African Journal of Biotechnology Vol. 9 (54), pp. 9208-9213, 27 December, 2010
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2010 Academic Journals

Review

Plant functional group classifications and a generalized hierarchical framework of plant functional traits

Bing-Hua Liao[1, 2]* and Xiao-Hui Wang[1,2]

[1]Institute of Ecological Science and Technology, Henan University, Kaifeng, 475001, China.
[2]College of Life Sciences, Henan University, Kaifeng, 475001, China.

Accepted 10 December, 2010

The plant functional group concept has been proven to be an excellent research framework for investigating the linkages between ecosystem functions and plant biodiversity. The large number of plant functional group classifications however makes it difficult to compare data from different studies and draw general conclusions. In this article, we briefly review the major plant functional group classifications, and then propose a generalized hierarchical framework that incorporates plant functional traits ranging from the molecular to the biospherical level, and operating on varying spatial/temporal/disturbance scales for in-depth studies of the relationship between plant biodiversity and ecosystem characteristics. This framework may help policy makers formulate better ecological conservation and restoration plans.

Key words: Plant functional traits, relationship, biodiversity, plant functional groups, ecosystem process.

INTRODUCTION

Many experiments have assessed the relationship between biodiversity and ecosystem processes from the plant functional group (PFG) perspective, trying to understand the links between plant functional traits and ecosystem functioning (Hooper and Dukes, 2004; Symstad et al., 2000; Raunkiaer, 1934; Smith et al., 1996; Chapin et al., 1996). Ecosystems are typically filled with large numbers of plant species, making species-centered studies of systemic processes and functions extremely difficult, if not outright impossible, to carry out. The plant functional group approach allows researchers to focus on a small set of functional traits commonly shared by many plant species instead of having to study every species in minute detail, thus allowing macro-scale studies of ecosystem functions to be successfully conducted. The plant functional group approach therefore plays critical roles in furthering large-scale ecological studies in general, and studies on ecological functioning in particular (Smith et al., 1996; Crowder et al., 2010; Kraft et al., 2008; Shipley et al., 2006; Kelly, 1996). Indeed in many instances, it is not only inadvisable but also unnecessary to study every species involved in an ecological function.

The plant functional group perspective moreover, has many real world applications in the field of ecological conservation and restoration. For example, people working on an ecological rejuvenation project are well advised to make plans based on the plant functional group perspective, because a degraded ecosystem must regain its former PFG diversity rather than just species richness in order to recover its full range of ecological functions (Smith et al., 1996; Crowder et al., 2010). Given the evident and increasing importance of the plant functional group concept, as well as the urgency to understand key ecological functions in a rapidly changing global environment, it is imperative for us to assess three key questions regarding the relationship between plant functional traits and ecosystem functioning. The first question is whether all of the myriad arrays of plant functional classifications facilitate our understanding of the contribution of plant biodiversity to ecosystem functioning, and if not, which classifications are more useful than others. The second question is whether we can merge the large set of often dissimilar plant functional classifications into a general

*Corresponding author. E-mail: lbh@henu.edu.cn. Tel: 086-13839962027 or 086-378-3390791.

Abbreviation: PFG, plant functional group.

Table 1. The classification methods of plant functional groups.

Classification method	Author
Multivariate statistical method	Sandra et al., 1998.
Functional attributes	Walker et al., 1999.
Strategy theory, C-S-R model	Grime, 1974, 1988, and 2002.
Cluster analysis	Shao et al, 1999.
Statistical plant geography	Raunkiaer, 1934.
Ecological characteristics	Kelly, 1996.
Subjective experience/personal knowledge	Woodward et al. 1996.
Dynamic classes/ theoretical ecosystem as networks	Pahl, 1995.
Triangular model (competitiveness, weediness, survival)	Grime, 1979.
Niche complementarily effect	Loreau et al., 2000.
Structural functional characteristics	Chapin et al., 1996.
"Two-layer" and "pulse-reserve"	Reynolds et al., 2004;
hypothesis	Ogle et al., 2004

model that is universally applicable to ecosystem studies. The third question is how the PFG concept can be applied in real world scenarios to combat biodiversity loss and manage degrading or degraded ecosystems.

