Supporting information to the paper:

Zhu, L.H. et al., **Do current definitions and methods promote the general application of functional traits and functional diversity?**

Appendix S1. Different definitions for functional trait.

Definition	Reference
Functional traits are the characteristics of an organism that are considered relevant to its response to the environment and/or its effects on ecosystem functioning.	Díaz & Cabido 2001
Functional trait is any attribute that has potentially significant influence on establishment, survival, and fitness.	Reich et al. 2003
Functional traits are those that influence ecosystem properties or species' response to environmental conditions.	Hooper et al. 2005
A functional trait is one that strongly influences organismal performance in the community.	McGill et al. 2006
Functional traits are defined as morpho-physio-phenological traits which impact fitness indirectly via their effects on growth, reproduction and survival, the three components of individual performance.	Violle et al. 2007
Functional traits are components of an organism's phenotype that determines its effect on processes and its response to environmental factors.	Reiss et al. 2009
Functional trait is a characteristic of an organism, which has demonstrable links to the organism's function. As such, a functional trait determines the organism's response to pressures (response trait), and its effects on ecosystem processes or services (effect trait). Functional traits are considered as reflecting adaptations to variation in the physical and biotic environment and trade-offs (ecophysiological and/or evolutionary) among different functions within an organism.	de Bello et al. 2010
A phenotypic trait that influences fitness through biochemical, physiological, morphological or developmental mechanisms.	Donovan et al. 2011
Functional traits are morphological, biochemical, physiological, structural, phenological, or behavioral characteristics that are expressed in phenotypes of individual organisms and are considered relevant to the response of such organisms to the environment and/or their effects on ecosystem properties	Díaz et al. 2013
Functional trait is any trait directly influencing organismal performance.	Mouillot et al. 2013
Functional traits have to be functional, meaning that they have to demonstrably effect or respond to ecosystem processes.	Mlambo 2014
A functional trait is defined as any phenotypic attribute that affects the fitness of organisms and/or their influence on other organisms and on ecosystem functions	Hortal et al. 2015
Functional trait is any morphological, physiological, phenological, or behavioral feature of an organism that can be measured at the individual level and that has an effect on its fitness.	Carmona et al. 2016
Traits are functional to the degree that they determine individual fitness	Shipley et al. 2016

References

Carmona, C.P., de Bello, F., Mason, N.W.H. & Lepš, J. 2016. Traits without borders: integrating functional diversity across scales. Trends in Ecology & Evolution 31(5): 382–394.

de Bello, F., Lavorel, S., Díaz, S., Harrington, R., Cornelissen, J.H.C., Bardgett, R.D., Berg, M.P., Cipriotti, P., Feld, C.K., (..) & Harrison P.A. 2010. Towards an assessment of multiple ecosystem processes and services via functional traits. Biodiversity and Conservation 19: 2873–2893.

Díaz S. & Cabido, M. 2001. Vive la différence: plant functional diversity matters to ecosystem processes. Trends in Ecology & Evolution 16 (11): 646–655.

Díaz, S., Purvis, A., Cornelissen, J.H.C., Mace, G.M., Donoghue, M.J., Ewers, R.M., Jordano, P. & Pearse W.D. 2013. Functional traits, the phylogeny of function, and ecosystem service vulnerability. Ecology and Evolution 3(9): 2958–2975.

Donovan, L.A., Maherali, H., Caruso, C.M., Huber, H. & de Kroon, H. 2011. The evolution of the worldwide leaf economics spectrum. Trends in Ecology and Evolution 26 (2): 88–95.

Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M. & Wardle, D.A. 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monographs 75(1): 3–35.

Hortal, J., de Bello, F., Diniz-Filho, J.A.F., Lewinsohn, T.M., Lobo, J.M. & Ladle, R.J. 2015. Seven shortfalls that beset large-scale knowledge of biodiversity. Annual Review of Ecology, Evolution, and Systematics 46: 523–549.

