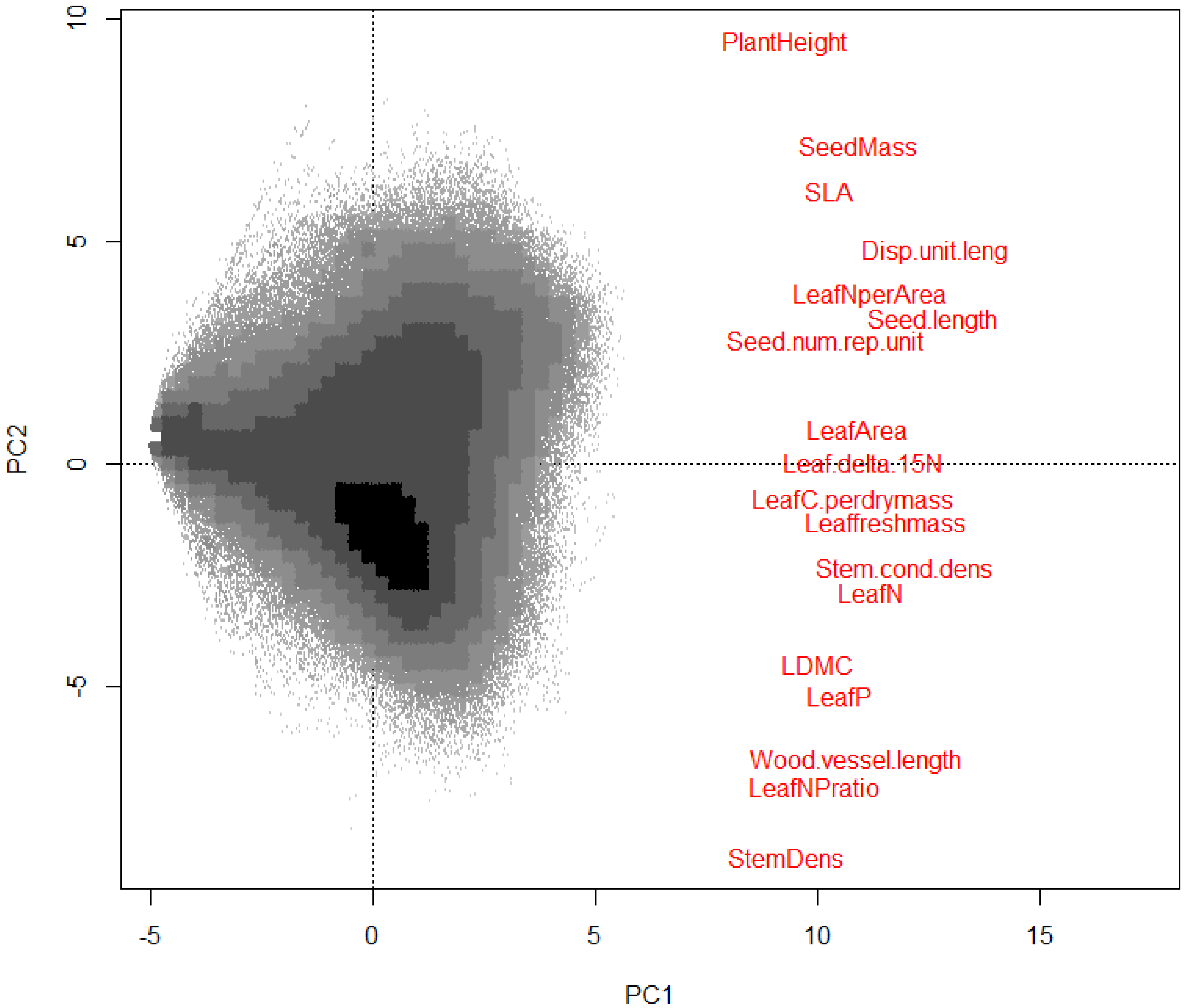
CWM of SLA

versus BIO_02