A QUICK GLIMPSE OF PLANT FUNCTIONAL CLASSIFICATIONS

Many researchers have discussed landscape dynamics and ecosystem stability studies that apply the plant functional group concept; great attention has also been paid on identifying useful functional traits (for example, structural, physiological, morphological, functional characters, etc.) (Hooper et al., 2004; Symstad et al., 2000; Raunkiaer, 1934; Smith et al., 1996; Chapin, 1996; Kelly, 1996; von Humboldt, 1849; Schimper, 1903; Clausen et al., 1948; Root, 1967; Box, 1981; Nobel et al., 1996; Bai et al., 2004; Wang et al., 2005; Sandra et al., 1998; Walker et al., 1999; Ratnam et al., 2008; Grime,1974, 1988, 2002; Shao et al., 1996; Woodward et al.,1996; Pahl, 1995; Grime, 1979; Loreau, 2001; Reynolds, 1996; Ogle and Reynolds, 2004). For example, von Humboldt (1849) found that there are 16 species-based structural classes having different physiognomies or plant growth forms.

Schimper (1903) examined the linkages between the geographical distributions of physiological functions, plant growth forms, life history traits and environmental factors. By using classification knowledge, Raunkiaer (1934) reorganized life forms into plant growth forms. Clausen et al. (1948) found the relationship between climatic and genetic controls on the distribution of plant growth forms. Root (1967) explained the linkages between ecological groupings of species and environmental resources. In a similar way, Box et al. (1981) identified 90 plant functional groups in the Earth's vegetations. Nobel et al. (1996) proposed a functional classification based on life history parameters that can be used to predict the dynamics of landscapes and communities.

Studying a grassland ecosystem, Bai et al. (2004) found that community level stability arose from compensatory interactions among major components at both species and PFG levels, and ecosystem stability increased progressively from the species level to the whole community level. Wang et al. (2004) suggest that there are no compensations between species and PFGs in the *Leymus chinesis* community, and the relative mass of one PFG or species in a community would inevitably rise (or fall) if the relative mass of the other PFG or species fell (or rose), irrespective of whether true compensation exists between them.

Literature reviewed in this study shows that the PFG concept groups plant species into distinct clusters according to similarities in their functions and/or responses to environmental conditions by using different classification methods of plant functional traits, many of these classification methods are based on well-established statistical approaches [for example, multivariate statistical method (Sandra et al.,1998), cluster analysis (Shao et al.,1996) and triangular model (Grime,1979)] (Table 1) (Raunkiaer,1934; Smith et al., 1996; Chapin,1996; Kelly, 1996; Walker et al., 1999; Ratnam et al., 2008; Grime,1974, 1988, 2002; Woodward et al.,1996; Pahl, 1995; Loreau, 2001; Reynolds, 2004; Ogle and Reynolds, 2004). Because plant functional groups link plant functional traits, environmental variations and ecosystem processes with great clarity, correctly identified plant functional traits and plant functional groups can help understand and predict how communities and ecosystem properties might be affected by environmental change (for example, global climatic change, dynamics of landscapes), variability, or disturbance (for example, frequency and intensity) (Chapin,1996; Smith et al., 1996; von Humboldt, 1849; Schimper, 1903; Clausen et al., 1948; Root, 1967; Box, 1981; Nobel et al., 1996; Schädel et al., 2010; Knapp et al., 2008).