McGill, B.J., Enquist, B.J., Weiher, E. & Westoby, M. 2006. Rebuilding community ecology from functional traits. Trends in Ecology and Evolution 21 (4): 178–185.

Mlambo, M.C. 2014. Not all traits are ‘functional’: insights from taxonomy and biodiversity-ecosystem functioning research. Biodiversity and Conservation 23:781–790.

Mouillot, D., Nicholas A.J., Graham, N.A.J., Villéger, S., Mason, N.W.H. & Bellwood, D.R. 2013. A functional approach reveals community responses to disturbances. Trends in Ecology & Evolution 28(3): 167–177.

Reich, P.B., Wright, I.J., Cavender-Bares, J., Craine, J.M., Oleksyn, J., Westoby, M. & Walters, M.B. 2003. The evolution of plant functional variation: traits, spectra, and strategies. International Journal of Plant Sciences 164(3): S143 – S164.

Reiss, J., Bridle, J.R., Montoya J.M. & Woodward, G. 2009. Emerging horizons in biodiversity and ecosystem functioning research. Trends in Ecology and Evolution 24(9): 505–514.

Shipley, B., de Bello, F., Cornelissen, J.H.C., Laliberté, E., Laughlin, D.C. & Reich, P.B. 2016. Reinforcing loose foundation stones in trait-based plant ecology. Oecologia 180: 923–931.

Violle, C., Navas, M.L., Vile, D., Kazakou, E., Fortunel, C., Hummel, I. & Garnier, E. 2007. Let the concept of trait be functional!. Oikos 116: 882–892.

Supporting information to the paper:

Zhu, L.H. et al., **Do current definitions and methods promote the general application of functional traits and functional diversity?**

Appendix S2. The context dependency of trait trade-offs and synergies.

The recent researches on plant strategies reveal that the trait trade-off or synergy in one context may not always hold in the other contexts, which constrains ecological interpretation and generalization of ordination analysis across ecosystems and challenge the use of ordination analysis in the quantification of functional diversity.

The changes of trait relationships across environmental or species gradients has long been studied (Reich et al. 1997; Wright et al. 2005; He et al. 2006; Liu et al. 2010; Messier et al. 2016). Different lines of evidence suggest that bipartite trait relationships in one context do not always hold in the other contexts (See the appendix S3-S5 for the three trait relationships collected from the literature). Trait relationship across samples results from the joint forces of the common factors affecting all the samples and the idiosyncratic factors affecting specific samples. The trait relationships might be different among different scales (from the global scale to the intraspecific scale), different environmental gradients (Wright et al. 2005; Wright & Sutton-Grier 2012), different ecosystems (Xiang et al. 2013), different species constellations (Wang et al. 2016), different plant sizes, different stages of life history (Forrestel et al. 2015; Fajardo & Siefert 2016) and different managements (Rose et al. 2013).

First, even some tradeoffs or synergies of traits result from some causal relationships (Reich et al. 2003), the scaling relationships among them may vary with ecosystems (e.g. the relationship between photosynthetic rate and leaf nitrogen concentration in the appendix S3), where the limiting factors of plant strategies are usually different. Second, the trait correlations that are not underpinned by causal relationships are also contingent on the studied ecosystem, species and trait constellations (Lavorel & Garnier 2002; Westoby & Wright 2006; Dormann et al. 2013). A phylogenetic structural equation modeling of four traits of leaf economics spectrum, revealed that the trait relationships at the global scale are similar to these of rosid clade, moderately different from these of 28 species of the genus *Helianthus*, and largely different from these of asteroid clade and these of 97 genitic families from eight populations of *Helianthus anomalus*. Their differences lie in not only the scaling relationships but also the directionality (Mason et al 2016). Previously, Reich et al. (2003) also pointed that trait relationship within an ecosystem can be in the opposite direction of that across ecosystems. This proposal was further validated by three studies implemented at the level of genotype, species and genus, which find that leaf traits previously considered as being conservative are associated with high photosynthetic rate or rapid growth (Grady et al. 2013; Edwards et al. 2014; Niinemets et al. 2015).

