Available online at www.sciencedirect.com

SciVerse ScienceDirect

Current Opinion in Environmental Sustainability

Linking ecosystem processes and ecosystem services

Bojie Fu[1], Shuai Wang[1], Changhong Su[1] and Martin Forsius[2]

The metaphor of ecosystem service may blind us to the complexity of the natural systems which underpin and produce services. We reviewed key references and propose a framework to illustrate the social system relying on the ecological system and the relationships between ecosystem composition, ecosystem structure, ecosystem processes and ecosystem services, in order to reduce this complexity. We argue that plans to manage ecosystem services will not be successful without a deep understanding of their link with the ecosystem processes that support them. By linking ecosystem processes and ecosystem services, we explore the possible determinants of the biodiversity components on the quantity, quality and reliability of ecosystem services at all levels, and its usefulness in making targeted decisions. Disentangling the complex interrelationships among multiple ecosystem services from the driven processes is helpful in lowering the risk of unwanted trade-offs, and taking advantage of synergies. In landscape management, it is advisable to design suitable ecosystem structures for maximizing ecosystem services based on knowledge of the natural ecosystem processes.

Addresses
[1] State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, P.O. Box 2871, Beijing 100085, PR China
[2] Natural Environment Centre, Finnish Environment Institute, P. O. Box 140, FI-00251 Helsinki, Finland

Corresponding author: Fu, Bojie (bfu@rcees.ac.cn)