A GENERAL MODEL OF PLANT FUNCTIONAL CLASSIFICATIONS

The plant functional group concept has been proven to be an excellent research framework for investigating the linkages between ecosystem functions and plant biodiversity, unfortunately, there are so many plant functional group classifications that are difficult to compare with data from different studies and draw general conclusions (Smith et al., 1996; Keeling et al., 2008; Steinmann et al., 2009; Tilman et al., 1997). It is therefore imperative that we should strive to develop a general PFG model universally applicable across the full range of terrestrial ecosystems so that the relationship between plant biodiversity and ecosystem processes can be better understood. Here we propose the use of a hierarchical PFG framework incorporating plant functional traits ranging from the molecular to the biospherical level, and operating on varying spatial/temporal/disturbance scales (Figure 1) for in-depth studies of the relationship between plant biodiversity and ecosystem characteristics (for example, ecosystem processes, ecosystem services and ecosystem stability) (Box, 1981; Nobel et al., 1996; Crawley et al., 2001; Bai et al., 2004; Wang et al., 2005; Smith et al., 1996; Esther et al., 2008; Körner and Jeltsch, 2008; Hector and Bagchi, 2007; Tilman et al., 2006; Landsberg, 1999). Such a framework should facilitate ecosystem studies that apply the plant functional group concept, allowing the elucidation of emergent properties. In studying a grassland ecosystem, Bai et al. (2004) found that ecosystem stability was greater at higher ecological organizational levels, and compensatory effects would occur primarily among dominant components in grassland ecosystems.

We believe that our framework can help identify the plant functional traits most relevant to tolerating environmental fluctuations or recovering from disturbances (Smith et al., 1996; Navarro et al., 2006; Kumaresan et al., 2010; Haddad et al., 2009; Vázquez et al., 2009; Kraft et al., 2008; Shipley et al., 2006). Examples of such plant functional traits include responses to extreme climatic events, directional climatic change, grazing or pathogens, recruitment abilities, sensitivity to pollutants, and other traits that contribute to the resistance and resilience of the biodiversity at a given ecological organization level to environmental stresses (Esther et al., 2008; Körner and Jeltsch, 2008; McIntrye et al., 1995; Box, 1996, Navarro et al., 2006; McIntrye et al., 1995; Box et al., 1996; Landsberg, 1999). Traits that are characteristic of a lower ecological organizational level can affect functions at a higher ecological organization level (for example, seed size and shape are related to seed persistence in the soil bank) (Funes et al., 1999; Thompson et al., 1994), influencing higher level ecosystem processes.

APPLYING THE PLANT FUNCTIONAL GROUP CONCEPT TO COMBAT CHALLENGES SUCH AS BIODIVERSITY CONSERVATION AND ECOSYSTEM MANAGEMENT

Our hierarchical framework of plant functional traits indicates that it is possible to elucidate emergent properties at multiple ecological organization levels and spatial/temporal/disturbance scales. Because of the effectiveness of the plant functional group approach for studying the relationship between biodiversity and ecosystem functioning, policy makers have already extensively applied this concept in formulating plans and regulations aimed at conserving and restoring biodiversity and ecosystem functions (Smith et al., 1996; Sachs et al., 2009; Heller and Zavaleta, 2009; Chazal et al., 2009; Gilbert 2010; James and Vorhies, 2010; Whiteman et al., 2010; Marris, 2010; Dirzo et al., 2005). Currently, efforts are however hampered by the confusion and misunderstanding that inevitably results from the large array of dissimilar plant functional group classifications. Our hierarchical framework may help clear and ameliorate this situation. It will nonetheless be a substantial challenge to apply our generalized conceptual framework to specific real world policy problems.

CONCLUSION

Progress in the following three key areas will substantially further efforts to gain a rigorous understanding of how functional attributes of plant species, and their interactions, influence the response of ecosystem properties to changing biodiversity:

1. Better understanding of how patterns of plant community assembly influence relationships between plant species and plant functional diversity in natural/artificial communities, and how this might differ in different environments.
2. Better understanding of how plant functional response and effect of plant traits are correlated independently, particularly with respect to the predominant forces of global change.
3. The research of plant functional groups within plant biodiversity studies was significant in understanding the effects of plant biodiversity on the ecosystem, and these studies might be a model (Figure 1) that emerged to explain plant functional classifications as a hierarchical level for understanding the contribution of plant biodiversity to the ecosystem.