References

Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Jaime R., Marquéz, G., Gruber, B., (..) & Lautenbach, S. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36: 027–046.

Edwards, E.J., Chatelet, D.S., Sack, L. & Donoghue, M.J. 2014. Leaf life span and the leaf economic spectrum in the context of whole plant architecture. Journal of Ecology 102: 328–336.

Fajardo, A. & Siefert, A. 2016. Phenological variation of leaf functional traits within species. Oecologia 180: 951–959.

Forrestel, E.J., Ackerly, D.D. & Emery, N.C. 2015. The joint evolution of traits and habitat: ontogenetic shifts in leaf morphology and wetland specialization in *Lasthenia*. New Phytologist 208: 949–959.

Grady, K.C., Laughlin, D.C., Ferrier, S.M., Kolb, T.E., Hart, S.C., Gerard, J., Allan, G.J. & Whitham, T.G. 2013. Conservative leaf economic traits correlate with fast growth of genotypes of a foundation riparian species near the thermal maximum extent of its geographic range. Functional Ecology 27: 428–438.

He, J.S., Wang, Z.H., Wang, X.P., Schmid, B., Zuo, W.Y., Zhou, M., Zheng, C.Y., Wang M.F. & Fang, J.Y. 2006. A test of the generality of leaf trait relationships on the Tibetan Plateau. New Phytologist 170: 835–848.

Lavorel, S. & Garnier, E. 2002. Predicting changes in community composition and ecosystem functioning from plant traits: revisiting the Holy Grail. Functional Ecology 16: 545–556.

Liu, G.F., Freschet, G.T., Pan, X., Cornelissen, J.H.C., Li, Y. & Dong, M. 2010. Coordinated variation in leaf and root traits across multiple spatial scales in Chinese semi-arid and arid ecosystems. New Phytologist 188: 543–553.

Mason, C.M., Goolsby, E.W., Humphreysand, D.P. & Donovan, L.A. 2016. Phylogenetic structural equation modelling reveals no need for an 'origin' of the leaf economics spectrum. Ecology Letters 19: 54–61.

Messier, J., McGill, B.J., Enquist, B.J. & Lechowicz, M.J. 2016. Trait variation and integration across scales: Is the leaf economic spectrum present at local scales? Ecography DOI: 10.1111/ecog.02006.

Niinemets, U. 2015. Is there a species spectrum within the world-wide leaf economics spectrum? major variations in leaf functional traits in the Mediterranean sclerophyll *Quercus ilex*. New Phytologist 205: 79–96.

Reich, P.B., Walters, M.B. & Ellsworth, D.S. 1997. From tropics to tundra: global convergence in plant functioning. Proceedings of the National Academy of Sciences of the United States of America 94: 13730–13734.

Reich, P.B., Wright, I.J., Cavender-Bares, J., Craine, J.M., Oleksyn, J., Westoby, M. & Walters, M.B. 2003. The evolution of plant functional variation: traits, spectra, and strategies. International Journal of Plant Sciences 164(3): S143 – S164.

Rose, L., Rubarth, M.C., Hertel, D. & Leuschner, C. 2013. Management alters interspecific leaf trait relationships and trait-based species rankings in permanent meadows. Journal of Vegetation Science 24: 239–250.

Wang, Z., Liu, X. & Bao, W.K. 2016. Higher photosynthetic capacity and different functional trait scaling relationships in erect bryophytes compared with prostrate species. Oecologia 180: 359–369.

Westoby, M. & Wright, I.J. 2006. Land-plant ecology on the basis of functional traits. Trends in Ecology and Evolution 21: 261–268.

Wright, I.J., Reich, P.B., Cornelissen, J.H.C, Falster, D.S., Groom, P.K., Hikosaka, K., Lee, W., Lusk, C.H., Niinemets, Ü., (…) & Westoby, M. 2005. Modulation of leaf economic traits and trait relationships by climate. Global Ecology and Biogeography 14: 411–421.