Current Opinion in Environmental Sustainability 2013, **5**:4–10

This review comes from a themed issue on **Terrestrial systems**

Edited by **Bojie Fu**, **Martin Forsius** and **Jian Liu**

For a complete overview see the Issue and the Editorial

Received 19 July 2012; Accepted 11 December 2012

Available online 1st January 2013

http://dx.doi.org/10.1016/j.cosust.2012.12.002

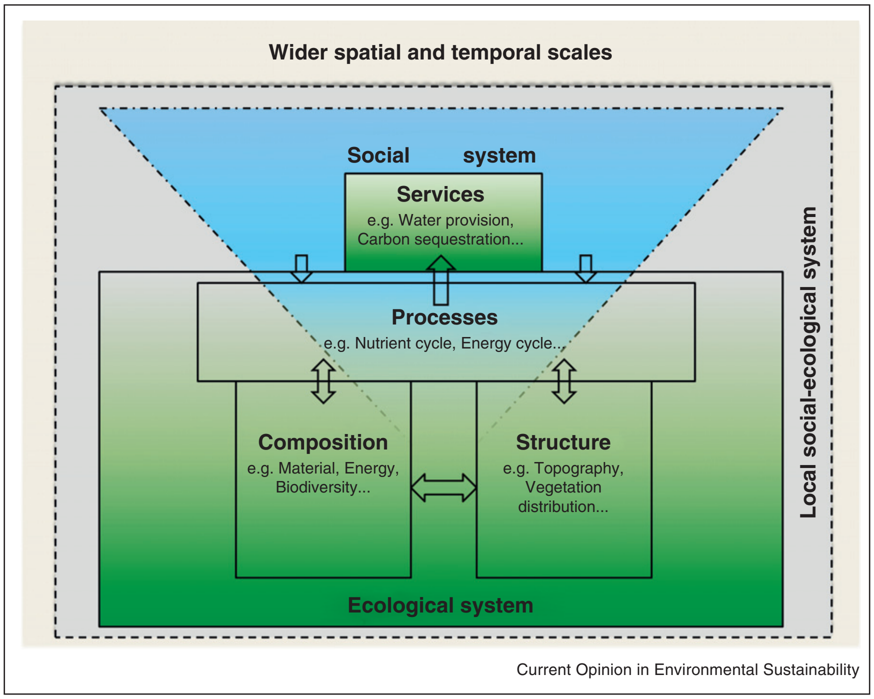
Introduction

The ecosystem service concept was proposed to attract public attention initially and to balance competing interests on natural resources [1,2]. During the past few decades, progress has been made in understanding the ecosystem services' generating mechanism [3,4••], calculating its value [5,6], mapping its supply and demand [7,8], as well as analyzing threats faced by ecosystem services [9,10], and its future consequences [11]. Current research has put much emphasis on ecosystem services assessments at regional and national scales, trade-off analyses and its role in decision making [12••,13,14]. Although the concept of ecosystem service conveys the social dependence on ecological life support systems and facilitated interdisciplinary research, it may blind us to the complexity of the natural systems underpinning the ecosystem services. The generation of ecosystem services relies on the ecosystem composition, structure and processes [15,16]. Accurately predicting the dynamic provision of ecosystem services requires a considerable understanding of ecosystem composition, structure and the processes that sustain them [17•], especially the links between ecosystem processes and ecosystem services. We would like to contribute to the ongoing debate with some proposals and analyses by examining these interrelations, based on reviewing the research progresses for a better understanding of the Coupled Human and Nature System (CHANS) and better environment management.

Ecosystem composition, structure, processes and services

Ecosystem services are benefits that people obtain from ecosystems; in the absence of people there are no services [18,19]. The framework (Figure 1) illustrates how the social system relies on the ecological system and the relationships between ecosystem composition, structure, processes and services. Ecosystem composition refers to 'the comprising types and abundance of biotic and abiotic elements in a defined ecosystem' [15]. These interacting biotic and abiotic components constitute natural biodiversity [20]. In other words, ecosystem composition is the material base and driver of ecosystem processes and services. Ecosystem structure refers to the distribution and arrangement of ecosystem components [15], which is subject to both physical and anthropogenic influences. Ecosystem processes are the interactions among the biotic and abiotic elements [21]. Some key ecological processes, such as energy transfer, nutrient cycles, and oxygen and water fluxes [15] are always regarded as synonymous with ecosystem function. Ecosystem services are the conditions and processes that sustain and fulfill human life [22]: the contents of which vary depending on the social-ecological context. Ecosystem processes are the means to deliver ecosystem services; for example, pollination, soil formation and water regulation provide the services of food and potable water. Given the complexity of ecosystems, the processes and services cannot be completely separated; some processes are themselves also services, such as flood regulation by vegetation, while

Figure 1



A framework linking ecosystem processes with ecosystem services. The blue triangle represents the social system and the green rectangle represents the ecological system. The interactions among compositions, structures and processes of the ecological system underpin the social system with various ecosystem services.

others are not, such as evapotranspiration by forest. On the basis of the classification system of Millennium Ecosystem Assessment (MA), within the process-services chains, supporting and regulating services are mainly intermediate, while provisioning services are definitely at the end point [23].

The biophysical components and structure underpin the ecosystem processes. When the latter are consumed by humans they are translated into ecosystem services [24]. Ecosystem processes interact with ecosystem components and structure. Humans manage ecosystem processes through arranging the ecosystem components and structure to deliver ecosystem services that better meet their needs, such as altering land cover/land use to safeguard a human's well being. In the Loess Plateau of China, a vast area of natural vegetation has been reclaimed as farmland in the last century for grain production. The past three decades saw the inception of a series of large-scale reforestation projects, which significantly increased the vegetation coverage percentage from 6.5% in the 1970s to 51.13% in 2010 and improved the ecosystem services of soil conservation, water regulation and carbon sequestration [25]. As the ecosystem processes, ecosystem services and their driving mechanisms are the key components of the CHANS [15], understanding the links between ecosystem processes and ecosystem services is essential for making a prudent ecological policy.

Basic ecosystem processes and services

Ecosystem composition, structure and processes can be summarized as ecosystem integrity, which depict the ecosystem resistance and resilience, represent its capacity or potential to provide ecosystem services. Within the ecological factors, water, soil and carbon play central roles in regulating ecosystem processes with strong spatial/temporal scales dependence, and providing key services for human beings.

Water-based services

Water is an important ecosystem factor, as it can provide the medium for multiple ecosystem processes. At a microscopic scale, researchers have done a multitude of explorations on water movement, especially within the Soil-Plant-Atmosphere Continuum (SPAC). The challenges lie in the spatial heterogeneity of the transporting medium (e.g. root and branch structure) and the temporal variability of the external drivers. Stable-water-isotopes tracing is widely used in capturing water movement. Braud *et al.* [26] integrated the isotope method with the Soil-Vegetation-Atmosphere (SVAT) model and successfully tested water movement of bare soil. At a large scale, topography, microclimate, vegetation and the hydrological process gradually demonstrate their roles in soil-water movement.

