生物多样性的生态系统功能:质与量的综合评价

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BIODIVERSITY'S ECOSYSTEM FUNCTIONING: A UNITY OF BOTH QUANTITY AND QUALITY

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The value of biodiversity is well-known, but how diversity performs its ecosystem function and provides services is less clear (Ehrlich, 1994; Grime, 1997; Wall, 2004; Xie *et al.*, 2006). In the last two decades, tremendous efforts have been devoted to investigating the biodiversity effects on ecosystem functioning (Hooper *et al.*, 2005). In most cases, particularly in grassland seeding experiments, productivity (i.e., rate of biomass production) has been used as the sole measure of ecosystem functioning, while what is being produced (i.e., the quality or product diversity) is frequently ignored. However, ecosystem functioning, like many other things in our life (e.g., the impacts of scientific papers), is a multifaceted concept and is far more than simply productivity and should be assessed by both quantity and quality¹⁾. Here we call for a reevaluation of the current measures used to evaluate biodiversity's ecosystem function. Although the quantitative (e.g., productivity) and qualitative (product quality) aspects may be assessed separately but their combination should be used for overall evaluation of ecosystem functioning. This is because both quantity and quality measures are important to both basic ecological research and land management, as we outline below.

First, in addition to being related to ecosystem productivity, many ecological processes also depend on the quality of the products; this quality includes the diversity of the products themselves. Ecosystems function and provide services to organisms at many trophic levels, including that of humans, and product quality is critical for many other related ecosystem functions and processes (Olff *et al.*, 2002). For example, high product quality

usually maintains and promotes the diversity of plants and other organisms through selective herbivory and hosting. Plant product diversity is often positively related to soil heterogeneity, belowground community stability (e.g., resistance to disturbances), and carbon sequestration, decomposition or litter mass loss (Costanza *et al.*, 1997; Hector *et al.*, 2000; Hättenschwiler *et al.*, 2005), soil respiration and nitrification, nutrient cycling, and N-fixing rates, among others. Species are interrelated, and species interactions are not just reflected by living bodies but also through by-products remaining after their death and subsequent decomposition. The litter of one plant species is still in many ways affecting other species, not just by its dry biomass, but also by its chemical composition. Thus, feedbacks from product quality in turn affect community diversity and productivity (Fig. 1).

Second, trade-offs (negative correlations or causal relationships) between quantity and quality are common in many physical, biological, and social settings and productivity and product quality clearly respond differently to environmental factors such as water and nutrients (Olff *et al.*, 2002). Therefore, interesting questions in the field of ecosystem functioning could include "is there a trade-off between productivity and product quality?", and if so, "is such a trade-off necessarily universal?". And if not, "under what conditions does it emerge?". Other questions may be "how might diversity (and resources) mediate its magnitude?", "can it be avoided by any means?" and "can we simultaneously choose both quantity and quality of the products?" The answers to these questions are critical for ecosystem management and restoration. In most

Received: 2006-05-11 Accepted: 2006-07-25

Funding: This study was funded by the U.S. Geological Survey and the KC Wong Foundation-Chinese Academy of Sciences

We thank B. Hanson, H. Kantrud, D. Mushet, and an anonymous reviewer for helpful comments

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1) Guo Q (2006). The diversity-biomass-productivity relationships in grassland management and restoration. *Basic and Applied Ecology*. (in press)

cases , optimal ecosystem functioning might be a combination of high quantity and high quality , but if there has to be a trade-off , it might be moderate levels of both measures (Olff *et al.* , 2002).

Fig.1 A hypothetical relationship between biodiversity and product quantity or product quality
Higher level of diversity might promote and maintain both higher productivity and product quality although there is a potential trade-off between product quantity and quality at a given level of diversity

Third , in reality , some very high productivity may be least desired by most ecological and societal measures . For example , some highly degraded (e . g . , through eutrophication) or heavily invaded (by exotics) ecosystems , particularly those impacted by both eutrophication and consequent invasion (e . g . , Dian-Chi Lake in Yunnan , China ; Q . Guo , Field Observations) , are highly productive in terms of both the dry materials and seed banks they produce . In such cases , quantity is not synonymous with quality . On the other hand , in most agricultural systems we want one or a few species , rather than overall high diversity , to have the highest productivity possible (Vandermeer , 1989) .

Finally , in terms of ecosystem service in human society , the diversity and quality of the products could be at least equally important as productivity , if not more so . Products must also be diversified (e . g . , bioenergy , medicine , culture , agriculture , ecotourism) to provide sufficient ecosystem service . While the diversity-productivity relationship is still in debate , high biodiversity basically leads to high product diversity that is a component of high quality . When ecosystem functioning is defined in a broader sense as described above (Jax , 2005) , it would be reasonable to assume that it is positively related to ecosystem service (Fig . 2) .

In short , solely addressing the importance of diversity in terms of productivity without considering product quality may not be appropriate as productivity alone cannot fully reflect ecosystem functioning . When this point is made clear , the arguments on whether diversity or domi-

nance contributes most to productivity may become less important (although still interesting) . In other words , regardless of the relationship between diversity and productivity , diversity ' s effect on product quality already warrants its importance . If this message is well-taken , future efforts may be focused on identifying the role of diversity in terms of both productivity and product quality . This message becomes even more important when one considers that , beyond simple ecosystem productivity , any species (particularly keystone species) may function in several ways that might or might not have been previously identified (Eviner & Chapin III , 2003 ; Wang *et al.* , 2006) . Thus , evaluating overall ecosystem functions and services may need to take both product quantity and quality into account .

Fig.2 A possible relationship between ecosystem function and service
An optimally functioning ecosystem should also provide the best services

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