Wright, J.P. & Sutton-Grier, A. 2012. Does the leaf economic spectrum hold within local species pools across varying environmental conditions? Functional Ecology 26: 1390–1398.

Xiang, S., Reich, P.B., Sun, S.C. & Atkin, O.K. 2013. Contrasting leaf trait scaling relationships in tropical and temperate wet forest species. Functional Ecology 27: 522–534.

Supporting information to the paper:

Zhu, L.H. et al., **Do current definitions and methods promote the general application of functional traits and functional diversity?**

Appendix S3. The relationshipa between leaf photosynthetic rate (the response variable) and leaf nitrogen concentration (the explanatory variable) on a mass basis.

Reference	Location, Species, Ecosystems, Environments	Ordinary least square regession				Standard major axis regression			
		Slope	Inter-cept	R^2	P	Slope	Inter-cept	R^2	P
Reich et al., 1997, 1999	111 species from six biomes	1.42	0.13	0.68					
Reich et al., 1997	170 species from global literature	1.64		0.66					
Wright et al., 2001	Wetter, high P site					1.55		0.31	0.016
	Wetter, low P site					0.83		0.14	0.146
	Drier, high P site					1.98		0.64	<0.001
	Drier, low P site					1.43		0.08	0.207
Wright et al., 2004	712 species					1.72		0.53	
Wright et al., 2005	712 species	1.25	1.68	0.531	< 0.001				
	37 Grasses	0.62	2.01	0.092	0.068				
	139 Herbs	1.11	1.86	0.553	< 0.001				
	228 Shrubs	1.02	1.68	0.440	< 0.001				
	302 Trees	1.10	1.67	0.429	< 0.001				
	84 Deciduous trees	0.62	1.89	0.245	< 0.001				
	151 Evergreen trees	0.67	1.67	0.132	< 0.001				
	118 Broad-leaf evergreen trees	0.56	1.75	0.153	< 0.001				
	30 Needle-leaf evergreen trees	1.23	1.37	0.183	0.018				
Reich et al., 2009	Low P	0.868	0.822	0.28	<0.0001				
	Medium P	1.378	0.020	0.41	<0.0001				
	High P	1.509	0.028	0.57	<0.0001				
Reich et al., 2009	Arctic	1.59	-0.14	0.62	<0.0001				
	Temperate	1.48	0.05	0.53	<0.0001				
	Tropical	1.23	0.43	0.52	<0.0001				

	Subtropical	1.10	0.56	0.43	<0.0001				
Reich et al, 2010						1.47	0.13	0.37	<0.0001
Heberling & Fridley 2012	Northern Hemisphere					1.84	1.54	0.58	
	Southern Hemisphere					1.39	1.65	0.28	
	East Asia					1.54	1.52	0.60	
	Eastern North America					1.76	1.63	0.48	
	Hawaii					1.88	1.49	0.26	
	Mainland tropics					1.81	1.51	0.24	
Xiang et al., 2013	13 tropical species					1.968	-3.809	0.39	< 0.001
	12 temperate species					1.54	-3.182	0.20	< 0.001
Wang et al., 2016	16 prostrate bryophytes					2.48		0.13	0.003
	12 erect bryophytes					2.71		0.09	0.045

References

Heberling, J.M. & Fridley, J.D. 2012. Biogeographic constraints on the world-wide leaf economics spectrum. Global Ecology and Biogeography 21: 1137–1146.

Reich, P.B., Ellsworth, D.S., Walters, M.B., Vose, J.M., Gresham, C., Volin, J.C. & Bowman, W.D. 1999. Generality of leaf trait relationships: a test across six biomes. Ecology 80(6): 1955–1969.

Reich, P.B., Oleksyn, J., Wright, I.J. 2009. Leaf phosphorus infuences the photosynthesis–nitrogen relation: a cross-biome analysis of 314 species. Oecologia 160:207–212.