Therefore, knowledge of effects of plant species and plant functional diversity on ecosystem services, particularly in the context of abiotic/biotic drivers, individual plant species effects and global change, will be critical where management priorities seek to plant functional groups composition directly. Intensive management often relies

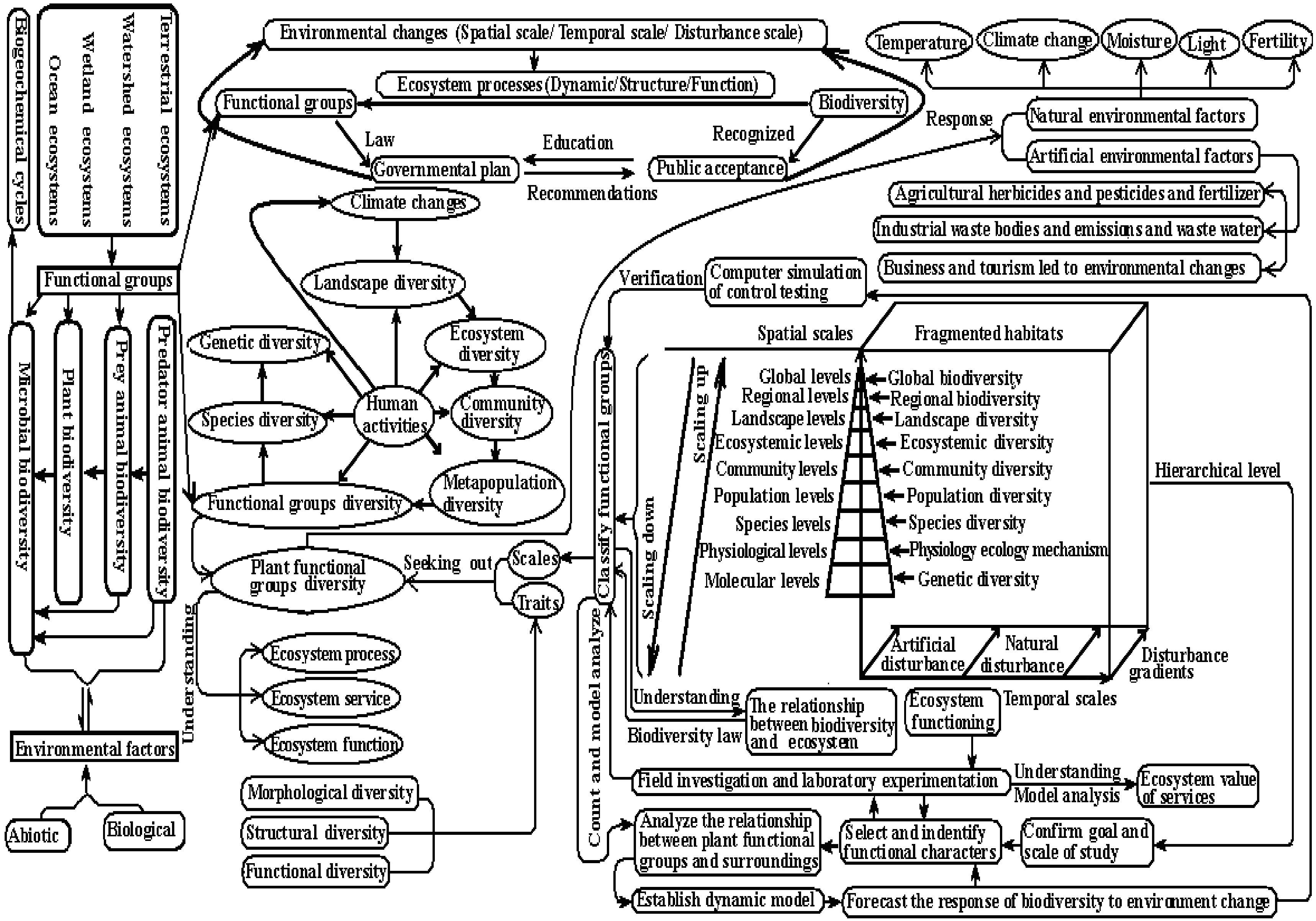

Figure 1. Our hierarchical PFG framework incorporating plant functional traits ranging from the molecular to the biospherical level, and operating on varying spatial/temporal/disturbance scales.