Water movement is critical in delivering the services of potable water, irrigation and industrial production, as well as indirectly influencing food production, microclimate regulation, the esthetic view and more.

Soil related services

The effectiveness of runoff control/soil erosion at the individual-plant scale depends on plant morphology. As the scale increases, land use gradually shows its role in curbing soil erosion. Research in the Guadiana Watershed, Puerto Rico indicated that reforestation of 5% of the highest-eroded watershed would decrease erosion by 20%, and the erosion will be decreased by 37% if the entire watershed were reforested [27]. Jordan *et al.*'s [28] investigation in the Kali Basin, Hungary showed that expansion of uncultivated land and its spatial fragmentation greatly decreased the average sediment production. Fu *et al.* [29], using radionuclide ^{137}Cs, quantitatively assessed the effects of the land-use combination on soil erosion. The results showed that the configuration of 'grass (6 years old) + mature forest (25 years old) + grass (25 years old)' from the foot to the top of the hill could lower soil erosion by 42%.

Rational soil movement helps to consolidate soil fertility and improve water availability; moreover, it helps to eliminate silting in rivers and reservoirs off-site.

Carbon sequestration services

CO_2 levels in the atmosphere are rising faster recently and pose a daunting challenge for those attempting to staunch global-climate warming. Carbon cycle refers to the biogeochemical cycle by which carbon is exchanged among different 'reservoirs' (the atmosphere, the terrestrial biosphere, the oceans, the sediments and the earth's interior). In the terrestrial biosphere, forests store 86% of the above-ground carbon and 73% of the planet's soil carbon. Carbon is sequestrated from the atmosphere by photosynthesis. Portions of the carbon return to the air via respiration or wood burning. Land use is the major factor affecting carbon cycling, which accounts for 17.4% of total anthropogenic greenhouse-gas emissions.

Carbon cycling plays an important role in buffering the global temperature within a range tolerable for human beings. In addition, it indirectly influences other services such as biodiversity conservation.

Ecosystem processes are not independent; rather they are intermingled. Changes in the water cycle (e.g. precipitation, runoff, stream flow, as well as soil moisture and atmospheric vapor) have strong impacts on carbon stocks/fluxes and disturbance events (e.g. fire frequency and intensity). These interactions within ecosystem processes partially explain the inherent links among ecosystem services; for example, maintaining carbon stocks can generate co-benefits other than the climate change mitigation, such as biodiversity conservation and agricultural production.

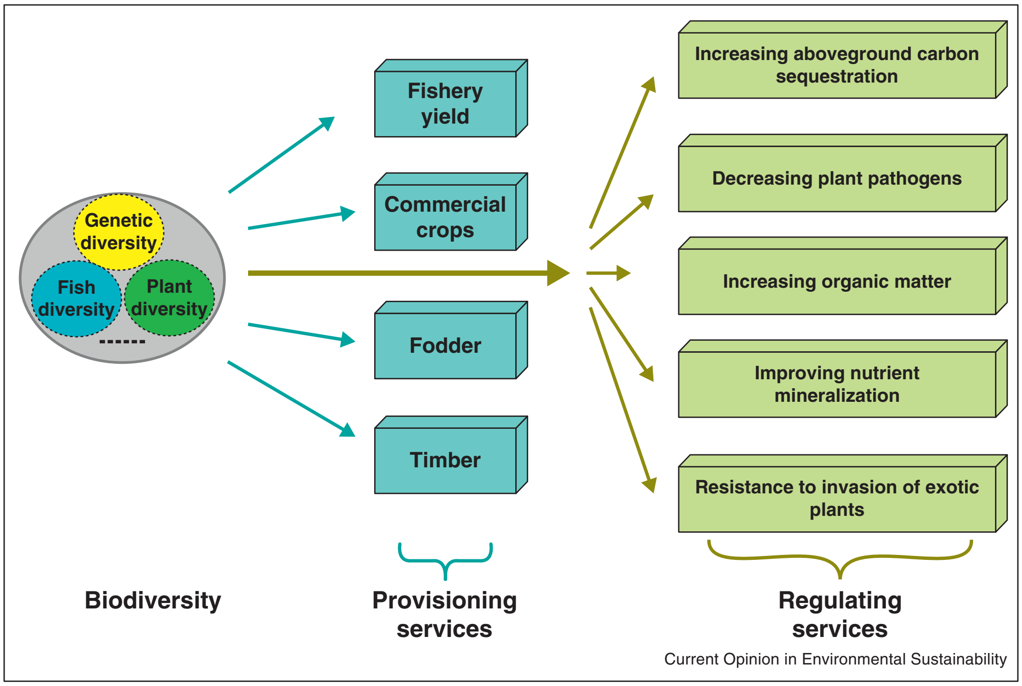
Understanding the relationship between biodiversity and ecosystem services