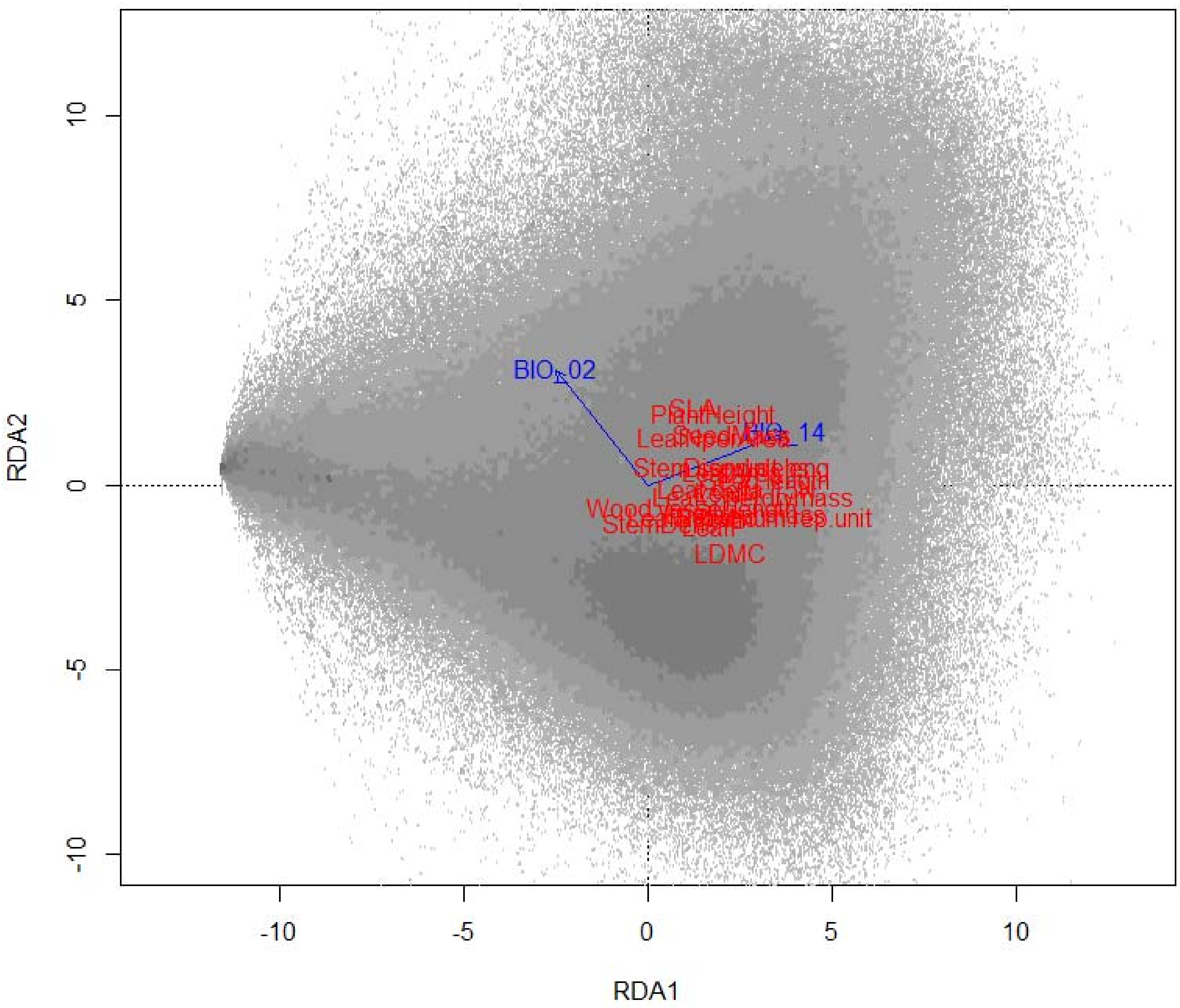
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))