on the functional characteristics of plant functional groups and substitution of human inputs for biotic processes. However, the insurance hypothesis and the precautionary principle emphasize that land managers and policy makers also must be prepared for unpredictable events and a changing world. Preserving plant functional groups may better allow long-term, internal dynamic and evolution of managed systems as they face new environmental conditions (unpredictability) (Hanski, 2005; Clark and McLachlan, 2004; Smith et al., 1996).

FUTURE WORK

The relationship between plant biodiversity and ecosystem functioning has been keenly debated. A critical question for the future is how to balance patterns of human use and plant functional groups at the landscape scale to maintain: (a) regional plant biodiversity and local plant biodiversity within sites, (b) ecosystem services that depend on small-scale functions (for example, crop productivity in a field), and (c) ecosystem services that depend on interactions among different landscape components (Hanski, 2005; Smith et al., 1996) (for example, nutrient transformations in riparian zones). We face the future challenges of understanding the applications of effects of plant functional groups to both ecosystem management and biodiversity loss. Answering this question will require a rigorous synthesis across all scales of ecological organization, from micro levels to macro levels in conducting an in-depth study.

ACKNOWLEDGEMENT

This work was supported by the National Natural Science Foundation of China (No.40671175).

REFERENCES

Bai YF, Han XG, Wu JG, Chuo ZZ, Li LH (2004). Ecosystem stability and compensatory effects in the Inner Mongolia grassland. Nature, 431: 181-184.

Box EO (1981). Macroclimate and plant forms: an introduction to predictive model in phytogeography. The Hague: Dr W. Junk Publishers.

Box EO (1996). Plant functional types and climate at the global scale. J. Veg. Sci. 7: 309-320.

Chapin III FS, Bret-Harte MS, Hobbie SE, Zhong HL (1996). Plant functional types as predictors of transient responses of arctin vegetation to global change. J. Veg. Sci. 7: 347-358.

Chazal JDE, Rounsevell MDA (2009). Land-use and climate change within assessments of biodiversity change: a review. Global Environ. Change, 19: 306-315.

Clark JS, McLachlan JS (2004). Neutral theory (communication arising): The stability of forest biodiversity. Nature, 427: 696-697.

Clausen J, Keck DD, Heisey WM (1948). Experimental studies on the nature of species III. Environmental responses of climatic races of Achillea. Washington, DC, USA: Carnegie Institute. Carnegie Institute of Washington Publication. p. 581.

Crawley MJ, Harral JE (2001). Scale Dependence in Plant Biodiversity. Science, 291: 864-868.

Crowder DW, Northfield TD, Strand MR, Snyder WE (2010). Organic agriculture promotes evenness and natural pest control. Nature, 466: 109-112.

Dirzo R, Loreau M (2005). Biodiversity Science Evolves. Science, 310: 943.

Esther A, Groeneveld J, Enright NJ, Miller BP, Lamont BB, Perry GLW, Schurr FM, Jeltsch F (2008). Assessing the importance of seed immigration on coexistence of plant functional types in a species-rich ecosystem. Ecol. Modelling. 213: 402-416.

Funes G, Basconcelo S, Diaz S, Cabido M (1999). Seed size and shape predict seed persistence in the soil bank in grasslands of central Argentina. Seed Sci. Res. 9: 341-345.

Gilbert N (2010). Biodiveristy law counld stymie reserch. Nature, 463: 598.

Grime JP (1974). Vegetation classification by reference to strategies. Nature, 250: 26-31.

Grime JP (1979). Plant strategies and vegetation processes. Chichester (UK): John Wiley.

Grime JP (1988). The C-S-R model of primary plant strategies – origins, implications and tests. In Gottlieb LD and Jain SK (eds), Plant Evolutionary Biology. London: Chapman and Hall: pp. 371-393.