Ecological interactions are both causes and consequences of biodiversity [30••]. The relationship between biodiversity and ecosystem services is still under debate [31–34]. There are many qualitative reviews about the effects of biodiversity on ecosystem properties and services [4••]. Balvanera *et al.* [35] conducted the first extensive quantitative meta-analysis on the relationship between biodiversity and ecosystem services and found that biodiversity has positive effects on regulating and supporting services, which is positively echoed by Cardinale *et al.* [36], who, through searching the ISI Web of knowledge, drew the conclusion that biodiversity *per se* either directly influences or is strongly correlated with provisioning and regulating services (Figure 2). Usually there are two approaches to fitting biodiversity into ecosystem services. One is the 'ecosystem service perspective,' which equates biodiversity with ecosystem services. Although this approach reflects the mutual enhancement between biodiversity and ecosystem services, it fails to explore the role of ecosystem processes pertaining to biodiversity and cannot reflect its values. Alternatively, the 'conservation perspective' regards biodiversity itself as an ecosystem service. This leads to ignoring the function of biodiversity in underpinning ecosystem services [30••]. In order to resolve this confusion over the role that biodiversity plays in ecosystem services, Mace *et al.* [30••] recognized three different relationships: biodiversity acts as regulator for key ecosystem processes, biodiversity is a final ecosystem service itself and biodiversity provides goods valued by humans [30••]. By distinguishing and linking ecosystem processes with ecosystem services, this analysis elucidated the multi-layered relationship between biodiversity and ecosystem services, and can help to enact targeted policy to ensure the continued maintenance of ecosystem processes (e.g. carbon sequestration), or to deliver a final ecosystem services (e.g. water supply), or to provide a specific conservation goods (e.g. saving giant pandas).

Designing ecosystem structures for optimizing services

Changes of community structure can both affect the provision of ecosystem services directly and indirectly [37]. For example, a decline in the abundance of keystone species directly leads to the loss of food production, infringing upon the esthetic values and option values, and indirectly resulting in a potential decrease in

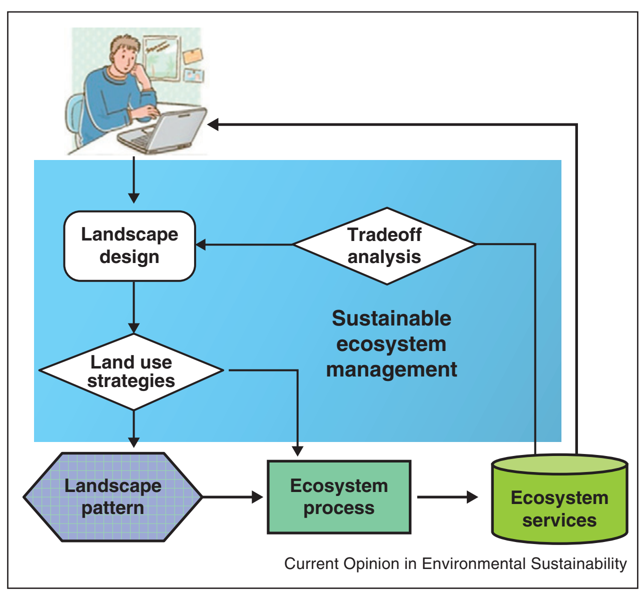
Figure 2



Biodiversity either directly influences or is strongly correlated with certain provisioning and regulating services. The dark green boxes show biodiversity's direct impacts on provisioning services, whereas the yellowish boxes show its indirect impact on regulating services.