Reich, P.B., Walters, M.B. & Ellsworth, D.S. 1997. From tropics to tundra: global convergence in plant functioning. Proceedings of the National Academy of Sciences of the United States of America 94: 13730–13734.

Wang, Z., Liu, X. & Bao, W.K. 2016. Higher photosynthetic capacity and different functional trait scaling relationships in erect bryophytes compared with prostrate species. Oecologia 180: 359–369.

Wright, I.J., Reich, P.B. & Westoby, M.. 2001. Strategy shifts in leaf physiology, structure and nutrient content between species of high- and low-rainfall and high- and low-nutrient habitats. Functional Ecology 15: 423–434.

Wright, I.J., Reich, P.B., Westoby, M., Ackerly, D.D., Baruch, Z., Bongers, F., Cavender-Bares, J., Chapin, T., Cornelissen, J.H.C., (..) Villar R. 2004. The worldwide leaf economics spectrum. Nature 428: 821-827.

Wright, I.J., Reich,P.B., Cornelissen, J.H.C., Falster, D.S., Garnier, E., Hikosaka, K., Lamont, B.B., Lee, W., Oleksyn, J., (...) & Westoby, M. 2005. Assessing the generality of global leaf trait relationships. New Phytologist 166: 485–496.

Xiang, S., Reich, P.B., Sun, S.C. & Atkin, O.K. 2013. Contrasting leaf trait scaling relationships in tropical and temperate wet forest species. Functional Ecology 27: 522–534.

Supporting information to the paper:

Zhu, L.H. et al., **Do current definitions and methods promote the general application of functional traits and functional diversity?**

Appendix S4. The relationshipa between leaf mass per area (the response variable) and leaf nitrogen concentration per mass (the explanatory variable).

Reference	Location, Species, Ecosystems, Environments	Ordinary least square regession				Standard major axis regression			
		Slope	Inter-cept	R^2	P	Slope	Inter-cept	R^2	P
Wright et al., 2004	1958 species					-1.28		0.57	
Wright et al., 2005	1958 species	-0.97	2.24	0.573	< 0.001				
	11 Ferns			0.077	0.408				
	95 Grasses	-1.18	2.18	0.546	< 0.001				
	378 Herbs	-0.60	2.00	0.198	< 0.001				
	621 Shrubs	-0.92	2.27	0.605	< 0.001				
	834 Trees	-0.81	2.22	0.416	< 0.001				
	19 Vines	-1.02	2.24	0.307	0.014				
	317 Deciduous trees	-0.52	2.06	0.158	< 0.001				
	345 Evergreen trees	-0.83	2.24	0.33	< 0.001				
	239 Broad-leaf evergreen trees	-0.71	2.23	0.379	< 0.001				
	34 Needle-leaf evergreen trees	-0.99	2.46	0.206	0.007				
Xiang et al., 2013	12 temperate species					-1.45	4.02	0.40	
	13 tropical species					-1.16	3.48	0.14	
Díaz et al., 2016	6712 species					-1.43		0.34	
	2368 herbaceous species					-1.31		0.20	
	4167 woody species					-1.37		0.40	

References

Díaz, S., Kattge, J., Cornelissen, J.H.C., Wright, I.J., Lavorel, S., Dray, S., Reu, B., Kleyer, M., Wirth, C., (…) & Gorné, L.D. 2016. The global spectrum of plant form and function. Nature 529: 167–171.

Wright, I.J., Reich, P.B., Westoby, M., Ackerly, D.D., Baruch, Z., Bongers, F., Cavender-Bares, J., Chapin, T., Cornelissen, J.H.C., (..) Villar R. 2004. The worldwide leaf economics spectrum. Nature 428: 821-827.

Wright, I.J., Reich,P.B., Cornelissen, J.H.C., Falster, D.S., Garnier, E., Hikosaka, K., Lamont, B.B., Lee, W., Oleksyn, J., (...) & Westoby, M. 2005. Assessing the generality of global leaf trait relationships. New Phytologist 166: 485–496.