Grime JP (2002). Plant strategies, vegetation processes, and ecosystem properties, 2nd Edition. Wiley- Knowledge for generations.

Haddad NM, Crutsinger GM, Gross K, Haarstad J, Knops JM, Tilman D (2009). Plant species loss decreases arthropod diversity and shifts trophic structure. Ecol. lett. 12: 1029-1039.

Hanski I (2005). Landscape fragmentation, biodiversity loss and the societal response. EMBO reports. 6: 388-392.

Hector A, Bagchi R (2007). Biodiversity and ecosystem multifunctionlity. Nature, 448: 188-190.

Heller NE, Zavaleta ES (2009). Biodiverisity management in the face of climate change: a review of 22 years of recommendations. Biol. Conserv. 142: 14-32.

Hooper DU, Dukes JS (2004). Over yielding among plant functional groups in a long-term experiment. Ecol. lett. 7: 95-105.

James AN, Vorhies F (2010). Green development credits to forest global biodiversity. Nature, 465: 869.

Keeling HC, Baker TR, Martinez RV, Monteagudo A, Phillips OL (2008). Contrasting patterns of diameter and biomass increment across tree functional groups in Amazonian forests. Oecologia. 158: 521-534.

Kelly CK (1996). Identifying plant functional types using floristic data bases: ecological correlates of plant range size. J. Veg. Sci. 7: 417-424.

Knapp S, Kühn I, Schweiger O, Klotz S (2008). Challenging urban species diversity: contrasting phylogenetic patterns across plant functional groups in Germany. Ecol. Lett. 11: 1054-1064.

Körner K, Jeltsch F (2008). Detecting general plant functional type responses in fragmented landscapes using spatially-explicit simulations. Ecol. Modeling, 210: 287-300.

Kraft NJ, Valencia R, Ackerly DD (2008). Functional traits and niche-based tree community assembly in an Amazonian forest. Science, 322: 580-582.

Kumaresan A, Bujarbaruah KM, Pathak KA, Brajendra, Ramesh T (2010). Soil-plant-animal continuum in relation to macro and micro mineral status of dairy cattle in subtropical hill agro ecosystem. Anim. Health Prod. 42: 569-577.

Landsberg J (1999). Response and effect-different reasons for classifying plant functional types under grazing. In D Eldridge and D Freudenberger, eds People and rangelands: Building the future, Proceedings of the VI International Rangeland Congress. VI International Rangeland Congress, Townsville, Australlia. pp. 911-915.

Loreau M, Naeem S, Inchausti P, Bengtsson J, Grime JP, Hector A, Hooper DU, Huston MA, Raffaelli D, Schmid B, Tilman D, Wardle DA (2001). Biodiversity and ecosystem functioning: Current knowledge and future challenges. Science, 294: 804-808.

Marris E (2010). UN body will assess ecosystems and biodiversity. Nature, 465: 859.

McCann KS (2000). The diversity-stability debate. Nature, 405: 228-233.