ecosystem resistance/resilience to change. At the landscape and regional scales, the ecosystem structure influences the ecosystem processes and subsequently the services by the spatial pattern configuration [36]. For example, forest patches near coffee plantations are helpful to increase coffee production [38]; the possible reason lies in the forest's alteration of key processes of the coffee plantation, such as increasing pollinator population and thus promoting a fruit set of coffee [39]. At the hill slopes, Fu *et al.* [29,40] indicated that patterns with contrasting hydrological response units, such as the fallow land–shrubland–intercropping land–woodland structure would increase the discontinuous runoff on a slope and thus control soil erosion better. Relationships between landscape pattern and processes constitute the key principle of landscape ecology. Nassauer and Opdam [41•] went one step further by embedding the concept of 'landscape design' into the pattern–process paradigm (Figure 3). Landscape design needs to focus on both the individual ecosystem components (e.g. a species) and their combined effects. Moreover, the concept of landscape designs is applicable to various scales, for example, the windbreak-forests arrangements at the agricultural ecosystems scale and the planning of China's principal function zone at the national scale. Landscape design is conducted collaboratively by scientists and practitioners based on

Figure 3



A framework linking landscape pattern, ecosystem process, and ecosystem services, as well as landscape design. At a large scale, humans exert their role on ecosystem management through land-use policy. Tradeoff analysis among ecosystem services can be of great significance in sustainable ecosystem management.

the ecosystem processes. Nassauer and Opdam [41•] designed a model in which landscape-pattern design was divided into process-knowledge, generalizable-pattern-rule and place-specific design.

Managing ecosystem services by ecosystem processes

Degradation of ecosystem services is the root cause for many ecological problems embodied by structural damage and functional disorders. Ecosystem processes are the means for ecosystem services; the essence of ecosystem management lies in managing the ecosystem process to maximize the delivery of services such as food, fiber or spiritual experiences for humans, and minimize the harm caused to the ecosystems [15]. Various process-based mechanism models were developed to predict the performance of natural systems. Aitkenhead *et al.* [42] developed the model of Modelling Soil Ecosystem Services (MOSES) to simulate soil processes and ecosystem services. Laurel and Harvey [43] modeled the hydrological feedbacks to predict landscape pattern, process and restoration potential in a shallow aquatic ecosystem.

When people modify ecosystems to increase specific ecosystem services, it often results in substantial declines of others; the deterioration of supporting services also affects the sustainability of the whole social–natural system [18]. Thus, managing multiple ecosystem services concomitantly poses a tough challenge for ecosystem management. At present, most studies use land use/land cover as a proxy to ecosystem services providers [44]; this taken-for-granted linear relationship between ecosystem structure and services which cannot reflect the competition or sharing relationships between different services and is likely to cause double counting [45]. Trade-offs are usually caused by scale mismatch between ecosystem processes and social governance [46], and avoiding such requires an in-depth knowledge of ecosystem processes and services (Figure 3). As trade-offs among ecosystem services are strongly scale-dependent [46], quantifying trade-offs and synergies at one point in time or merely examining the spatial concordance among multiple services cannot reflect the panorama of the ecosystem services. It is necessary to understand the underlying mechanisms of ecosystem services linked through processes [15]. Bennett *et al.* [18] proposed a typology of relationships between ecosystem services by the role of drivers and the interactions between services. They also developed three propositions on services-based ecosystem management: identifying the relationship through integrated social-ecological approaches, tapping the underlying mechanism to maximize the management effects and strengthening the research on ecosystem resilience [18]. Lautenbach *et al.* [47] compared the ecosystem services' trade-offs using map comparison, scenario analysis and optimized landscapes, an approach that is questioned by others for merely applying to a small set of ecosystem services and underestimating the consequences of social choice.