$r^2 = 0.1277$

PCA of all FDs



Variance in FD explained by the first two axes = 58.18 %



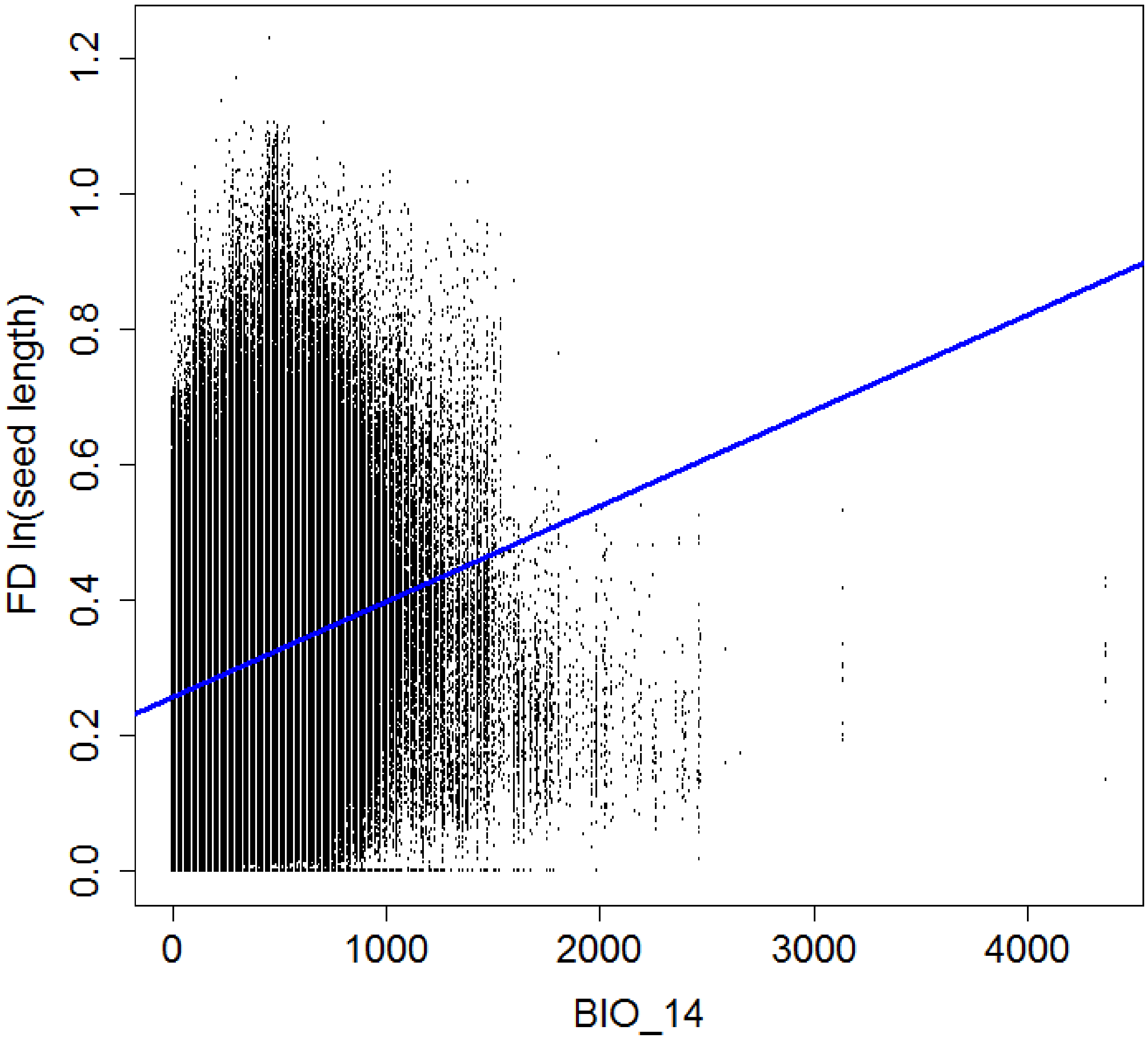
RDA of all FDs

Step forward selection of all Bioclim variables. Variance in FD explained by BIO_14 and BIO_02 as first two RDA axes = 2.48 %.

BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))

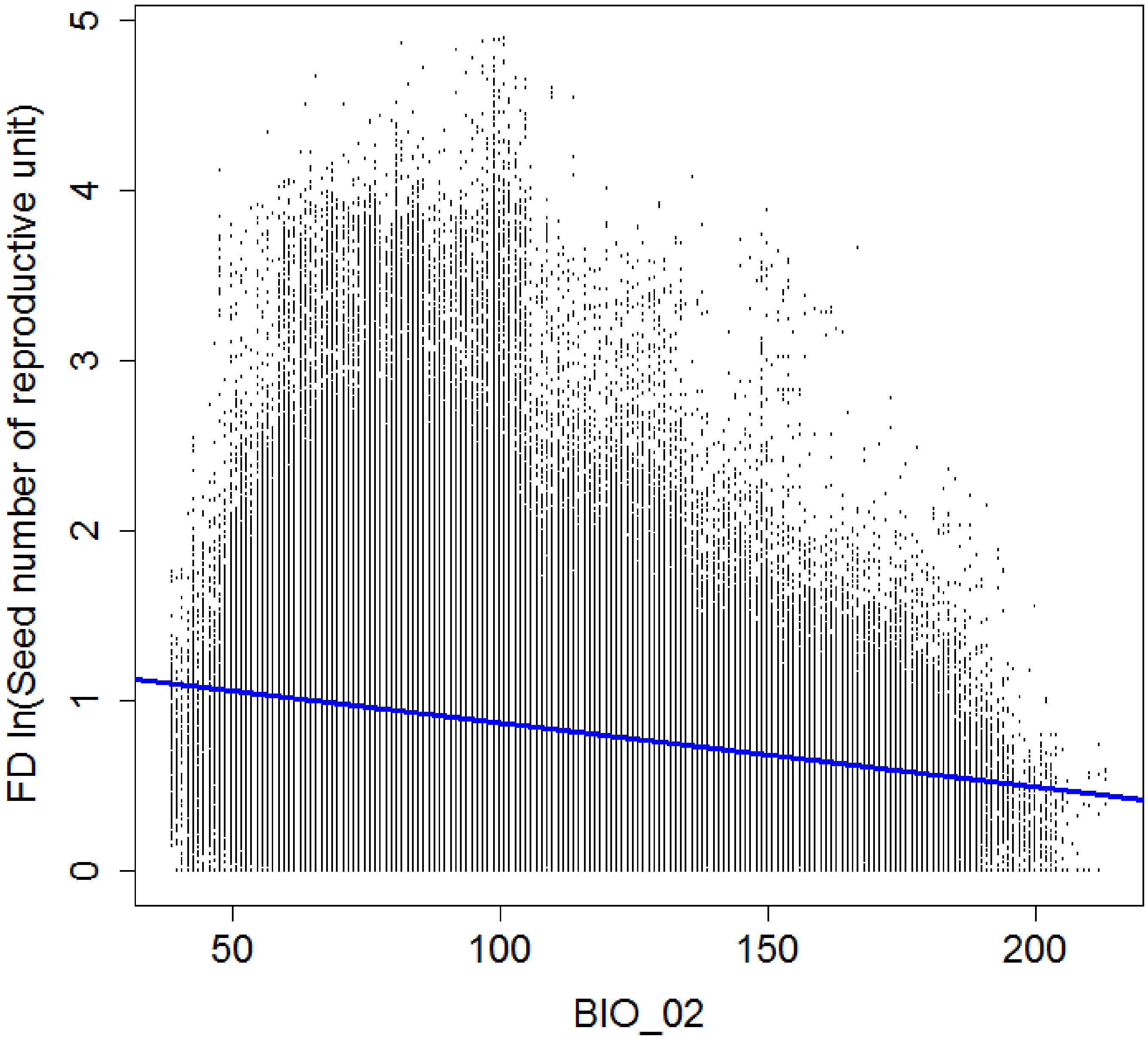
FD of Seed length

versus BIO_14



BIO14 = Precipitation of Driest Month

$r^2 = 0.0370$



FD of Seed number of repro-ductive unit

versus BIO_02

BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))

$r^2 = 0.0330$

Discussion

1. The amount of variation explained by macroclimate is similarly high for FD than CWM. ☑

2. The strongest response to global macroclimatic drivers have traits that are related to productivity, such as SLA, leaf N, leaf P, LDMC. ☒

3. The amount of variation explained by macroclimate is similarly high for FD than CWM. ☒

Acknowledgements

German Research Foundation (DFG)

sDiv crew

Gunnar Seidler (Bioclim, GVRD)

All sPlot contributors

www.idiv.de/splot