McIntrye S, Lavorel S, Tremont RM (1995). Plant life-history attributes: their relationship to disturbance response in herbaceous vegetation. J. Ecol. 83: 31-44.
Navarro T, Alados CL, Cabezudo B (2006). Changes in plant functional types in response to goat and sheep grazing in two semi-arid shrublands of SE Spain. J. Arid Environ. 64: 298-322.
Nobel IR, Gitay H (1996). A functional classifications for predicting the dynamics of landscapes. J. Veg. Sci. 7: 329-336.
Ogle K, Reynolds JF (2004). Plant responses to precipitation in desert ecosystems: integrating functional types, pulses, thresholds, and delays. Ecology, 141: 282-294.
Pahl WC (1995). The dynamic nature of ecological: chaos and order entwined. New York: John Wiley.
Ratnam J, Sankaran M, Hanan NP, Grant RC, Zambatis N (2008). Nutrient resorption patterns of plant functional groups in a tropical savanna: variation and functional significance. Oecologia, 157: 141-151.
Raunkiaer C (1934). The life forms of plants and statistical plant geography. Introduction by Tansley AG. Oxford University Press, Oxford. p. 632.
Reynolds JF, Kemp PR, Ogle K, Fernández RJ (2004). Modifying the 'pulse-reserve' paradigm for deserts of North America: precipitation pulses, soil water, and plant responses. Oecologia, 141: 194-210.
Root RB (1967). The niche exploration pattern of the blue grey gnatcatcher. Ecological monographs. 37: 317-350.
Sachs JD, Baillie JE, Sutherland WJ, Armsworth PR, Ash N, Beddington J, Blackburn TM, Collen B, Gardiner B, Gaston KJ, Godfray HC, Green RE, Harvey PH, House B, Knapp S, Kümpel NF, Macdonald DW, Mace GM, Mallet J, Matthews A, May RM, Petchey O, Purvis A, Roe D, Safi K, Turner K, Walpole M, Watson R, Jones KE (2009). Ecology: Biodiversity conservation and the Millennum Development Goals. Science, 325: 1502-1503.
Sandra L, Blaise T, Jean DL, Clément B (1998). Identifying functional groups for response to disturbance in an abandoned pasture. Acta Oecologica, 19: 227-240.
Schädel C, Blöchl A, Richter A, Hoch G (2010). Quantification and monosaccharide composition of hemicelluloses from different plant functional types. Plant Physiol. Biochem. 48: 1-8.
Schimper AFW (1903). Plant geography upon a physiological basis. Oxford, UK: Clarendon Press, English translation by WR Fisher from German edn. p. 1898.
Shao GF, Shugart HH, Hayden BP (1996). Functional classification of coastal barrier island vegetation. J. Veg. Sci. 7: 391-396.
Shipley B, Vile D, Garnier E (2006). From plant trait to plant communities: a statistic mechanistic approach to biodiversity. Science, 314: 812-814.
Smith TM, Woodward FI, Shugart HH (1996). Plant function Types. Cambridge University Press, New York.
Steinmann K, Linder HP, Zimmermann NE (2009). Modelling plant species richness using functional groups. Ecol. Modelling, 220: 962-967.
Symstad AJ, Siemann E, Haarstad J (2000). An experimental test of the effect of plant functional group diversity on arthropod diversity. Oikos, 89: 243-253.
Thompson K, Green A, Jewels AM (1994). Seeds in soil and worm casts from a neutral grassland. Funct. Ecol. 8: 29-35.
Tilman D, Knops J, Wedin D, Reich P, Ritchie M, Siemann E (1997). The influence of functional diversity and composition on ecosystem processes. Science, 277: 1300-1302.
Tilman D, Reich PB, Knops JM (2006). Biodiversity and ecosystem stasbility in a decade-long grassland experiment. Nature, 441: 629-632.
Vázquez DP, Chacoff NP, Cagnolo L (2009). Evaluating multiple determinants of the structure of plant-animal mutualistic networks. Ecology, 90: 2039-2046.
Von Humboldt A (1849). Aspects of nature in different lands and different climates, with scientific elucidations. Translation Mrs. Sabine, 3rd edn. London, UK: Longman, Brown, Green and Longman. pp. 227-246.
Walker B, Kinzig A, Langridge J (1999). Original articles: plant attribute diversity, resilience, and ecosystem function: the nature and significance of dominant and minor species. Ecosystem, 2: 95-113.
Wang SP, Niu HS, Cui XY, Jiang S, Li YH, Xiao XM, Wang JZ, Wang GJ, Huang D, Qi QH, Yang ZG (2005). Plant communities: ecosystem stability in Inner Mongolia. Nature, 435: 5-6.
Whiteman G, Dorsey M, Wittneben B (2010). Businesses and biodiversity: they would say that. Nature, 466: 435.
Woodward FI, Cramer W (1996). Plant functional types and climatic changes: introduction. J. Veg. Sci. 7: 306-308.