Conclusion

It is beyond doubt that ecosystem services play significant roles in shaping humans' well-being. In-depth understanding of the relations between ecosystem processes and ecosystem services plays a significant role in ecosystem management [17•,48]. Only then could we disentangle the roles of biodiversity components in determining the quantity, quality and reliability of ecosystem services, and make more targeted decisions [30••]. In addition, examining the complex relationships between multiple ecosystem services from the underpinning driving processes is necessary to avoid the risk of unwanted trade-offs, and helps to take advantage of synergies [18]. In landscape design, the physical and biological processes underpinning ecosystem services should be paid due attention [41•], as processes are the means for services pursuit. In conclusion, ecosystem services are generated by several interacting processes related to the composition and structure of the ecological systems, also influenced by human inputs. This reminds that the ecological processes cannot be ignored in ecosystem service planning and managing procedures. We hope this examination helps ecosystem service becoming a really good instrument for environmental management.

Acknowledgements

This work was funded by the National Basic Research Program of China (No. 2009CB421104), National Natural Science Foundation of China (No. 41230745) and Joint Project of CLIMES of Academy of Finland and Chinese Academy of Sciences (No. GJHZ 1215).

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Gómez-Baggethun E, de Groot R, Lomas PL, Montes C: **The history of ecosystem services in economic theory and practice: from early notions to markets and payment schemes**. *Ecol Econ* 2010, **69**:1209-1218.

2. Wainger LA, King DM, Mack RN, Price EW, Maslin T: **Can the concept of ecosystem services be practically applied to improve natural resource management decisions?** *Ecol Econ* 2010, **69**:978-987.

3. Palmer MA, Bernhardt E, Chornesky E, Collins SL, Dobson A, Duke C, Gold B, Jacobson R, Kingsland S, Kranz R *et al.*: **Ecology for a crowded planet**. *Science* 2004, **304**:1251-1252.

4. •• Kremen C: **Managing ecosystem services: what do we need to know about their ecology?** *Ecol Lett* 2005, **8**:468-479.
The authors argued that ecological understanding of ecosystem services is quite limited. They proposed research agenda including four areas to assist in developing environmental policy and natural resource management plans.

5. Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Naeem S, Limburg K, Paruelo J, O'Neill RV *et al.*: **The value of the worlds ecosystem services and natural capital**. *Nature* 1997, **387**:253-260.

6. Gallai N, Salles JM, Settele J, Vaission BE: **Economic valuation of the vulnerability of world agriculture confronted with pollinator decline**. *Ecol Econ* 2009, **68**:810-821.

7. van Jaarsveld AS, Biggs R, Scholes RJ, Bohensky E, Reyers B, Lynam T, Musvoto C, Fabricius C: **Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SAfMA) experience**. *Philos Trans R Soc Lond B Biol Sci* 2005, **360**:425-441.

8. Deutsch L, Graslund S, Folke C, Troell M, Huitric M, Kautsky N, Lebel L: **Feeding aquaculture growth through globalization; exploitation of marine ecosystems for fish meal**. *Glob Environ Change* 2007, **17**:238-249.

9. Tilman D, Fargione J, Wolff B, D'Antonio C, Dobson A, Howarth R, Schindler D, Schlesinger WH, Simberloff D, Swackhamer D: **Forecasting agriculturally driven global environmental change**. *Science* 2001, **292**:281-284.

10. Millennium Ecosystem Assessment: *Ecosystems and Human Well-being: Synthesis*. Island Press; 2005.

11. Carpenter SR, DeFries R, Dietz T, Mooney HA, Polasky S, Reid WVR, Scholes J: **Millennium ecosystem assessment: research needs**. *Science* 2006, **314**:257-258.

12. Ehrlich PR, Kareiva PM, Daily GC: **Securing natural capital and
•• expanding equity to rescale civilization**. *Nature* 2012, **486**:68-74.

This review analyzed the existing problems we face currently and explored prospects in critical areas for transformative change in of sustainable development.

13. Lü YH, Fu BJ, Feng XM, Zeng Y, Liu Y, Chang RY, Sun G, Wu BF: **A policy-driven large scale ecological restoration: quantifying ecosystem services changes in the loess plateau of China**. *PLoS ONE* 2012, **7**:e31782 http://dx.doi.org/10.1371/journal.pone.0031782.

14. O'Farrell P, Anderson Pippin ML: **Sustainable multifunctional landscapes: a review to implementation**. *Curr Opin Environ Sustain* 2010, **2**:59-65.