Xiang, S., Reich, P.B., Sun, S.C. & Atkin, O.K. 2013. Contrasting leaf trait scaling relationships in tropical and temperate wet forest species. Functional Ecology 27: 522–534.

Supporting information to the paper:

Zhu, L.H. et al., **Do current definitions and methods promote the general application of functional traits and functional diversity?**

Appendix S5. The relationshipa between leaf nitrogen concentration (the response variable) and leaf phosphorus concentration (the explanatory variable) on a mass basis.

Reference	Location, Species, Ecosystems, Environments	Ordinary least square				Standard major axis regression			
		Slope	Inter-cept	R^2	P	Slope	Inter-cept	R^2	P
Wright et al., 2001	Wetter, high P site					1.22		0.063	0.318
	Wetter, low P site					1.47		9×10^{-6}	0.992
	Drier, high P site					0.94		0.50	<0.001
	Drier, low P site					0.92		0.48	<0.001
Wright et al., 2004	745 species					0.66		0.72	
Wright et al., 2005	745 species	0.56	0.73	0.724	< 0.001				
	11 Grasses	0.44	0.55	0.920	< 0.001				
	5 Herbs	0.92	1.12	0.678	0.087				
	366 Shrubs	0.59	0.75	0.718	< 0.001				
	351 Trees	0.47	0.65	0.526	< 0.001				
	7 Vines	0.27	0.55	0.476	0.086				
	168 Deciduous trees	0.12	0.41	0.038	0.012				
	146 Evergreen trees	0.49	0.64	0.594	< 0.001				
	86 Broad-leaf evergreen trees	0.52	0.68	0.678	< 0.001				
	13 Needle-leaf evergreen trees	0.27	0.35	0.232	0.096				
Reich et al, 2010	About 2556 specis					0.676	1.113	0.37	< 0.0001
	Angiosperm					0.637	1.166	0.48	<0.0001
	Gymnosperm					0.696	1.002	0.22	<0.0001

	Graminoid					0.688	1.105	0.42	<0.0001
	Forb					0.664	1.127	0.23	<0.0001
	Shrub					0.652	1.155	0.56	<0.0001
	Trees					0.633	1.195	0.48	<0.0001
	Temperature					0.686	1.134	0.21	<0.0001
	Mediterranean					0.655	1.143	0.68	<0.0001
	Moist tropical					0.651	1.203	0.38	<0.0001
Wang et al., 2016	16 prostrate bryophytes					0.74		0.50	< 0.001
	12 erect bryophytes					0.86		0.60	< 0.001

References

Reich, P.B., Oleksyn, J., Wright, I.J., Niklas, K.J. Hedin, L. & Elser, J.J. 2010. Evidence of a general 2/3-power law of scaling leaf nitrogen to phosphorus among major plant groups and biomes. Proceedings of the Royal Society B-Biological Sciences 277: 877–883.

Wang, Z., Liu, X. & Bao, W.K. 2016. Higher photosynthetic capacity and different functional trait scaling relationships in erect bryophytes compared with prostrate species. Oecologia 180: 359–369.

Wright, I.J., Reich, P.B. & Westoby, M. 2001. Strategy shifts in leaf physiology, structure and nutrient content between species of high- and low-rainfall and high- and low-nutrient habitats. Functional Ecology 15: 423–434.

Wright, I.J., Reich, P.B., Westoby, M., Ackerly, D.D., Baruch, Z., Bongers, F., Cavender-Bares, J., Chapin, T., Cornelissen, J.H.C., (..) Villar R. 2004. The worldwide leaf economics spectrum. Nature 428: 821-827.

Wright, I.J., Reich,P.B., Cornelissen, J.H.C., Falster, D.S., Garnier, E., Hikosaka, K., Lamont, B.B., Lee, W., Oleksyn, J., (...) & Westoby, M. 2005. Assessing the generality of global leaf trait relationships. New Phytologist 166: 485–496.