15. Wallace KJ: **Classification of ecosystem services: problems and solutions**. *Biol Conserv* 2007, **139**:235-246.

16. Haines-Young R: **Exploring ecosystem service issues across diverse knowledge domains using Bayesian Belief Networks**. *Prog Phys Geog* 2011, **35**:681-699.

17. Nicholson E, Mace GM, Armsworth PR, Atkinson G, Buckle S,
• Clements T, Ewers RM, Fa JE, Gardner TA, Gibbons J *et al.*: **Priority research areas for ecosystem services in a changing world**. *J Appl Ecol* 2009, **46**:1139-1144.

In this review, authors analyzed the shortcomings of current research approaches on ecosystem services. They argued need to emphasize on mechanistic understanding of processes and engage fully with the inter-disciplinarity of the problem.

18. Bennett EM, Peterson GD, Gordon LJ: **Understanding relationships among multiple ecosystem services**. *Ecol Lett* 2009, **12**:1394-1404.

19. Palmer MA, Filoso S: **Restoration of ecosystem services for environmental markets**. *Science* 2009, **325**:575-576.

20. Currie WS: **Units of nature or processes across scales? The ecosystem concept at age 75**. *New Phytol* 2011, **190**:21-34.

21. Lyons KG, Brigham CA, Traut BH, Schwartz MW: **Rare species and ecosystem functioning**. *Conserv Biol* 2005, **19**:1019-1024.

22. Daily GC: *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press; 1997.

23. Costanza R: **Ecosystem services: multiple classification systems are needed**. *Biol Conserv* 2008, **141**:350-352.

24. Lamarque P, Quetier F, Lavorel S: **The diversity of the ecosystem services concept and its implications for their assessment and management**. *C R Biol* 2011 http://dx.doi.org/10.1016/j.crvi.2010.11.007.

25. Wang S, Fu BJ, Gao GY, Zhou J: **The hydrological responses of different land cover types in a re-vegetation catchment area of the Loess Plateau, China**. *Hydrol Earth Syst Sci Discuss* 2012, **9**:5809-5835 http://dx.doi.org/10.5194/hessd-9-5809-2012.

26. Braud I, Bariac T, Gaudet JP, Vauclin M: **SiSPAT-Isotope, a coupled heat, water and stable isotope (HDO and H218O) transport model for bare soil. Part I. Model description and first verifications**. *J Hydrol* 2005, **309**:277-300 http://dx.doi.org/10.1016/j.jhydrol.2004.12.013.

27. Lopez del Mar T, Aide TM, Scatena FN: **The effect of land use on soil erosion in the Guadiana watershed in Puerto Rico**. *Caribb J Sci* 1998, **34**:289-307.

28. Jordan G, van Rompaey A, Szilassi P, Csillag G, Mannaerts C, Woldai T: **Historical land use changes and their impact on sediment fluxes in the Balaton basin (Hungary)**. *Agric Ecosyst Environ* 2005, **108**:119-130 http://dx.doi.org/10.1016/j.agee.2005.01.013.

29. Fu BJ, Wang YF, Lu YH, He CS, Chen LD, Song CJ: **The effects of land-use combinations on soil erosion: a case study in the Loess Plateau of China**. *Prog Phys Geog* 2009, **33**:793-880 http://dx.doi.org/10.1177/0309133309350264.

30. Mace GM, Norris K, Fitter AH: **Biodiversity and ecosystem
•• services: a multilayered relationship**. *Trends Ecol Evol* 2012, **27**:19-27.

In this review, they clarified the definition of biodiversity and distinguished that it has key roles at all levels of the ecosystem service hierarchy: as a regulator of underpinning ecosystem processes, as a final ecosystem service and as a good that is subject to valuation, whether economic or otherwise.

31. Naeem S, Wright JP: **Disentangling biodiversity effects on ecosystem functioning: deriving solutions to a seemingly insurmountable problem**. *Ecol Lett* 2003, **6**:569-579.

32. Moone HA, Lariguaderie E, Elmquist O, Hoegh-Guldberg S, Lavorel GM, Mace MA, Palmer R, Scholes TY: **Biodiversity, climate change, and ecosystem services**. *Curr Opin Environ Sustain* 2009, **1**:46-54.

33. Larigauderie A, Prieur-Richard A, Mace GM, Lonsdale M, Mooney HA, Brussaard L, Cooper D, Cramer W, Daszak P, Díaz S *et al.*: **Biodiversity and ecosystem services science for a sustainable planet: the DIVERSITAS vision for 2012–2020**. *Curr Opin Environ Sustain* 2012, **4**:101-105.

34. Perrings C, Duraiappah A, Larigauderie A, Mooney H: **The biodiversity and ecosystem services science-policy interface**. *Science* 2011, **4**:1139-1140.

35. Balvanera P, Pfisterer AB, Buchmann N, He JS, Nakashizuka T, Raffaelli D, Schimid B: **Quantifying the evidence for biodiversity effects on ecosystem functioning and services**. *Ecol Lett* 2006, **9**:1146-1156.

36. Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle D, Kinzig AP, Daily GC, Loreau M, Grace JB, Larigauderie A, Srivastava DS, Naeem S: **Biodiversity loss and its impact on humanity**. *Nature* 2012, **486**:59-67 http://dx.doi.org/10.1038/nature11148.

37. Fu BJ, Liang D, Lü N: **Landscape ecology: coupling of pattern, process, and scale**. *Chinese Geog Sci* 2011, **21**:385-391.

38. Olschewski R, Tscharntke T, Benitez PC, Schwarze S, Klein AM: **Economic evaluation of pollination services comparing coffee landscapes in Ecuador and Indonesia**. *Ecol Soc* 2006, **11**:7 http://www.ecologyandsociety.org/vol11/iss1/art7.

39. Priess JA, Mimler M, Klein AM, Schwarze S, Tscharntke T, Steffan-Dewenter I: **Linking deforestation scenarios to pollination services and economic returns in coffee agroforestry systems**. *Ecol Appl* 2007, **17**:407-417.

40. Fu BJ, Wang J, Chen LD, Qiu Y: **The effects of land use on soil moisture variation in the Danangou catchment of the Loess Plateau, China**. *Catena* 2003, **54**:197-213.

41. Nassauer JI, Opdam P: **Design in science: extending the
• landscape ecology paradigm**. *Landscape Ecol* 2008, **23**:633-644.

Knowledge about pattern–process relations has been fully studied in the landscape ecology. The authors proposed that the pattern–process paradigm should be extended to include a third part: design. This helps

to bring scientific knowledge into decision making about landscape change.

42. Aitkenhead MJ, Albanito F, Jones MB, Black HIJ: **Development and testing of a process-based soil model (MOSES) for ecosystem services**. *Ecol Model* 2011, **222**:3795-3810.

43. Laurel GL, Harvey JW: **Modeling of hydroecological feedbacks predicts distinct classes of landscape pattern, process, and restoration potential in shallow aquatic ecosystems**. *Geomorphology* 2011, **126**:279-296.

44. Nelson E, Mendoza G, Regetz J, Polasky S, Tallis H, Cameron DR, Chan KM, Daily GC, Goldstein J, Kareiva PM *et al.*: **Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales**. *Front Ecol Environ* 2009, **7**:4-11.

45. Fu BJ, Su CH, Wei YP, Willett I, Lü YH, Liu GH: **Double counting in ecosystem services valuation: causes and countermeasures**. *Ecol Res* 2011, **26**:1-14.

46. Rodriguez JP Jr, Bennett EM, Cumming GS, Cork S, Agard J, Dobson AP, Peterson GD: **Trade-offs across space, time, and ecosystem services**. *Ecol Soc* 2006, **11**:28 http://www.ecologyandsociety.org/vol11/iss1/art28/.

47. Lautenbach S, Kugel C, Lausch A, Seppelt R: **Analysis of historic changes in regional ecosystem service provisioning using land use data**. *Ecol Indic* 2011, **11**:676-687 http://dx.doi.org/10.1016/j.ecolind.2010.09.007.

48. de Groot RS, R. Alkemade LB, Hein L, Willemen L: **Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making**. *Ecol Complex* 2010, **7**:260-272.